SYSTEMIQ

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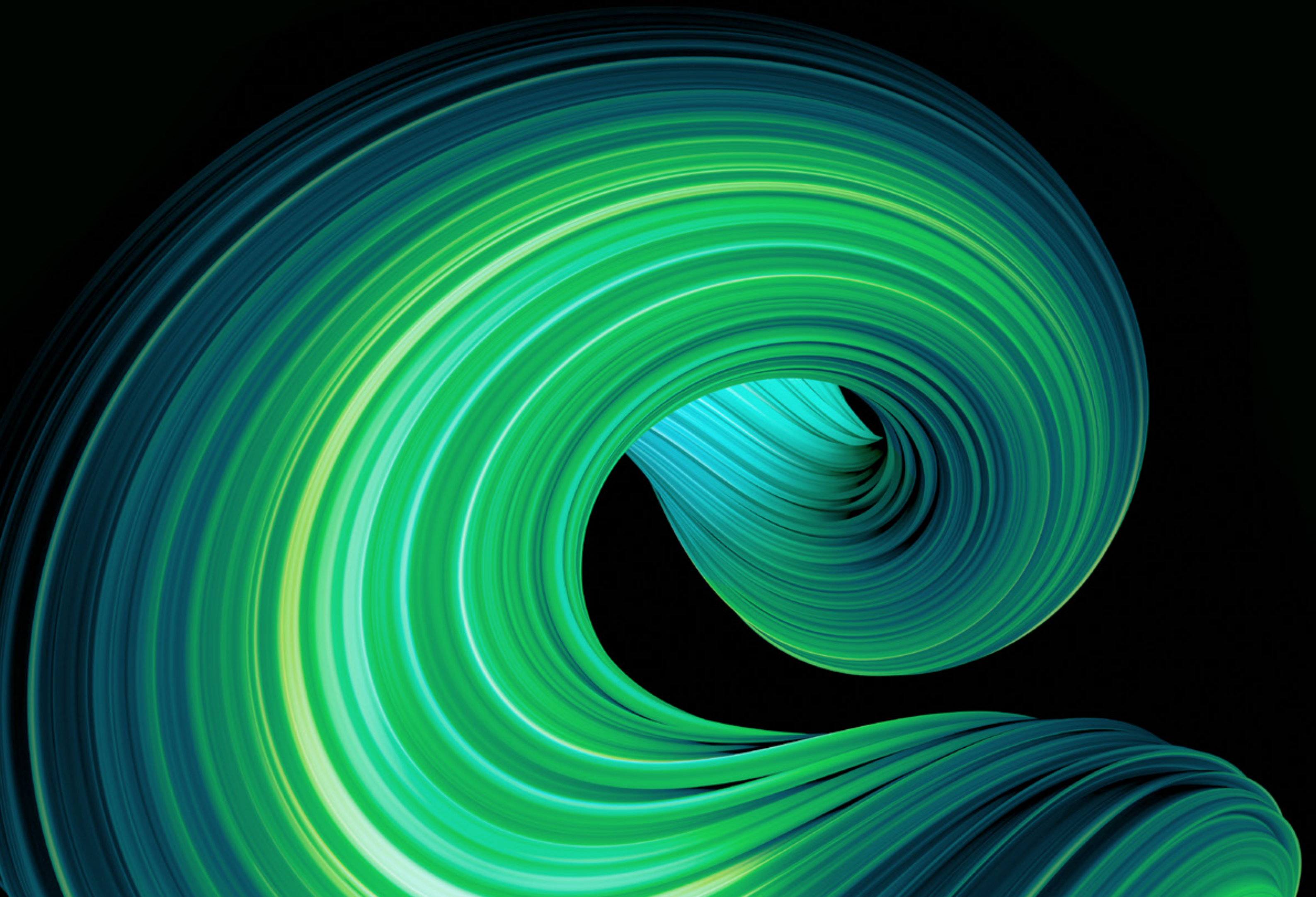
ReShaping Plastics

PATHWAYS TO A CIRCULAR, CLIMATE NEUTRAL PLASTICS SYSTEM IN EUROPE



About SYSTEMIQ

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

For more information, contact us at plastic@systemiq.earth
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Disclaimer

The scenarios developed in this report have high uncertainty and should not be considered as predictions. The range of scenarios modelled are meant to provide high level insights by presenting alternative pathways towards achieving plastics system circularity and GHG reductions. The scenarios presented in this report are not the only possible scenarios, they are one view among an almost infinite number of scenario variations that can be generated. However, they are intended to be the most illuminating combination of pathways to guide plastics systems decision making within and between stakeholder groups. There can be no assurance that estimates or projections will be realized, that forward-looking statements will materialize, or that actual results will not be materially different to those presented. All forward-looking statements included are based on information available on the date hereof. The "ReShaping Plastics" report was prepared by SYSTEMIQ with strategic guidance from an independent Steering Committee with representation from the public sector, civil society and industry and supported by an external Expert Panel. While the report was financed by Plastics Europe, the Steering Committee and Expert Panel helped ensure its independence and unbiased nature. The statements and views presented in this report do not necessarily reflect those of Plastics Europe, or any individual or organization associated with this project.

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Preface

Signed:

Jyrki Katainen

President of the Finnish Innovation Fund Sitra,
Former European Commission Vice-President,
Former Prime Minister of Finland,
Steering Committee Chair

Prof. Kim Ragaert

Chair of Circular Plastics at Maastricht University
Steering Committee Deputy Chair

Yoni Shiran

SYSTEMIQ Partner
Programme Director

Plastic is both an icon of prosperity and a cautionary example of how linear models of consumption can undermine Earth's planetary limits. Plastic has been long valued for its consumer benefits – affordability, convenience, performance, flexibility, durability – but a rapid shift in awareness among governments, civil society, investors, producers, and consumers is leading to mounting demands that industry take the necessary steps to embrace circular economy approaches and mitigate climate change, in line with the Paris Agreement and Glasgow Climate Pact and the goals of the European Green Deal and Circular Economy Action Plan.

In recent years, a number of excellent studies have advanced our understanding of the plastics system, both at a global and national level. However, most studies and dialogues about plastic in Europe, focus *either* on the question of circularity *or* on the question of plastic's climate impact. But these are not separate issues. The plastics system must adapt in ways that ensure that it is both circular ***and*** generates minimal carbon emissions – hence we need to design a system that addresses these two challenges simultaneously. The "ReShaping Plastics" report aims to do precisely that.

The goal of this study is to accelerate the transition to a circular, net zero carbon emissions plastics system in Europe by providing a practical, science-based roadmap. Our hope and belief are that this work will strengthen the collaboration between industry, the public sector, civil society, and investors in the search for a better plastics system for Europe based on a shared fact base.

In July 2020, The Pew Charitable Trusts and SYSTEMIQ published "Breaking the Plastic Wave", a study that developed a first-of-its-kind full-system model to quantify the economic, environmental, and social implications of different plastic pollution scenarios on a global scale. The new "ReShaping Plastics" study now applies that modelling approach to the European plastics system to illuminate potential pathways to a fully circular, net zero carbon emissions plastics system. It is driven by the conviction that a new and shared evidence base is required to plot a science-based pathway to address current systemic challenges in the plastics system.

The analysis underpinning this report was designed to be impartial and a rigorous governance mechanism was deployed. An independent Steering Committee was established comprising a balanced mix of senior leaders across civil society, the public sector, and industry. The Steering Committee provided strategic guidance and direction in all major project decisions and had complete independence in approving the strategic approach and recommendations. Detailed assumptions underlying the analysis were also peer-reviewed and approved by an independent Panel of Experts with deep competence in the range of subject areas touched on by this study.

This work was designed to help guide policymakers, industry executives, investors, and civil society leaders through highly contested, often data-poor, and complex terrain. Our wish is that the results of "ReShaping Plastics" can serve as a map for stakeholders in search of solutions to enhance the circularity and reduce the greenhouse gas emissions of the European plastics system. But such a solution requires political leaders, policymakers, business executives, and investors to shift from incremental to systemic change.

The circular, net zero carbon emissions plastics system vision is one which designs out waste, eliminates unnecessary production and consumption, keeps products and materials in the economy, and safely collects and disposes waste that cannot be economically processed, thereby permanently increasing material circularity, reducing GHG emissions, and stopping plastic pollution.

Providing the evidence and insight needed to realize this vision of a circular, net zero carbon emissions European plastics system is the North Star guiding the "ReShaping Plastics" project.

Acknowledgements

Steering Committee

To ensure the independence of this study, we assembled a balanced Steering Committee composed of members from the public sector, civil society, and industry. The Steering Committee provided strategic guidance and direction in all major project decisions. We are deeply grateful to all the organizations and individuals who contributed for their unique perspectives. Steering Committee members endorse the overall project approach and findings, although not all statements in this publication necessarily represent the views of all individuals or the organizations they represent.

The Steering Committee members are:

Jyrki Katainen

President of the Finnish Innovation Fund Sitra,
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Former Prime Minister of Finland,
Steering Committee Chair

Prof. Kim Ragaert

Chair of Circular Plastics at Maastricht University
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Sirpa Pietikäinen

Member
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Joan Marc Simon

Executive Director
Zero Waste Europe

Prof. Martin Stuchtey

Founder SYSTEMIQ, Professor for Resource
Strategies and Management,
University Innsbruck
Project Principal

Expert Panel

To ensure the scientific accuracy of this study, we assembled a panel of 10 experts representing different sectors and parts of the value chain. The Expert Panel reviewed all assumptions and provided input into the approach. We are deeply grateful to all the organizations and individuals who contributed for their deep content expertise. Expert Panel members endorse the overall project approach and findings, although specific statements do not necessarily represent their individual views or those of the organizations they represent.

The Expert Panel members are:

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Endorsements

This report sets a comprehensive picture on how the plastic industry in Europe can meet the carbon neutrality challenge. Its findings makes it clear: we need to start by reducing, reusing, substituting and recycling which are all circular economy features. More costly and uncertain technological approaches such as carbon capture storage and use may only play a secondary role, once circular solutions have been fully implemented. We hope this will help create a sound base to prioritise policy developments and innovations in the plastic sector.

We also appreciate the recognition of the data gap that still exists, and of the current focus on climate impacts, which leave the door open for reinforced data collection and monitoring, as well as for further investigations on other human health and environmental impacts, complementary to the climate perspective.

The plastic sector's sustainability journey needs to continue and intensify, and we welcome the idea to set up a stakeholders platform to best approach such a journey.

Stéphane Arditi
Director of Policy Integration and Circular Economy
European Environmental Bureau (EEB)

The plastics Industry is committed to the EU's circularity & emission reduction goals. We strongly believe that plastics have a critical contribution and enabling role to the transition of many downstream industries to net zero. This will require collaboration throughout the value chain and an enabling framework from policymakers to drive a sustainable and competitive Europe. SYSTEMIQ's report is an important step in our joint understanding and journey.

Marco Ten Bruggencate
Commercial Vice President
Dow Packaging & Specialty Plastics

This report shows a path for the European plastic industry to achieve climate neutrality by 2050 and puts the application of the circular economy principles in the core of this transition. Adoption of circular strategies for both private sector and civil society are needed to tackle the three most pressing challenges of climate crisis, nature loss and mounting the inequality. Cross industry collaboration within the plastic value chain will be instrumental to overcome the challenges. Plastics Europe has the opportunity to lead the transformation and we look forward to contribute to that through our work with WBCSD's Circular Plastics & Packaging project.

Cyrille Durand
Lead, Plastics & Packaging
WBCSD

The report is a good read for all people involved in the plastic industry as well as for policymakers and all speaking about CO_2 neutrality. The report shows the potential of near, mid and long-term solutions as well as the current unknown's related to the end life of the plastics that are being used in Europe. For instance, it is still unknown what happens to the 40 % statistic gap between the volume put on the market and the volume of plastic waste collected. Prevention and re-use models are also taken into consideration in this report. It gives a good understanding of the recycling technology available today such as mechanical recycling which is efficient cost effective circular technology well established in Europe. Besides that the investments needed to reach the European targets. As well as the issues related to chemical recycling such as the choice and the competition on feedstock, the right technology and the competitiveness, regulation and traceability.

The report also shows opportunities for diverse technologies for industrial decarbonization without switching to alternative feedstock energy or resources.

Ton Emans
President PRE & Director
Group Recycling Cedo

The plastics industry is working towards higher levels of circularity and reducing the emissions throughout its value chains. The "ReShaping Plastics" report helps all stakeholders to better understand feasibilities and limitations on this path. Foremost, it aims to encourages all stakeholders to closely co-operate and listen to each other in order to advance a truly sustainable plastics economy.

Dr Martin Jung
President, Performance Materials Division
BASF

This formidable work addresses a key current issue, plastics in society. The report summarises the scale of the challenge and develops powerful future scenarios to inform concerted action. The key message is 'Act Now', because we cannot continue as we have done for roughly the last 80 years, which have seen increasing volumes of commercial plastic used in a linear fashion. Plastic use is treated as a system with diverse actors, demands and pressures, with no simple lever for change ("no silver bullet"). The report emphasises holistic thinking, for example, by rejecting the false dichotomy between upstream and downstream solutions. The important potential of behaviour change is considered as an integral part of the system, but without assigning excessive responsibility to the individual consumer, rather, consumers should be supported and enabled to be part of the solution. I truly hope this work gets the attention it deserves and leads to rapid impact, future-proofing essential uses of plastics but drastically reducing leakage to the environment.

Sabine Pahl
Professor of Urban and Environmental Psychology
University of Vienna

In general there are no good or bad materials. There are just materials in wrong use or badly handled. Plastics are a valuable material, which we are going to need also in the future, but we need to design out the waste from plastic goods and create 10-fold resource efficiency in material use to halt the prognosis of the sharply increasing plastic production. We need to create a closed-loop plastic economy. This report is a significant step in this road.

Sirpa Pietikäinen
Member
European Parliament

As we are already front runners in waste logistics and collection, it is important to differentiate the European plastics system and its challenges from the global one. Littering is not the main European challenge and therefore gratuitous reductions and substitutions are not the answer. ReShaping Plastics has given us a long-awaited science-based quantification on the potential gains of different approaches to reaching net zero. Single solutions will not cut it and neither will continued responsibility-shifting between actors. Read the report, absorb the recommendations and get to work. Everyone.

Kim Ragaert
Full Professor & Chair of Circular Plastics,
Faculty of Science and Engineering
Maastricht University

This report on the future of the European plastics system is an important roadmap for an industry that is facing an existential challenge to carve-out a cleaner, more sustainable future, and provides important guidance for the entire value chain on where the biggest impacts need to happen. As a pioneering investor in the technologies that can support this transition, we hope this report serves as an important catalyst to drive further capital towards the solutions required to achieve a circular, net zero plastics industry.

Jamie Rowles
Head of Investments
Sky Ocean Ventures

With plastic pollution continuing to abound, the ReShaping Plastics study is a key framing exercise to bring in circularity and decarbonisation into the agenda. This report portrays the scale of political, technological and financial leap forward needed in order to make plastic a sustainable material. The findings of this report constitute a measuring tape that we should use to evaluate whether the upcoming laws and industry commitments can deliver to the challenge of stopping plastic pollution.

Joan Marc Simon
Executive Director
Zero Waste Europe

Closing the loop for plastics is an essential part in the development of circular economy. This idea generates a broad range of challenges, as plastics have an enormous diversity in properties and applications. Low hanging fruit has been captured, so we need to develop more innovative strategies. The current report provides a solid basis to understand where the opportunities lie to make the necessary step changes in the plastics system.

Prof. Karl Vrancken
Research Manager Sustainable Materials
VITO

Around the world, businesses and governments are taking action to build a circular economy for plastics, by eliminating the plastics we don't need, innovating towards new business models and materials, and circulating the plastics we do use. Yet, despite recent progress, we know that much more and faster action is required. This report provides a strong fact base to support such accelerated action in Europe, and I encourage all stakeholders to engage with it.

Rob Opsomer
Executive Lead - Systemic Initiatives
Ellen MacArthur Foundation

Executive Summary:

5 essential findings

Plastic provides excellent utility for society across many sectors, including healthcare, construction, food chains, energy and transportation. Plastic has long been valued for its consumer benefits – affordability, convenience, flexibility, durability - and increasingly for its contribution to climate change mitigation, for example by insulating buildings or light-weighting vehicles. However, a rapid shift in awareness among governments, civil society, investors, producers, and consumers has led to growing demands that the makers and users of plastic – along with other industries – take the necessary steps to mitigate climate change and embrace circular economy approaches, in line with the Paris Agreement and Glasgow Climate Pact and the goals of the European Green Deal and Circular Economy Action Plan.

Despite progress on circularity and bold commitments on greenhouse gas (GHG) emissions, the plastics sector faces significant challenges. The European plastics system in 2021 is predominantly linear, with only 14% of plastic waste estimated to be recycled each year and the remainder being either incinerated with energy recovery, landfilled, exported, or littered. Countries are increasingly pivoting from landfilling waste to incineration with energy recovery, a European policy objective[i] that is in-line with the waste hierarchy, but which increases system-level GHG emissions from plastic in Europe, particularly as the growth in renewable energy generation makes the environmental outcomes of waste-derived electricity comparatively worse. This shifting dynamic means that goals to increase circularity and reduce the amount of plastic waste disposal are now closely aligned with goals to reduce GHG emissions from the plastics system.

The dominant environmental challenges faced by the European plastics system[ii] are high levels of waste generation and GHG emissions from both production and disposal, with environmental littering representing a relatively low percentage of waste volumes, although continuing to raise concerns. While each of these challenges in isolation would require significant logistical changes and investments, addressing them concurrently presents an even bigger challenge. To address this, there is a high expectation for the European plastics system to: (a) ambitiously implement circularity principles across the value chain; (b) define and commit to a credible path to net zero GHG emissions; and (c) continue intensifying efforts to eliminate plastic pollution in the environment.

However, while many stakeholders want to take meaningful action, the economic, fiscal, environmental, and social implications of different pathways are often unclear, making it difficult to determine which actions should be prioritized for different plastic applications, or to understand the synergies between different solutions. Fast and coordinated system changes are needed in order for all industries to align with climate mitigation and circularity goals, but without a shared view of potential scenarios and trade-offs, grounded in science and economics, stakeholder positions could become increasingly polarized and opportunities for convergence and collective action could be lost.

"ReShaping Plastics" focuses on four of the most important plastic-using sectors: packaging, household goods, automotive, and construction. The scope of this study covers 75% of total European plastic demand and 83% of known post-consumer waste generation.[iii] The study draws on analyses carried out by researchers, civil society organizations, companies, universities, and government agencies. It has been guided by an independent Steering Committee and Expert Panel with representation from government, industry, academia, and civil society. At the heart of the study is a data-driven model of the European plastics system, which allows the research team to assess the impact of different interventions and system scenarios from now until 2050. This scenario analysis produced five essential findings that could help leaders and decision makers across the public sector, private sector and civil society to find an effective pathway towards a highly circular, low-carbon emission plastics system.

1 The European plastics system is already adapting to address the challenges of climate change mitigation and circularity, but not yet fast enough to align with the goals of the Circular Plastics Alliance, European Green Deal, or the Paris and Glasgow climate agreements.

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[i] The Landfill Directive limits the share of municipal waste landfilled to 10% by 2035.

[ii] Some plastic enables the reduction GHG emissions during the use phase, such as through insulation of housing and light-weighting vehicles; this study focuses on plastic production and end-of-life carbon emissions and did not quantify emission savings during the use phase.

[iii] Europe refers to the 27 European Union member states and the United Kingdom. Note that industrial packaging is out of scope for this study.

Current industry and policy actions[iv] could more than double system circularity from 14% to 33% by 2030 (measured as the share of expected plastic demand that is reduced, reused, or recycled). This would lead to a reduction of 11 million tonnes (Mt) of CO_2e emissions and 4.7 Mt less plastic waste disposed in landfills or incinerators, compared to a continuation of business as usual trends by 2030. While this is positive development, these actions are insufficient to address the scale of the challenge and would still leave a highly resource inefficient system. Government and company actions are not currently on track to deliver 10 Mt of recycled plastic production by 2025 commitment made by the Circular Plastics Alliance (a multistakeholder initiative under the European Strategy for Plastics) and do not align the industry with the necessary trajectory for achieving the Paris and Glasgow climate agreements. Achieving existing commitments will require a substantial effort on behalf of industry, regulators, and other stakeholders, but they still do not go far or fast enough.

2 **There is no "silver bullet" solution to significantly reduce waste disposal and GHG emissions. Upstream and downstream solutions are complementary and are most effective when deployed together.**

To date, many stakeholders have focused on either "upstream" (pre-consumer, such as material redesign, plastic reduction, and substitution) or "downstream" (post-consumer, such as mechanical and chemical recycling) solutions. Our analysis shows that this is a false dichotomy. Scenarios of single-group levers modelled in this study are not adequate to change the system. Upstream solutions that aim to reduce or substitute plastic use are critical but will need to be scaled carefully to limit adverse social or environmental effects. While there are significant opportunities to reduce, redesign or – in some cases - substitute plastic in the system, relying on these solutions alone leaves substantial waste disposal and GHG emissions, even if solutions are scaled ambitiously. Similarly, downstream solutions are essential but limited by economic viability and the realistic speed of infrastructure development and feedstock tolerance. Relying on an ambitious scale-up of mechanical and chemical recycling also leaves substantial waste disposal and GHG emissions in the system. All these solutions have an important role to play in the future plastics system, and none can be left out, but none are sufficient on their own.

3 **Ambitious adoption of circular economy approaches in the plastics value chain – i.e. applying upstream and downstream solutions together - can drive significant reductions in GHG emissions and waste disposal in the next decade and beyond.**

The Circularity Scenario developed in this study applies proven circular economy technologies and approaches together and at scale, within feasibility constraints. It provides an affordable and achievable pathway for reducing GHG emissions and plastic waste disposal by 33% and 46% respectively by 2030 compared to 2020 (and even more by 2040/2050), and for achieving 78% circularity in the European plastics system by 2050 (see Figure 1). The analysis indicates that this scenario requires major shifts in policy, public behaviour change, and an investment of approximately €160-180 billion between 2020 and 2050. Circularity levers are the fastest, most affordable, most effective, and most reliable method of reducing GHGs and waste disposal in the system available to stakeholders today, and most of their benefits can be achieved before 2040. Circularity also has a positive impact on employment levels, although some workforce reskilling may be required. Achieving this scenario requires concurrently scaling up five synergistic system interventions, specifically:

- Elimination[v] of unnecessary plastic, reuse, and other new delivery models have the potential to reduce almost 5 Mt of plastic waste per year by 2030 (current commitments and regulations reduce plastic waste by only 1.5 Mt by 2030).
- Mechanical recycling across all sub-systems, which could grow by 1.8 times to almost 6 Mt by 2030. This will require design for recycling, as well as scaling the entire recycling value chain, including collection and sorting.
- Chemical recycling, which can scale to 3 Mt by 2030, giving rise to a step change in system circularity. Chemical recycling should be used to tackle the hardest to address waste streams, thereby enabling circularity for food packaging that cannot meet the food safety and hygiene requirements for mechanical recycling, and

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[iv] Includes approved regulation at the European level or credibly voluntary commitments made by industry; further details can be found in Chapter 1.

[v] Elimination refers to practices that reduce packaging that does not serve an essential function while maintaining utility, either through direct elimination at source of unnecessary packaging or through innovative product and packaging design.

making the two interventions complementary. This technology has the potential to address hard-to-recycle waste streams but needs to be implemented correctly, with adequate policy support, to avoid building out plastic-to-fuel routes or increasing the system's GHG emissions.

- Substitution levers, that have the potential to replace 1.5 Mt of plastic by 2030, while accounting for unintended consequences.
- Continued increase of anti-littering efforts and the elimination of exports of plastic waste to countries outside Europe, where littering cannot be controlled, which together could lead to a domestication of plastic waste within an optimized and scaled European waste management system.

Figure 1 shows the fate of plastic waste under the Circularity Scenario, as calculated in this study.

4 **In addition to these proven circular economy approaches, there are multiple less mature pathways to develop and deploy innovative technologies and approaches that further decrease GHG emissions and tend to decouple plastic from fossil fuel feedstocks.**

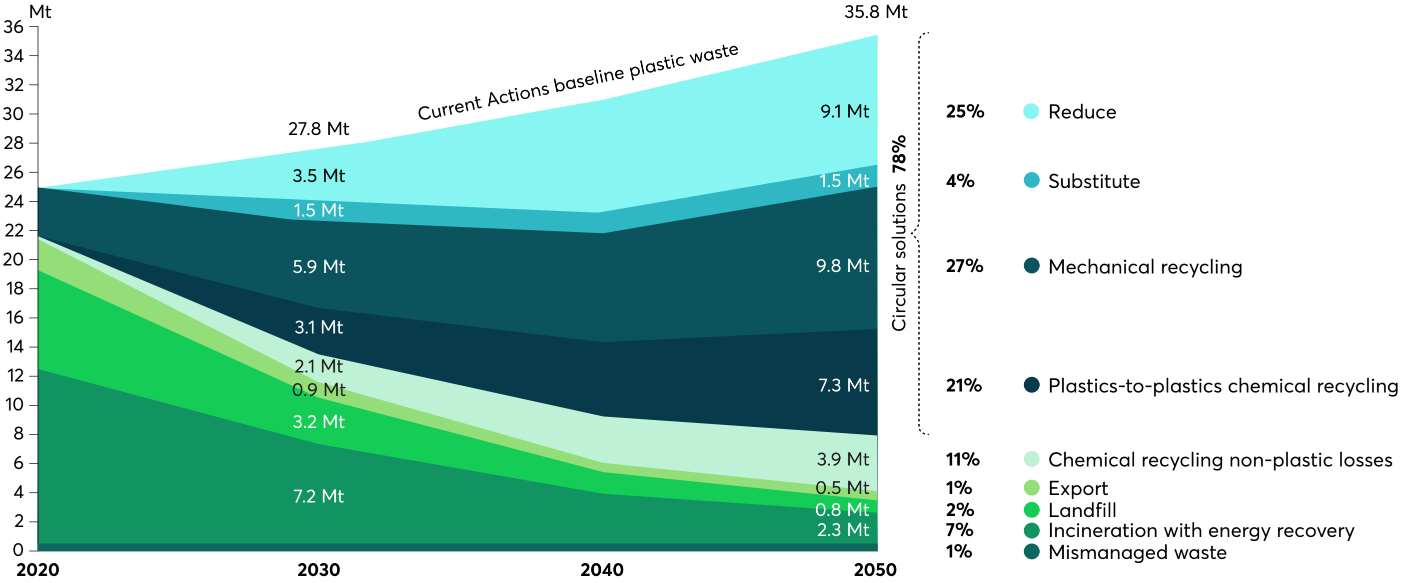
This study models two scenarios that build on the Circularity Scenario and further decrease GHG emissions in the European plastics system in line with the Paris and Glasgow climate agreements. The results are promising, but achieving these scenarios requires radical innovation, ambitious policies, cross-sector partnerships, and significant capital investment, and the analysis is based on many uncertainties.

- The Retrofit Systems Change Scenario describes a pathway of retrofitting the existing fossil fuel based plastics manufacturing system with GHG reduction technologies. It includes the substitution of carbon intensive fuels (e.g., moving from fossil fuels to green hydrogen in steam crackers) and the capture/storage of carbon dioxide (CO_2) emissions from plastic manufacturing and incineration with energy recovery.

Figure 1

By 2050, the Plastics system could achieve 78% circularity with 30% of waste avoided through reduction and substitution and 48% being recycled, leaving 9% in landfills and incinerators

Physical fate of plastic waste from packaging, household goods, automotive and construction 2020-2050 (Mt)



Source: "ReShaping Plastics" model

This is a capex-efficient method of reducing GHGs while maintaining production from existing assets, but it does not provide a route to net zero emissions by 2050 as 27% of GHG emissions remain.

- The Net Zero Systems Change Scenario describes a potential pathway to a net zero emissions plastics system by 2050. In addition to all the system interventions from previous scenarios, this scenario expands the role of hydrogen and the use of alternative feedstocks from both biological sources and CO$_2$ capture. Exclusive dependence on biological sources of carbon feedstock is risky, but by expanding the use of captured CO$_2$ (enabled by a clean hydrogen economy), the plastics system could strategically reposition itself as a carbon sink and enabler of climate change mitigation. This scenario also assumes an increased use of electricity to heat cracker facilities. By 2050, under this scenario, the European plastics system is projected to emit -5 Mt of CO$_2$e per annum and reduce virgin fossil plastic demand by an estimated 68%, signalling that a partial decoupling from fossil feedstock may be possible. However, this scenario relies on wider developments in industry, for example shifts to renewable energy and the scale-up of green hydrogen production. It requires that approximately 1 in 4 Euros in the plastics system be re-allocated from low risk-return, established business models to higher risk-return, less mature business models. The Net Zero Systems Change Scenario is one of multiple possible scenarios to reach a net zero emissions system, but the only one that this study analyzes in greater depth.

5 The next three to five years are a critical window for action. Long technology maturity cycles and capex lock-in for large infrastructure investments mean that the decisions taken in the early 2020s will determine whether or not the European plastics system will achieve a circular economy and net zero GHG emissions by 2050.

The plastics industry is currently targeting pyrolysis as the dominant pathway for chemical recycling in the 2020s, implying a continued reliance on steam cracker production, the need to further invest in steam cracker capacity, and impacting the implementation of decisions on major decarbonization infrastructure with long-term ramifications. Given the lifespans of these assets, the long technology maturity cycles, and the capital investment required, there are imminent infrastructure lock-in implications. Recycling plants, incinerators, and steam crackers all have lifespans of 20 years or more. That means investment decisions made this decade, and particularly in the next three to five years, will determine what the European plastics system looks like in 2050. Similarly, given the nascence of these technologies and the plastic-to-plastic chemical recycling industry, data shows that it takes an average of 17 years[1] from the concept stage for technology providers to reach growth scale. Capital investments made today will have long term consequences.

Despite the prominence of plastic as a pillar of European industry, and the growing attention paid to circular economy solutions, there are significant data gaps that will need to be resolved to enable a circular economy and mitigate climate and environmental risks. An estimated 43% of the plastic put on the market in Europe is unaccounted for in waste statistics (approximately 22 Mt per year). Some of this plastic is entering a growing "stock" contained in buildings, cars, and consumer products (or being exported in finished goods), but some may be ending up as unclassified materials in mixed waste streams going to landfill or incineration. This data gap presents a major challenge to our understanding of the environmental and climate impacts of the industry, and to our efforts to design and implement circular economy solutions. It is also a limitation of this study, which uses published data statistics and may be under-representing the end-of-life impacts of plastic in Europe.

Achieving the ambitious outcomes modelled in this study requires substantial changes in the business models of firms producing and using plastics and their substitutes; overhauls to the recycling and waste disposal industries; new investment models and criteria; and the modification of consumer behaviour at scale. These are unlikely to materialize unless government policies create significant incentives and mechanisms for circular business models such as recycled materials or reused products. To remain competitive with linear, emissions-intensive plastics systems around the globe, targeted policies and support for the European plastics industry may be needed, as well as greater transparency of carbon and environmental footprints of all products placed on the EU market. At the same time, industry should ensure that all plastic put on the market is recyclable, invest in material and business model innovations, and join with governments to help finance and scale advanced collection, sorting and recycling systems.

Further research, dialogue and collaboration between industry, government and civil society will be essential to ensure a stable investment climate and effective policy enablers for a circular, net zero emissions European plastics system. Delivering the systems transformation needed will very likely require a system-level coordination body, active innovation, and the implementation of upstream and downstream circularity and GHG reduction projects by industry, accompanied by major financing for an innovation agenda and infrastructure expansion. Data transparency and definition consistency also are critical ingredients to enable the necessary trust and collaboration between parties.

Fortunately, there are promising emerging efforts to build on. In addition to existing EU initiatives, the Circular Plastics Alliance is a unique multistakeholder collaboration at the European level aimed at helping plastic value chains boost the EU market for recycled plastic. The Ellen MacArthur Foundation's New Plastics Economy initiative has already united more than 1,000 organizations behind a vision for a circular economy under a global commitment for plastic that is a good first step towards pursuing the systemic changes identified in this report. Early discussions are also underway regarding establishing a new international agreement on plastic pollution that may help provide a global policy framework for united government action and ensure that the European plastics system is competitive.

This report focuses on the best-case scenario to transform the system. How close the system comes to achieving it will depend on the level of ambition and leadership shown by key decision makers across industry, policy, and civil society in the coming few years. A circular, net zero plastics system in Europe is within reach, but it will require enhanced ambitions and bold decisions.

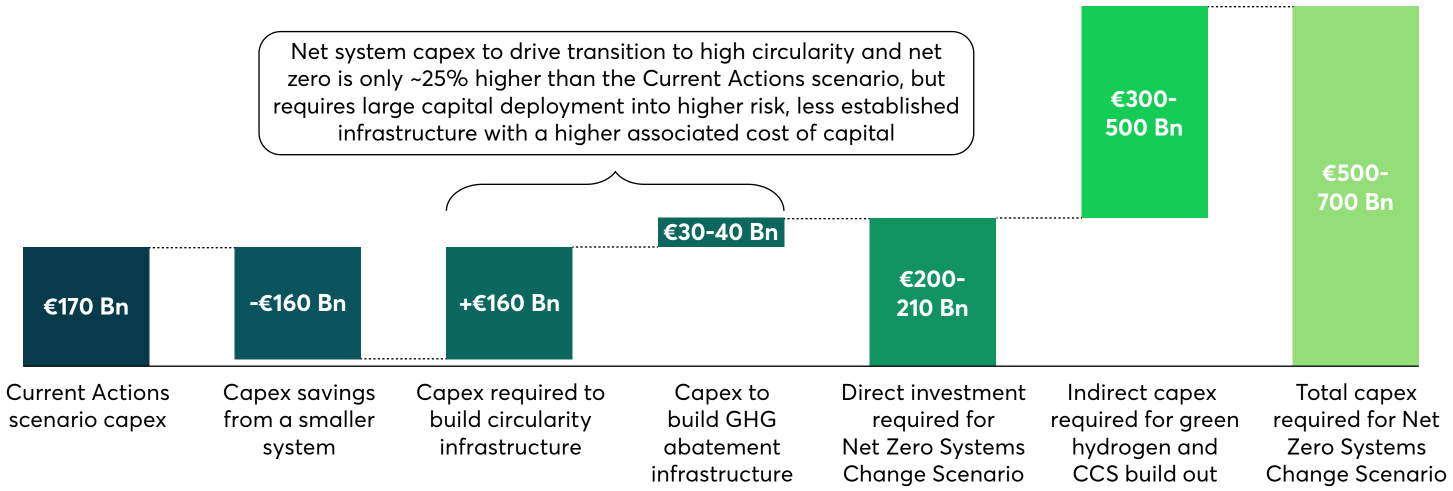
> ***"While many stakeholders want to take meaningful action, the economic, fiscal, environmental, and social implications of different pathways are often unclear, making it difficult to determine which actions should be prioritized for different plastic applications, or to understand the synergies between different solutions. "ReShaping Plastics" attempts to fill that gap."***

ReShaping the European Plastics System

Scenario	Scenario description	Key Assumptions
Current Actions Scenario	All major commitments already made by the public and private sectors until 2020 are implemented and enforced These include European regulation and voluntary industry commitments	• Current regulation (as of April 2021) is implemented and enforced • No additional regulation is put in place • Voluntary commitments are met in full • Basel convention strengthens and international waste trade is increasingly controlled and regulated
Reduction & Substitution Scenario	Reduction of plastic use through elimination, ambitious introduction of reuse and new delivery models, and plastic substitutions where it makes sense	• Strong policy intervention to incentivize reuse, new delivery models and DRS • Investment into reuse and new delivery models infrastructure, including reverse logistics, and technological improvements • Wide consumer and business adoption of these models • Performance & cost improvements of compostables and other substitutes
Recycling Scenario	Ambitious expansion and investment into collection for recycling, sorting, mechanical recycling, and chemical recycling infrastructure	• All plastic packaging is designed for recycling • Supportive policy incentives including minimum recycled content, recycling targets, EPR and more • Financial investment into recycling investment and R&D • Chemical recycling scales across Europe from its low base today
Circularity Scenario	All circularity levers are applied concurrently and ambitiously, including both upstream (see Reduction & Substitution Scenario) and downstream (see Recycling Scenario)	• All "Recycling Scenario" and "Reduction & Substitution Scenario" conditions are met concurrently • Consumers are educated, engaged and change behaviours regarding consumption and waste management
Retrofit System Change Scenario	On top of Circularity Scenario, assumes the substitution of carbon intensive fuels with low-carbon hydrogen and the capture and storage of CO_2 emissions from plastic manufacturing and incineration	• Affordable and abundant low-carbon hydrogen is available at ~€2/kg • CCS technologies scale and are affordable in multiple geographies • Methanol to olefins capabilities are available (commercially) to upgrade steam cracking off-gasses • Chemical recycling can improve its carbon profile
Net-Zero System Change Scenario	On top of Retrofit Scenario, assumes expansion of the role of hydrogen, the use of alternative feedstocks from both biological sources and CO_2 capture, and electrification of some steam crackers	• Carbon usage technologies reach maturity and affordability • Sufficient quantities of sustainable biomass is available for plastics • Electrification of steam cracking technical barriers can be overcome • GHG reduction can be applied to chemical recycling

THE COST OF NET-ZERO & HIGH CIRCULARITY

Cumulative system capex (2020-2050)


Net system capex to drive transition to high circularity and net zero is only ~25% higher than the Current Actions scenario, but requires large capital deployment into higher risk, less established infrastructure with a higher associated cost of capital

2050 ENDSTATE Scenario	Circularity (%)	GHG Emissions ($MtCO_2e$)	Virgin Fossil Plastic Use (Mt)
Base Case (Current System)	14%	112	44
Current Actions Scenario	33%	92	37
Reduction & Substitution Scenario	52%	68	29
Recycling Scenario	69%	41	24
Circularity Scenario	78%	33	20
Retrofit System Change Scenario	78%	25	20
Net-Zero System Change Scenario	78%	~0	11

[1] Defined as the share of plastic utility that is either reduced, substituted by circular materials, or recycled mechanically or chemically excluding plastic entering stock.

[2] Cumulative capital investments 2020-2050. Excludes cost of decommissioning legacy assets; some scenarios may have higher operating costs not shown in this table.

[3] Includes direct investment into the Plastics system (e.g., recycling facilities, new delivery models, etc) and indirect capex not made directly by the Plastics system (e.g., carbon capture and storage or green hydrogen) but paid by plastics industry in long-term offtake contracts to suppliers of GHG reduction infrastructure. Does not include opex efficiency savings in production from upstream circularity levers.

FAST FACTS

ReShaping Plastics in numbers

State of Play
Today

24.5 million tonnes
of **plastic waste generated** in 2020

14%
of **plastic waste were recycled**, providing 3.5 Mt of recyclates in 2020

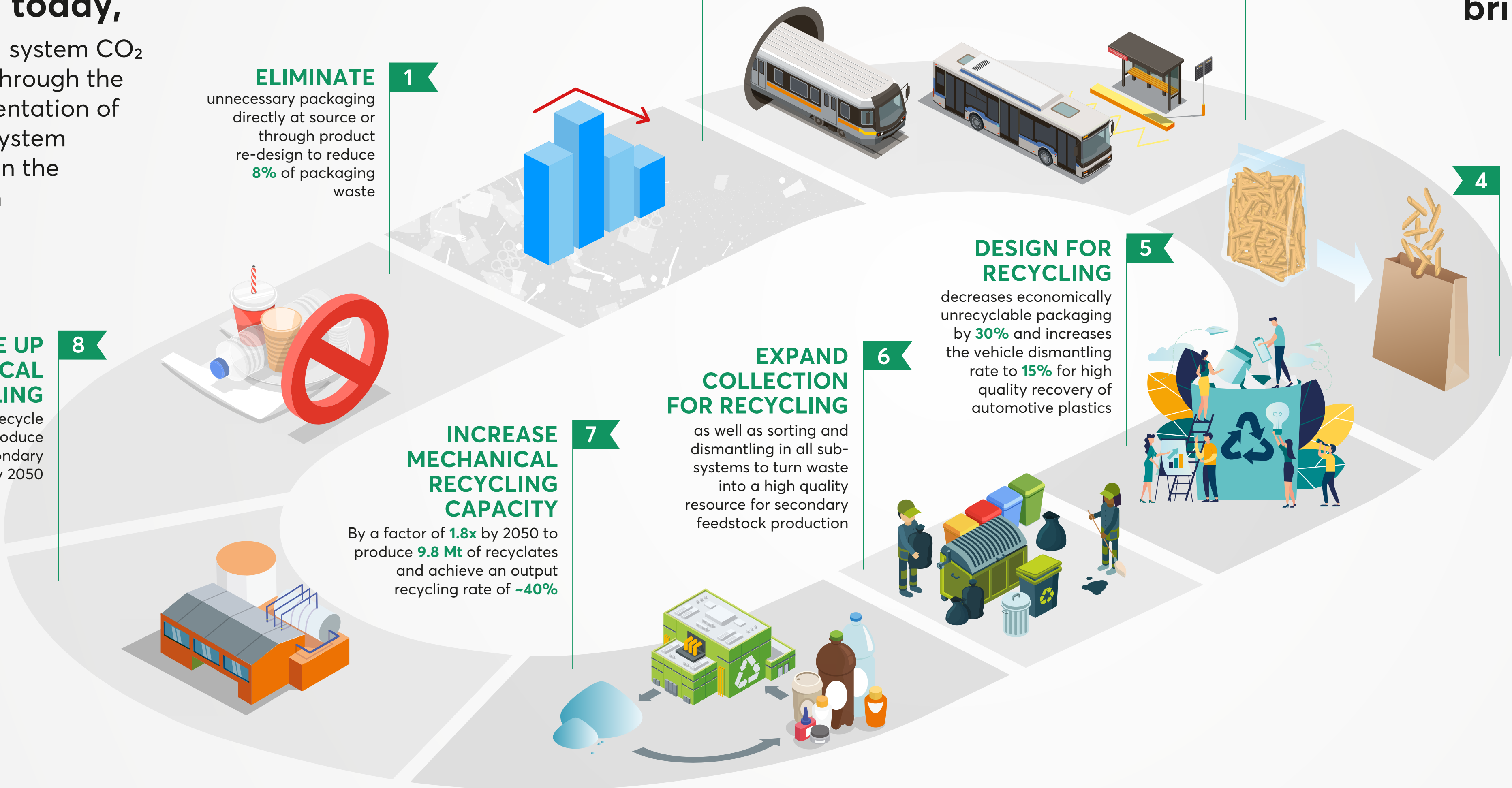
50%
of today's European plastic waste is **incinerated for energy recovery**

95 million tonnes
of **CO_2e are emitted per year** in 2020, one-third is caused by incineration

8-15 million tonnes
of **unaccounted for plastic** as a result of gaps in waste data

The CIRCULARITY SCENARIO reduces 80% of end-of-life plastic disposal by 2050 compared to today,

effectively reducing system CO_2 emissions by 65% through the immediate implementation of 8 complementary system intervention levers in the plastics value chain



ELIMINATE 1
unnecessary packaging directly at source or through product re-design to reduce **8%** of packaging waste

REDUCE 2
1/3 of plastic packaging through reuse and new delivery models by 2050

REDUCE 3
the overall vehicle stock and corresponding automotive plastics demand by **22%** through shared mobility service models by 2050

SUBSTITUTE 4
plastic packaging with paper and compostables alternative to switch **8%** of projected plastic waste by 2050

DESIGN FOR RECYCLING 5
decreases economically unrecyclable packaging by **30%** and increases the vehicle dismantling rate to **15%** for high quality recovery of automotive plastics

EXPAND COLLECTION FOR RECYCLING 6
as well as sorting and dismantling in all sub-systems to turn waste into a high quality resource for secondary feedstock production

INCREASE MECHANICAL RECYCLING CAPACITY 7
By a factor of **1.8x** by 2050 to produce **9.8 Mt** of recyclates and achieve an output recycling rate of **~40%**

SCALE UP CHEMICAL RECYCLING 8
for hard-to-recycle plastics to produce **7.3 Mt** of secondary feedstock by 2050

The NET ZERO SYSTEMS CHANGE SCENARIO builds on the Circularity Scenario and brings the European Plastics system on a net zero pathway through 4 methods of GHG reduction:

A
CHANGE THE FEEDSTOCK CARBON SOURCE
to provide 1/4 of feedstock by 2050 via sustainable bio-based materials or captured carbon and hydrogen

B
APPLY BLUE AND GREEN HYDROGEN
as fuel and feedstock to reduce production emissions

C
ELECTRIFY HEAT SOURCES
for steam crackers with cumulative production capacity of 1.5 million tonnes by 2050

D
CAPTURE PRODUCTION AND END-OF-LIFE EMISSIONS
through applying CCS to steam crackers or CCU/S to waste-to-energy plants

The NET ZERO SYSTEMS CHANGE SCENARIO achieves environmental and economic benefits

Target State
2050

-60%
(255 Mt) less waste incinerated between 2020-2050

>70%
less virgin plastic produced from fossil fuels

1.6 Gigatonnes
cumulative CO_2 emissions saved between 2020-2050

+160,000
jobs from circularity levers

1 in **4**€
to be redeployed to innovative low carbon technologies and circular business models

Introduction

Many plastic applications provide excellent utility for society, health, wellbeing, and food chains, most are recyclable, and some can even support society's transition to net zero emissions. However, increased awareness around the environmental impacts of plastic waste and the greenhouse gas (GHG) emissions from the production and disposal of plastics risks undermining the sector's social license to operate.

Policymakers, investors, and civil society groups are demanding that the plastics industry (along with other industries) aligns with the Paris Agreement and Glasgow Climate Pact, the European Green Deal and Circular Economy Action Plan, and the United Nations Sustainable Development Goals. The European plastics industry, with its progressive regulators, consumers, and shareholders, may be experiencing even greater pressure to act rapidly and decisively to meet these commitments than competitors in other regions. Despite its role in helping society to achieve net zero emissions, the plastics industry faces significant challenges in its own transition towards net zero emissions and a circular economy because:

1. Society's view of plastics has been harmed by the high awareness of plastic waste pollution on land and in the ocean. This is a highly significant issue for the plastics industry, but in the European context, with high collection rates and the anticipated increasing export controls, it is less significant than in emerging markets.
2. The plastics system depends on fossil inputs for both fuel and feedstock. From a carbon management perspective, the end-of-life of plastic is just as important as production, thus the trend towards incineration with energy recovery as the predominant means of disposal in Europe poses a big challenge.
3. Collection, sorting, and recycling all pose major challenges as plastic applications are extraordinarily diverse and widely dispersed. Plastic is often used in disposable, "single-use" applications, in composites of different types of plastic, and in non-plastic materials, and it is distributed in its use phase into millions of households, buildings, factories, cars and other applications.

The European plastics industry is already responding to these challenges with new commitments, investments, and actions, both collectively and by individual companies. The "ReShaping Plastics" scenario analysis study – commissioned by industry and guided by an independent Steering Committee and Expert Panel - is further evidence of the industry's commitment to actively pursuing circularity and climate mitigation, and their growing understanding of the direction and pace of change that will be required.

About this report

While most stakeholders want to take meaningful action, the economic, environmental and social implications of different solutions are often unclear, making it difficult to identify which actions should be prioritized or to fully understand the synergies between different solutions.

A ground-breaking study published by The Pew Charitable Trusts and SYSTEMIQ in July 2020, "Breaking the Plastic Wave", developed a first-of-its-kind full-system model to quantify the economic, environmental, and social implications of different plastic scenarios on a global scale. The new "ReShaping Plastics" study applies that modelling approach to illuminate potential pathways to a fully circular, net zero emissions plastics economy in Europe. It is worth noting that it is not intended as a policy review but may inform policy decision-making.

Project objectives:

This project has three objectives:

A. To produce a data-driven plastic flow model and scenario analysis for the European plastics system that can inform strategies and resource allocation for all stakeholders in the value chain (private and public sector and civil society).
B. To provide a roadmap and clear set of evidence-based recommendations on priority areas to improve the European plastics system.
C. To strengthen the partnership and collaboration between industry, the public sector, and civil society by enabling evidence-based conversations between all stakeholders to explore different strategies for achieving a better plastics system in Europe.

Research questions:

ReShaping Plastics follows two reports from the Ellen MacArthur Foundation that established the vision of a circular economy, aimed at eliminating waste and encouraging the continual use of resources through reuse, redesign, and recycling. It also follows and relies on the many other studies listed as sources in this document. ReShaping Plastics builds on this previous research to provide an evidence-based, data-driven, solution-focused, full-system approach aimed at answering the following key questions about the plastics system in Europe:

1. Where would the plastics system be headed if it continued along its historic trajectory?
2. What are the economic, environmental, and social impacts of current actions taken by governments and industry?
3. What are the impacts on plastic waste and GHG emissions by 2050 under different scenarios? What are the economic, environmental, and social implications of these scenarios and what is the benefits if they are implemented?
4. Can the European plastics system reach net zero emissions? What is required to achieve this goal and what are the costs?
5. What specific levers should be prioritized in the short, medium, and long-term to have maximum impact? What is a desirable innovation roadmap and how much could its implementation cost?

This report was developed under a rigorous independent governance mechanism. While the report was financed by Plastics Europe, an independent Steering Committee was established comprising a balance of leading civil society organizations, public sector leaders, and industry representatives (see full list of members on page 4). The Steering Committee provided strategic guidance and direction in all major project decisions and had complete independence in approving the strategic approach and recommendations. The detailed assumptions underlying the analysis were also supported by an independent Panel of Experts with deep competence in the range of subject areas touched on by this study (see full list of members on page 5). Plastics Europe were consulted to provide industry data, however all information was weighed against multiple alternative sources and final decisions were made by the independent Panel of Experts, Steering Committee, and SYSTEMIQ to ensure the report presents an unbiased position. The findings and conclusions of this report do not necessarily reflect the views of Plastics Europe or its member companies.

Approach:

The scope of this study covers 75% (36.9 Mt) of total European plastic demand and 83% of known waste generation, focusing on EU 27 + 1 countries[vi]. The analysis considers the four largest plastic consuming sectors: packaging[vii] (34%); non-packaging household goods (11%); the construction sector (21%); and the automotive sector (9%)[viii], as presented in Figure 2.

All references to plastic in this report refer to these four categories only, unless otherwise explicitly stated. Plastic was grouped into these "sub-systems" according to its specific behaviour so that flows and levers over time can be modelled. Industrial packaging, tyres, microplastics, electronics and fibres are all outside the scope of the study.

When analyzing GHG emissions, the scope of the study covers the production and end-of-life carbon emissions only. The use-phase emissions benefits of plastic (e.g., insulation of buildings, light-weighting of vehicles, and more) are not quantified within this study although they are considered in the analysis. The study relies on a sophisticated stock-and-flow model, similar to the one used in "Breaking the Plastic Wave" but adjusted to the European context. The model quantifies different stocks and flows in the system, and the relationship between them under different scenarios, as shown in the system map in the Technical Appendix. On top of the volumetric analysis, an economic layer, a climate layer, and an employment layer have been modelled in order to quantify the implications of different scenarios. Additional information about the methodology and detailed assumptions can be found in the Technical Appendix to this study.

[vi] The analysis focuses on the 27 EU member countries plus the United Kingdom. Norway and Switzerland are not included. Note that the data in *Plastics - the Facts* by Plastics Europe includes Norway and Switzerland, i.e. it is for EU 28 + 2.

[vii] Excluding industrial packaging

[viii] The categorization highlighted in Figure 2 forms the baseline of the analysis. It was developed based on analyses of municipal solid waste composition for packaging and household goods (WRAP[2] and Conversio[3]) and associated volume data by Plastics Europe[4], construction data reported by Plastics Europe[4], vehicle registration statistics from Eurostat[5], and data on the automotive sector from Deloitte et al.[6]

A range of scenarios have been modelled to establish potential pathways towards circularity and GHG reduction. These scenarios are not forecasts, nor are they the only possible scenarios. They are one view among an almost infinite number of scenario variations that can be generated. However, they are intended to represent the most illuminating combination of possible pathways, to help guide plastics system decision-making both within and between stakeholder groups. The scenarios were constructed by identifying systems change levers, for example the elimination of unnecessary plastic[ix], automotive design for disassembly, or the scaling up of chemical recycling, and then quantifying the maximum possible efficacy of these levers (as constrained by key system factors) on the system baseline over the 2022-2050 time series.

These systems change levers aim to establish the most likely impacts of the technologies available to drive change in the plastics system today.

The analysis assumes that major change is possible with adequate policy, behaviour change, financing, leadership, and technology. Given the high level of uncertainty inherent in any exercise that takes a 30-year forward-looking view, significant margins of error must be assumed for the outputs, especially in the later years.

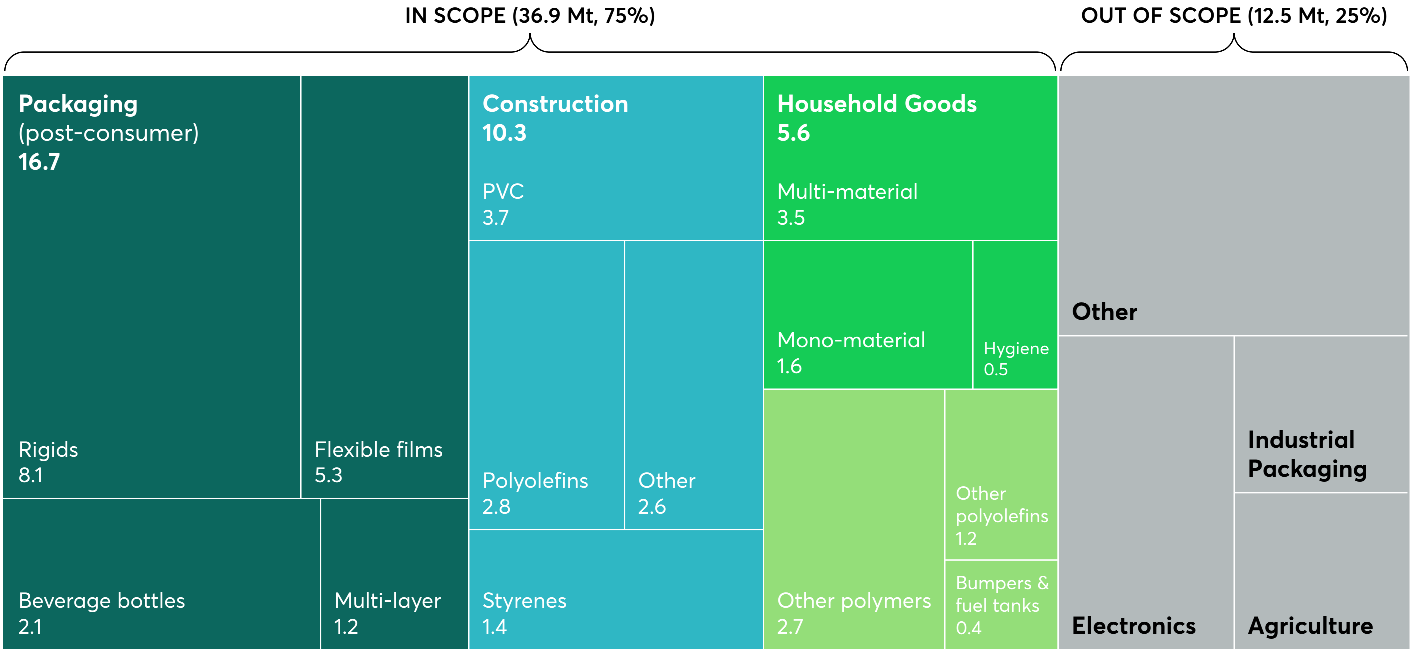
This uncertainty has multiple drivers: some levers may run into "real-world" barriers that are difficult to predict; the cost of certain technologies (e.g., carbon capture and storage, green hydrogen, and others) may vary significantly; implementation of policies may not happen as expected (e.g., institutional reform in waste collection); international supply chains could mean that Europe cannot rely on product redesign to the extent required; required investments may not come to fruition; and potentially other factors. Despite this uncertainty, comparisons among scenarios can be very informative and help show both the relative impact of different levers and the necessary pace of change.

For full and detailed methodology and assumptions please click here.

Figure 2

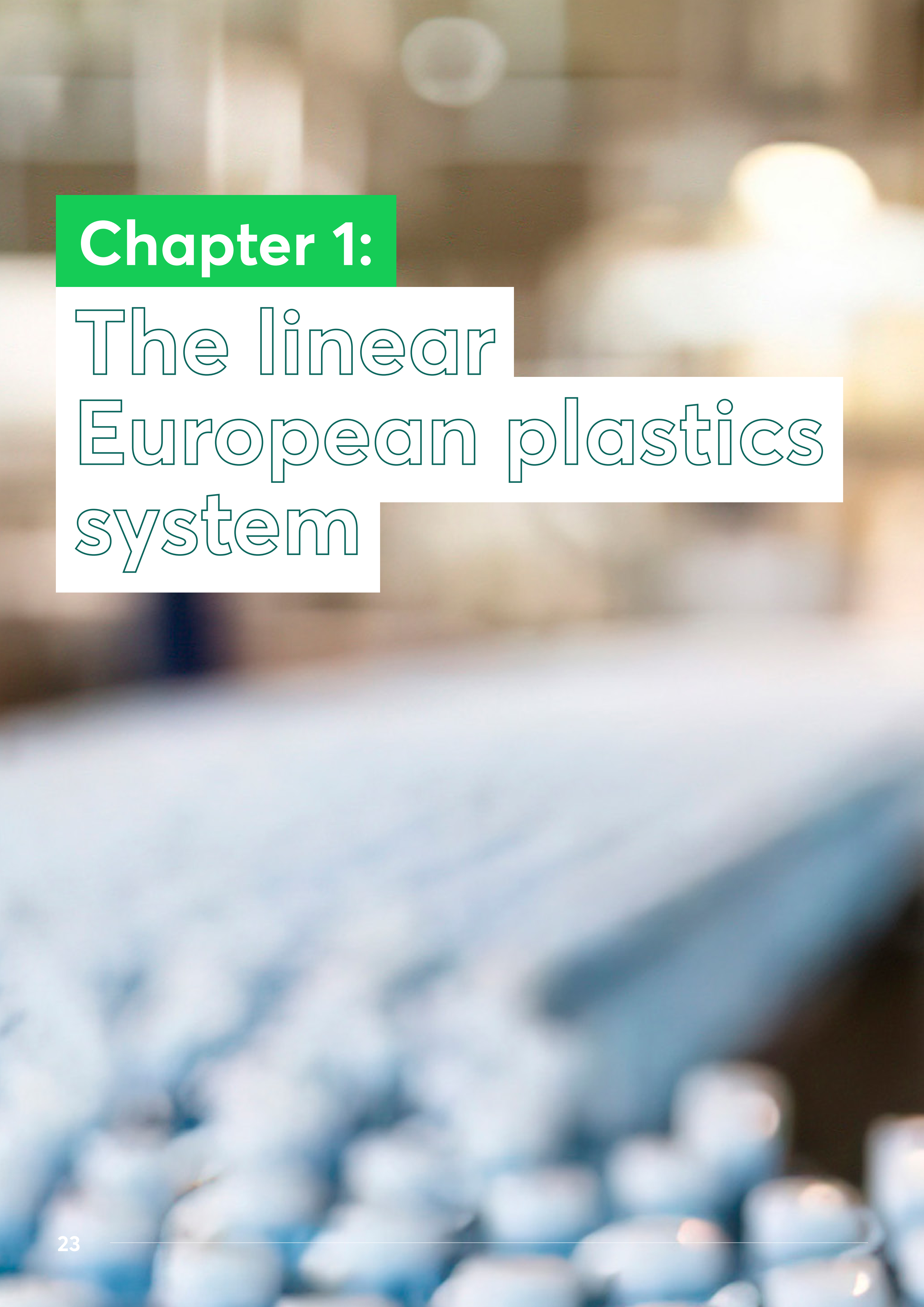
The four sub-systems analysed in this study account for 75% (36.9 Mt) of total plastics demand in 2020 in the EU (27+1)

Composition of the European plastics market broken down by in-scope and out of scope for this study (Mt)



Source: SYSTEMIQ analysis based on WRAP (2018), Conversio (2020), Plastics Europe (2020), Deloitte et al. (2019)

[ix] Elimination of unnecessary plastic refers to the reduction of packaging that does not serve an essential function (e.g., food preservation) while maintaining utility, either through direct elimination at source or through innovative design. An example of unnecessary packaging is that used for solely branding purposes or to incentivize purchasing multipacks.



Chapter 1:

The linear European plastics system

A. Continuing on historic trajectories leads to an untenable pathway

The current European plastics system has low levels of resource efficiency, with only 14% of waste generated today being recycled[x], high rates of waste disposal, and 95 $MtCO_2e$ of GHG emissions per year[xi]. Plastic consumption across the packaging, household goods, construction, and automotive sectors is expected to grow from 37 to 48 Mt between 2020 and 2050. Rising GHG emissions in this "Do Nothing" Scenario show that the current system is not compatible with the Paris and Glasgow climate agreements and increasingly detract from the plastic sector's net benefit to the European economy.

The European plastics system is growing, with demand for in-scope plastic projected to reach 48 Mt by 2050, a 30% rise from 2020. This includes only the plastic analyzed in this project: packaging, household goods, construction, and automotive for the EU27+1. Overall plastic demand in Europe has been experiencing between 1-2% annualized growth over the last decade[xii], with a significant part of this driven by durable applications in which plastic is increasingly playing a role in mitigating climate effects, for example by improving the fuel economy of vehicles and increasing the thermal efficiency of buildings.[4,7]

There are three main challenges facing the current European plastics system: resource inefficiency due to the linear nature of the system, rising GHG emissions, and plastic pollution due to the mismanagement of waste (a lesser issue in Europe relative to other regions, but still a concern). A fourth challenge relates to the toxicity of the materials and their impacts on human health (especially as plastic breaks down into micro- and nano-plastics), but these impacts are not well understood and are not a focus of this study.

This study's material flow analysis reveals that the European plastics system is effectively linear as 86% of plastic waste is being either disposed of[xiii], exported, or mismanaged, as shown in Figure 3. Only 14% of reported waste generated is recycled each year, satisfying a mere 8% of plastic demand (given process losses and some substitution of non-plastic materials by recycled plastic). This finding aligns well with comparable studies.[8–10] Every year, 19 Mt of plastic is either landfilled or incinerated – representing not just significant environmental externalities of 29 $MtCO_2e$ per year, but also an economic cost as the European economy loses around €35-55 billion[xiv] of material value annually as a result. The lower value and quality of recycled plastic relative to virgin plastic is another barrier holding back system circularity. In 2020, out of 3.6 Mt of plastic recycled in the sectors analyzed[xv], roughly 50% was recycled in a closed loop, but only a small share of this was like-to-like recycling. Most of the recycled content is used in plastic applications with lower technical requirements, such as textile fibres or construction, which represents an inherent loss in value.

The current system is responsible for 95 $MtCO_2e$ emissions per year[xvi], 67% of which is generated upstream during production, conversion, and polymerization, and 31% during incineration with energy recovery (waste-to-energy) at end-of-life. As all sectors of the European economy seek to reduce their emissions, targeting net zero emissions by 2050 is increasingly important for the European plastics system to avoid its share of total emissions growing disproportionately. Notable efforts have been made to reduce production emissions in recent years[xvii], but the shift from landfilling to incineration – driven by the Landfill Directive – means end-of-life plastic emissions are currently diametrically opposed to the trajectory of the Paris and Glasgow climate agreements. Significant system and policy restructuring is required to steer the system away from this high-emissions pathway.

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[x] SYSTEMIQ analysis based on best available academic and industry data.

[xi] Plastics "system" here refers to plastic production and end-of-life treatment.

[xii] Plastic - the Facts 2010-2020.

[xiii] Disposal includes incineration with energy recovery and sanitary landfilling.

[xiv] In accordance with the Ellen MacArthur Foundation [11], the value yield amounts to 38% for closed loop recovery. With an effective recycling rate of 15%, the value retained is 5.6%, i.e. 94% of economic value is lost annually, not accounting for the value generated from waste-to-energy. With a virgin plastic price of €1,500 per tonne, the economic losses amount to €35 billion annually in the in-scope sectors of this study. "Material Economics" (2020) estimates the value lost for the entire European plastics sector at €55 billion.[12]

[xv] 3.6 Mt of recycled plastic were produced in the EU27+1 in-scope sectors in 2020; for EU28+2, recyclate production was 4.1 Mt.

[xvi] From upstream production and downstream known waste, but this notably excludes the GHGs that may result from any disposal of plastics missing in the waste statistics through incineration. This study covers 75% of demand in the European plastics system; if emissions were scaled to represent the full system they would be about 130 $MtCO_2e$, which aligns with "Material Economics" calculations of 127 $MtCO_2e$.[9]

[xvii] Specific industry initiatives focused on GHG reduction have not been discussed as the request of industry players to avoid presenting a biased landscape.

As mentioned above, some plastic applications enable the reduction of GHG emissions during their use phase, however this study focuses on plastic production and end-of-life carbon emissions and did not quantify emission savings during the use phase.

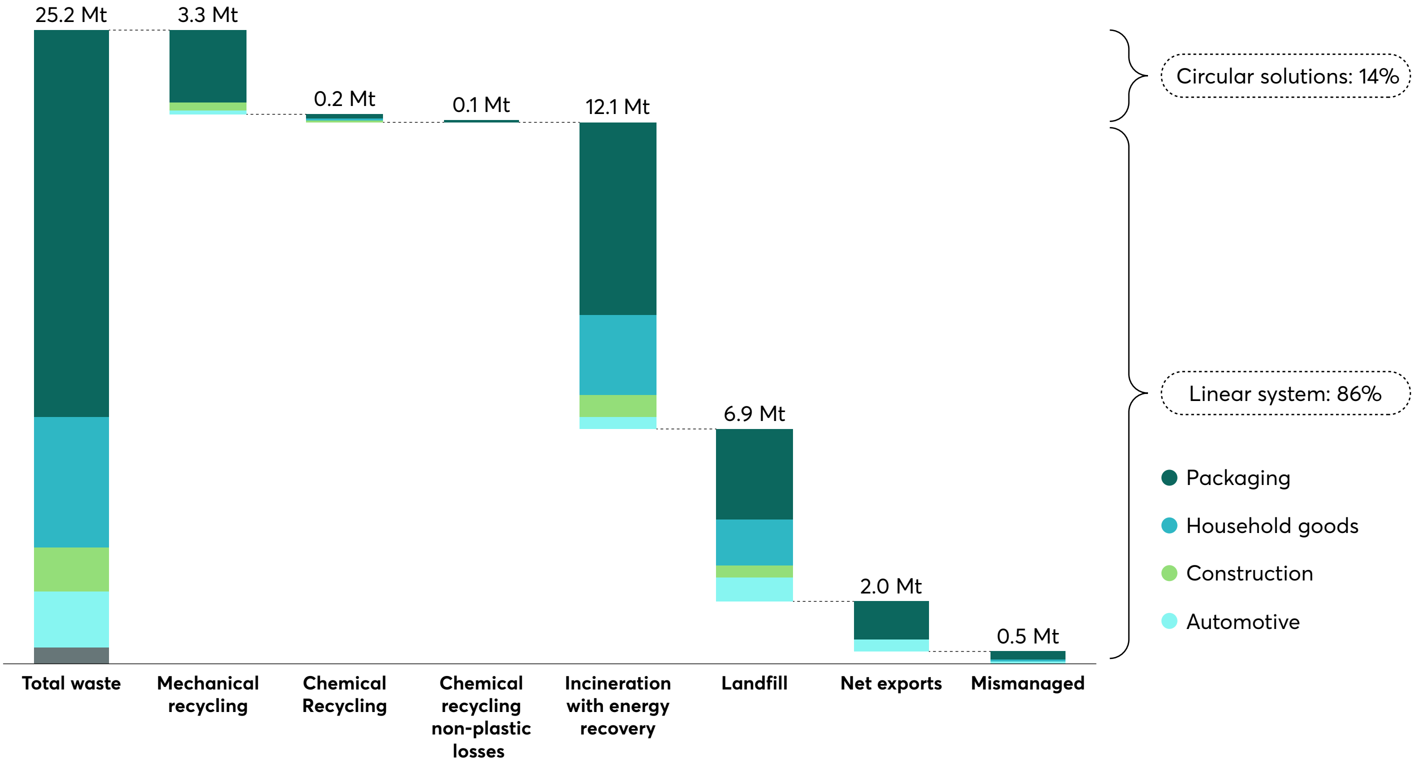
Leakage of plastic waste into the environment, particularly into the ocean, remains a concern for Europe but waste within the system has become increasingly well-controlled over time. Improvements to the collection and recycling infrastructure in Europe, as well as bans and restrictions on goods such as plastic bags, have reduced levels of open dumping, littering, and uncontrolled landfilling. Leakage is most relevant in the less economically developed regions in Europe, which tend to have higher quantities of mismanaged waste, including poorly managed landfill sites near water ways, as well as more open burning, particularly in colder countries. Continued efforts to improve waste management in these regions are essential.

Exports of plastic waste to non-EU countries carry a significant environmental risk but are declining as a result of new EU regulations and waste import bans by key receiving countries. Due to limited waste management capacity in the EU, plastic waste is still being exported to non-EU countries, primarily in South Asia and Turkey. There is a lack of transparency about how these exports are managed in the receiving countries and about the fate of this plastic. Receiving countries often do not have sufficient capacity to manage the imported waste in an environmentally sound manner, increasing the risk of mismanagement and environmental leakage. Major reductions and redistributions of European exports have taken place in recent years, largely because of import restrictions in China and the addition of more plastic types to the Basel Convention. By 2019, EU exports of plastic waste had decreased by 44% relative to 2015.[13]

Figure 3

86% of plastic waste in the European system is currently disposed of, exported or mismanaged in 2020

2020 Physical fate of plastic waste in Europe across four sub-systems



Note: [1] Chemical recycling non-plastic losses describes gaseous and process losses in chemical recycling (gasification and pyrolysis)
Source: "ReShaping Plastics" model

Box 1:
DATA GAP

Our analysis indicates a significant gap in European waste statistics, both at continental and national levels. It is therefore likely that the plastic waste generated is higher than the reported data suggests. Each year, since the beginning of the century, reported statistics have shown a consistent discrepancy between demand for plastic and plastic waste. In 2019, for example, there was a demand for 51.4 Mt[xviii] of plastic, but only 29.1 Mt[xix] of plastic waste was reported, a 45% gap. Until now, it has been reported that the vast majority of this difference is accounted for by plastic entering the economy as a net addition to in-use stock (e.g., plastic in cars, buildings, and household goods), implying an annual growth of the European plastic stock of approximately 22.3 Mt.[14] This would mean that, relative to 2006, the use of in-stock plastic per capita has approximately doubled.

Building on analysis by Material Economics[9,12], this report's stock and flow analysis suggests that this rate of stock growth is unlikely. While the net addition to in-use stock could account for approximately 50%[xx] of the 22.3 Mt, it is unlikely to account for the full gap. The plastic that is not entering stock, and not being exported in secondary goods[xxi], is therefore likely to be additional plastic waste generation that is unaccounted for in the reported statistics, suggesting an additional 8-15 Mt of plastic waste generation in Europe per year, or 30-50% more than the data shows (see Figure 4). This aligns well with the findings of Material Economics (2020), which estimates the statistical gap at 15 Mt, indicating significantly higher end-of-life waste volumes and GHG emissions.[12]

There are several potential explanations for this unaccounted for "gap" between demand and waste data:

1. **Underestimation of plastic in mixed waste**
   If there is more plastic in mixed waste than estimated[xxii], the disposal of plastic waste could be much higher than reported. Given the trend toward incineration with energy recovery in Europe, this presents a risk that the GHG emissions from the plastics sector are significantly higher than those reported by emissions from known plastic. This could mean that incineration of plastic waste, if left unchecked, could account for over a gigatonne of unknown emissions in addition to the 1.2 Gt of known incineration emissions, representing a non-trivial proportion of a 1.5 degree scenario European carbon budget.[xxiii]
2. **Underestimation of plastic products lifetime**
   The "unaccounted for" plastic could be net growth to plastic stock in the economy. If true, this would imply a net addition of over 200 Mt to in-stock plastic in the last decade, which will begin to churn from stock in the future, potentially at a faster rate than demand growth. If this explanation is valid, the European system will need to prepare for an escalation in the proportion of waste vs demand.
3. **Higher levels of exports of secondary goods**
   System leakage may be occurring through higher levels of exports of secondary goods, illegal exports of plastic waste, or greater levels of mismanagement.

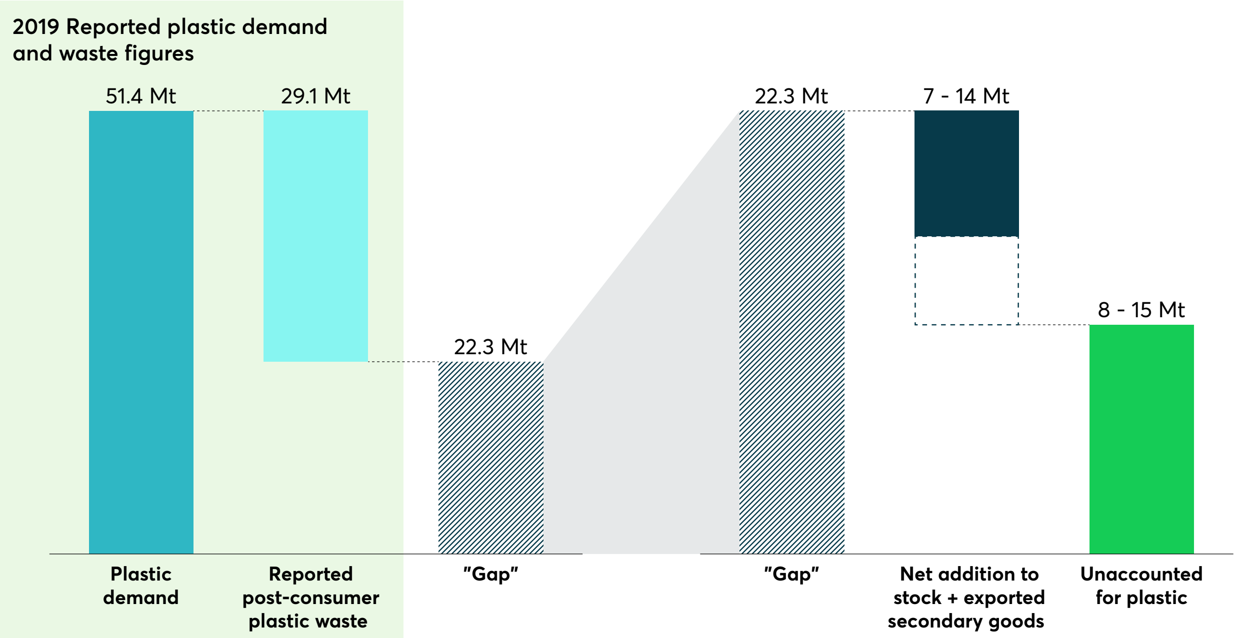
[xviii] Includes net trade balance.
[xix] Includes exports of packaging waste but not of secondary goods.
[xx] With a 10% margin of error.
[xxi] Estimated to be 500 kt.
[xxii] Data from both Sweden and Denmark provides evidence for the historic underestimation of plastic in residual waste.
[xxiii] The carbon budget for Europe is the European share of the global carbon budget for a 50% chance of restricting global warming to 1.5° Celsius based on population allocation.

Box 1 (continued):
DATA GAP

Figure 4

Each year, 8-15 Mt of plastic remain unaccounted for in the reported waste statistics

A mass balance of plastic demand and waste in 2019 (Mt)



Notes: [1] These waste figures include exports of waste but do not include the plastic in exported vehicles which is included in the model.
[2] Net addition to stock based on a stock and flow model with demand extrapolated back to 1985 to account for long life categories
Source: SYSTEMIQ analysis based on PlasticsEurope (2020) Plastics – The Facts

Given the potential environmental and economic implications, it is critical to conduct further research, analysis, and data collection around this gap in waste statistics. While any conclusions are currently speculative due to inadequate data, this highlights a need for improved tracking of plastic flows through the use phase to enable greater visibility and control. This study decided to use existing known waste figures until more is understood about this waste gap, but clarity over where this mass of plastic is ending up in the system is vital if Europe is to effectively drive towards a truly circular economy.

"By 2030, this Current Actions Scenario could reduce plastic entering waste streams by 5%, increase the share of waste being effectively recycled to 27%, and curtail some growth in waste incineration. While these are all positive developments, the pace of change is not yet fast enough to align with the goals of the Circular Plastics Alliance, the European Green Deal, or the Paris and Glasgow climate agreements."

Packaging and household goods

Plastic packaging and household plastic goods collected via municipal solid waste (MSW)[xxiv] are both characterized by low circularity (17% and 1% respectively). In 2020, of the 22.0 Mt of packaging and household goods plastic demand, 20.6 Mt entered the waste system within one year. From an economic perspective, this means that ~95% of economic value is lost to the economy after one short use cycle. This is driven predominantly by the growing preference for convenient, disposable applications combined with a low probability of material recovery in the current system.[11]

Of the 20.6 Mt of plastic waste generated by these two sub-systems, the analysis shows that only 14% was effectively recycled in 2020. While recycling rates are generally reported to be higher – estimated at 42% in EU28+2 in 2018 for household, industrial, and commercial packaging[15] – this refers to volumes collected for recycling rather than volumes actually recycled.[9] Current waste recovery infrastructure in Europe is inadequate to tackle the large quantities of municipal plastic waste dispersed across millions of households, posing significant challenges for collection and sorting and the resulting quality of input into the recycling process. Recycling can be an effective way to decrease environmental damage, but products need to be designed accordingly: chemicals, additives, mixed materials, and food contamination all make recycling difficult and costly. Today, large quantities of plastic packaging cannot be economically recycled, especially multilayer, multimaterial packaging[16] and the majority of household goods, which are therefore sent straight to disposal.

Based on historical trends, and convergence to modest demand growth projections[xxv], waste generation of packaging and household plastic goods is assumed to increase by 1% per year until 2050.[4,9]

On the current trajectory, more than half of packaging and household goods waste will end up in incinerators in 2050, representing a linear system that will produce approximately 1.2 $GtCO_2e$ of GHG emissions between 2022-2050.

Construction

Demand for plastic in the construction sector is on the rise and estimated to increase by 48% by 2050, from 10 Mt today to 15 Mt[xxvi], and multiple challenges are severely limiting plastic waste recovery in the sector. Sectoral growth in the use of plastic over recent decades stems from the fact that it can deliver significant benefits over non-plastic counterparts in several applications. Although alternatives exist, plastic is often the superior choice in terms of affordability, maintenance requirements, durability, and ease of installation. Certain plastic applications, such as for building insulation, also provide important use-phase benefits by improving the overall energy efficiency of Europe's building stock and reducing GHG emissions. With an upcoming EU renovation wave generated by the EU's strategy to improve the energy and resource efficiency of European building stock (launched in 2020), the EU is likely to see rising volumes of plastic demand in construction, with a particular impact on applications such as cable insulation, cladding, and thermal building insulation.

Construction is a significant offtake market for recycled plastic, accounting for 46% of recycled plastic content use in Europe.[14] Despite this contribution to circularity and the use-phase benefits of plastic in some construction applications, construction plastic faces a similar set of challenges at end-of-life to consumable applications, with very low levels of circularity (20%) and virtually no reuse of plastic components. Non-destructive demolition is made extremely challenging as plastic components are typically embedded in buildings and adhered to structural elements, while on-site sorting is limited because of logistical challenges and poor economics. Coupled with the low value of plastic waste from demolition, the low costs of disposal, and the general preference for speed of demolition over material recovery, this means that separate collection of plastic waste remains minimal. Plastic components typically end up in mixed waste streams, posing significant challenges to sorting as plastic makes up less than 1%[17] of the approximate 840 Mt of mixed waste generated by the European construction sector each year. For all these reasons, the recovery of plastic from the construction sector remains minimal.

[xxiv] These sub-systems encompass the plastic fraction of MSW, i.e. waste that is produced mainly by households, but also by other comparable sources such as commerce, offices, and public institutions, and is collected by or on behalf of municipal authorities. Therefore, the packaging sub-system consists of house hold and commercial plastic packaging, excluding large commerce and industrial packaging waste, which is separately collected and thus a different sub-system.

[xxv] The projection is based on historical compound annual growth rates (CAGRs) reported by Plastics Europe and adjusted for estimations by Material Economics (2018). The latter are based on population and GDP growth developments and the assumption that all regions converge to 120 kg plastics/capita at an income level of 40,000 USD/person.

[xxvi] The demand growth has been projected based on floorspace projections from the International Energy Agency.

The longevity of plastic construction products, which have lifetimes ranging from 15 to 100 years, also introduces significant challenges as today's system is addressing the waste of plastic products designed several decades ago, which are far less recyclable.[xxvii] Even in 2050, the waste system will still not, for the most part, be addressing the plastic being injected into the system today. The issue of legacy additives that are now restricted under current legislation, will continue to present challenges over the next 30 years. This causes complications for mechanical recycling, as well as for collection and sorting, as analysing and identifying the additive content in order to sort the plastic is very difficult.

With limited industry focus on the circularity of plastic in construction, business-as-usual operations put the sector on a challenging trajectory. However, while the policy focus in this area has also been limited to date, this is likely to change with upcoming legislation to meet the Circular Economy Action Plan 2.0 (CEAP 2.0), as mandatory recycled content regulation and material-specific recycling targets for plastic construction products are expected. Such policies are likely to drive significant improvement in the circularity of the sector, but will require significant efforts to achieve in full.

Automotive

Driven by lightweighting trends, plastic demand in the automotive sector is rising. By 2050, it is estimated that the average weight of plastic per vehicle in Europe will increase by approximately a third relative to today, resulting in a 25% increase in overall demand from 4.4 Mt to 5.5 Mt.[xxviii] Plastic has enabled improvements in the safety, functionality and affordability of vehicles and has been credited with lowering the average vehicle weight by 200 kg[19], resulting in a 3% to 7% improvement in fuel efficiency.[20] This has delivered substantial emissions savings in the use-phase, reducing the GHG impact of road transport. Even with the rise in electric vehicles, this trend towards lightweighting via a greater share of plastic in vehicles is expected to continue to drive higher energy efficiencies as well as greater range and load capacity. However, while important, these use-phase benefits are at least partly offset by end-of-life emissions from incineration with energy recovery of shredder residue.

The whereabouts of a third of vehicles leaving stock is unknown, and 10% are exported to be used outside of the EU, leaving only 59% of vehicles being transferred to Authorized Treatment Facilities at end-of-life. Despite the best efforts of the End-of-Life Vehicle Directive, a lack of enforcement mechanisms has resulted in continued illegal exports[21] and treatment of end-of-life vehicles (ELVs) by unauthorised facilities. This carries significant environmental risk as vehicles are usually exported to countries with poorer ELV management practices[13], potentially resulting in environmental pollution elsewhere in the world. In addition, less plastic waste is recovered domestically and available for European recycling.

However, even the plastic from the ELVs that are currently treated by authorized facilities has very low levels of recovery, with only 9% recycled or reused.[22] Plastic used in vehicles is highly dispersed, integrated in complex composites, and over 39 different polymer types are used.[23] These design choices have led to significant challenges at end-of-life, including limited dismantling of plastic components (4% of total plastic on average[22]) and low recovery of plastic from the shredder light fraction. The dismantling of plastic components from ELVs remains marginal as, although it allows for a clean uncontaminated waste stream, the economics are unfavourable, productivity is limited, and automation is virtually impossible given the diversity and complex composite structure of vehicle components. As a result, the predominant destination for plastic from vehicles is in automotive shredder residue. The lack of advanced post shredder technology capacity in the EU, and the focus to date on the recyclability of metals, has meant that plastic is typically disposed of

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[xxvii] A lifetime probability distribution with a mean of 35 years is assumed for plastics products in construction.
[xxviii] In-scope demand from EU 27 +1.

in landfill or, increasingly, via incineration with energy recovery. Recycling of automotive plastic is extremely challenging, not least owing to the difficulties in segregating individual polymer streams from the shredder light fraction, but also because of the complex and highly specialized properties of the engineering plastics and plastic composites that are used by the automotive sector.

Due to the increasing amount of plastic in vehicles and the lack of policy focus to date, the current trajectory suggests that the environmental burdens associated with managing plastic waste from ELVs could worsen, resulting in greater levels of landfilling and incineration and, in turn, higher GHG emissions.

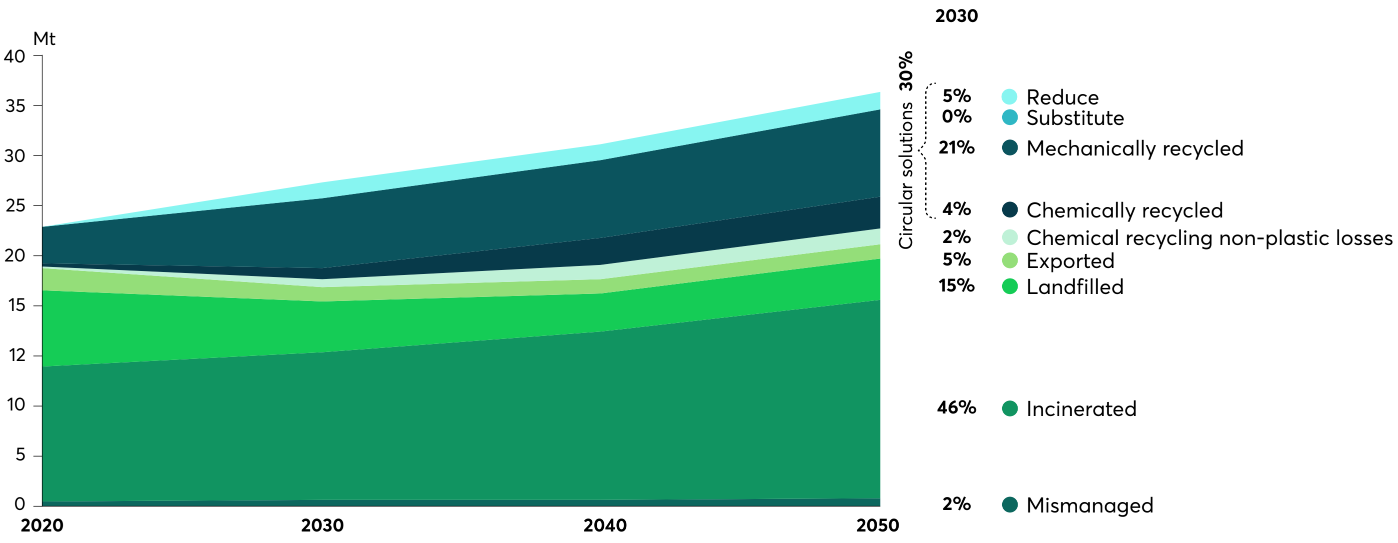
B. Current government and industry actions build great momentum, but are insufficient for the scale of the challenge

The European plastics system is adapting to address the challenges described in the previous section, but it is not happening fast enough to align with societal expectations or European climate commitments. Ambitious actions from industry and governments in Europe are building momentum towards system circularity[xxix] from 14% to 30% by 2030 (as shown in Figure 5), and driving a 11% decrease in GHG emissions from the plastics system and a 5% reduction in system cost[xxx]. By 2030, this Current Actions Scenario could reduce plastic entering waste streams by 5%, increase

Figure 5

Current Actions increase the share of circular solutions to 30% by 2030, up from 14% today

Physical fate of plastic waste from packaging, household goods, automotive, and construction (Mt)



Source: "ReShaping Plastics" model

[xxix] Defined as the share of plastic utility that is either reduced, substituted by circular materials, or recycled mechanically or chemically, excluding plastic entering stock.

[xxx] Total system cost comprises cumulative capex and opex for the respective scenarios and periods, including production and waste management of both plastics and substitute materials.

the share of waste being effectively recycled to 27%, minimize exports, and curtail some growth in waste incineration. While these are all positive developments, the pace of change is not yet fast enough to align with the goals of the Circular Plastics Alliance, the European Green Deal, or the Paris and Glasgow climate agreements[xxxi]. Meeting these commitments will require an unprecedented effort on behalf of industry, regulators, and other stakeholders; the system is currently not on track to achieve this by 2025. More comprehensive cross-stakeholder efforts to translate ambitions into action are required, underpinned by the wave of legislative reform underway as part of the Circular Economy Action Plan 2.0.

Under growing pressure to improve the system performance of plastic in Europe (and globally) being exerted by multiple stakeholders, policymakers and industry leaders are taking several ambitious actions to improve system outcomes, including total plastic waste, recycling rates, GHG emissions, use of virgin feedstock, and landfill rates. This section reviews these actions and quantifies their impact on the plastics system. The combined result is analysed in a Current Actions scenario, which is used as the baseline in the rest of this report.

The impact of current actions, if achieved, is expected to increase from today through to 2030. Analysis using the model developed for this report shows that current actions are expected to have four major effects on the European plastics system:

1. **A moderate reduction of 5% in plastic demand, mainly in single-use packaging, by 2030** The Single-Use Plastic Directive (SUPD) is the most important commitment to reduce plastic waste in Europe. However, while this is an important first step, given the limited plastic applications included in scope of the Directive, the model suggests that it will result in only 1 Mt of plastic being reduced by 2030. While prevention is at the top of the waste hierarchy, so far this has not been an explicit key priority of most policy or industry actions. A notable exception is France, which is taking bolder steps by establishing reuse targets that mandate 5% of packaging being reusable by 2023 and 10% by 2027, and that 100% of plastic packaging should be recyclable by 2025, as per the "Anti-waste Law" adopted in 2020, which implements the SUPD.[24,25] At the same time, reduction targets are emerging among brands and retailers, and are expected to become a key part of the Ellen MacArthur Foundation's Global Commitment on plastic as well as the European Plastic Pact going forward.[10,26] Corporate pledges made under the Global Commitment add up to an estimated 0.3 Mt of plastic reduction in Europe. Combined with SUPD measures, this could eliminate up to 5% of plastic from the waste stream by 2030.

2. **A 2.3 Mt uplift in mechanical recycling and 0.7 Mt uplift in chemical recycling by 2030 vs business as usual** Approximately 3.6 Mt of plastic in-scope for this study is recycled annually today, or 14% of plastic waste generated in 2021. Several policies - including the Packaging and Packaging Waste Directive (PPWD), EU Plastics Packaging Levy, and the Waste Framework Directive (WFD) - as well as pan-industry commitments, such as the Circular Plastics Alliance and individual company actions, have been designed and introduced to significantly increase this number[xxxii]. Current government and industry actions can grow mechanical recyclate output volumes for the in-scope sectors[xxxiii] in Europe to an estimated 5.3 Mt and 6.3 Mt by 2025 and 2030 respectively, and the chemical recyclate production to an estimated 0.4 Mt and 1 Mt[xxxiv] by 2025 and 2030 respectively. This means 27% of waste generated is recycled, with most of this growth driven by packaging waste recovery to meet PPWD targets. Achieving this growth will require substantial improvement and scaling of the entire recycling value chain (collection for recycling, sorting, mechanical recycling, and chemical recycling), as not all plastic categories are currently on track to achieve these targets, let alone many of the more ambitious commitments.

[xxxi] European plastics company GHG reductions commitments have not been included in the Current Actions Scenario as they did not, as an industry collective, meet the stringent criteria for inclusion as a pan-industry GHG reduction agenda.

[xxxii] Packaging and Packaging Waste Directive targets 50% plastic recycling by 2025 and 55% by 2030. Waste Framework Directive targets the preparing for reuse and recycling of MSW to a minimum of 55% by 2050, 60% by 2030, 65% by 2035, by weight but without specific plastic targets. EU Plastics Packaging Levy charges member states €800 per tonne of plastic waste that is not recycled according to reported Eurostat waste statistics beginning Jan 2021. The Circular Plastics Alliance has targeted growing the EU recycling market to 10 Mt by 2025. Other notable industry commitments include PCEP, Petcore, Vinyl Plus, EU PlasticsPact and Plastics Europe.

[xxxiii] Includes only the plastics in-scope for this report, namely post-consumer packaging, household goods, automotive, and construction. These sectors represent the vast majority of recycled plastic.

[xxxiv] Assumes that 1/3 of industry pledges to Plastics Europe will be achieved given current policy and investment environment.

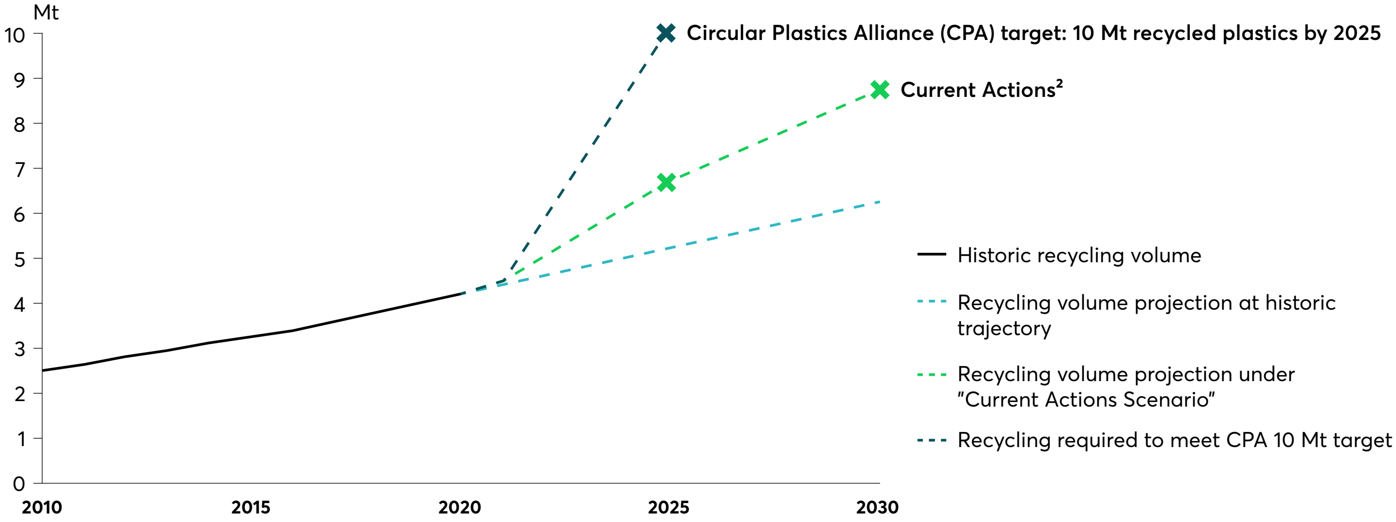
For example, Figure 6 shows the gap between current actions and the growth in recycling needed to meet the Circular Plastics Alliance target of 10 Mt of recycled plastic by 2025. Given the challenging environment for mechanical recycling today, achieving these targets requires cross-cutting collaboration between value chain players to de-risk investments, supportive policy, and actions from brands and retailers to purchase recycled plastic. More details on scaling this industry can be found in Section 2 b. Without appropriate policy support, chemical recycling is unlikely to scale to a level that will achieve significant systems impact.

3. **A continued shift away from landfilling at end-of-life leading to an additional 1.2 Mt of plastic incineration and nearly 8 $MtCO_2e$ more emissions per year by 2030** The Landfill Directive prohibits EU members from sending more than 10% of their total MSW to landfill after 2035. As there is no other apparent disposal alternative in Europe, this Directive will continue to drive MSW towards incineration with energy recovery. There was a 4.8% compound annual growth rate (CAGR) in plastic waste heading to incineration between 2006 and 2018,[4] and this is set to continue under the Current Actions scenario. Incineration will grow from 12.1 Mt in 2020 to 13.4 Mt in 2030, ultimately emitting 37 $MtCO_2e$ annually, a nearly 8 Mt per year growth in incineration-related emissions by 2030. Emissions from plastic entering incinerators could add up to 1.2 Gt by 2050, the implications of which are detailed in Box 2. Until a step change in plastics system circularity is achieved, or an alternative destination for end-of-life plastic is identified, there is every reason to assume that incineration emissions will continue to increase at a rate diametrically opposed to the broader EU emissions trajectory, as shown in Figure 7.

Figure 6

Trajectories are not on track to meet current policy and industry actions and even these actions fall short of the CPA target

Historic and future projection of recycled plastics in the full system[1] along historic trajectory, to meet current actions and the CPA target (Mt)



Notes: [1] These projections are extrapolated for the entire European plastics system (EU 28 + 2), including all sectors for easy reference for readers familiar with full system numbers;
[2] Includes PPWD, VinylPlus, EMF, and 1/3 of the Plastics Europe chemical recycling pledge
Source: SYSTEMIQ analysis

4. **A reduction in waste exports outside the EU, making waste increasingly domesticated within the EU** Waste exports from Europe have already decreased from approximately 3.1 Mt to 1.7 Mt between 2016 and 2019, driven by several restrictions on the trade in international waste, including the Chinese waste import ban.[13] In the future, European plastic exports could decrease further if the Basel Convention and EU-adopted plastic waste shipment rules are successfully implemented, and thanks to import bans in additional countries in the Global South, following China's lead. Europe needs to prepare for a scenario where waste becomes increasingly domesticated on the continent, as the report analysis anticipates will be the case under current actions. Ideally, continued intensification of anti-littering efforts and the elimination of exports of plastic waste to countries outside the EU, where littering cannot be controlled, could lead to a domestication of plastic waste within an optimized and scaled European waste management system.

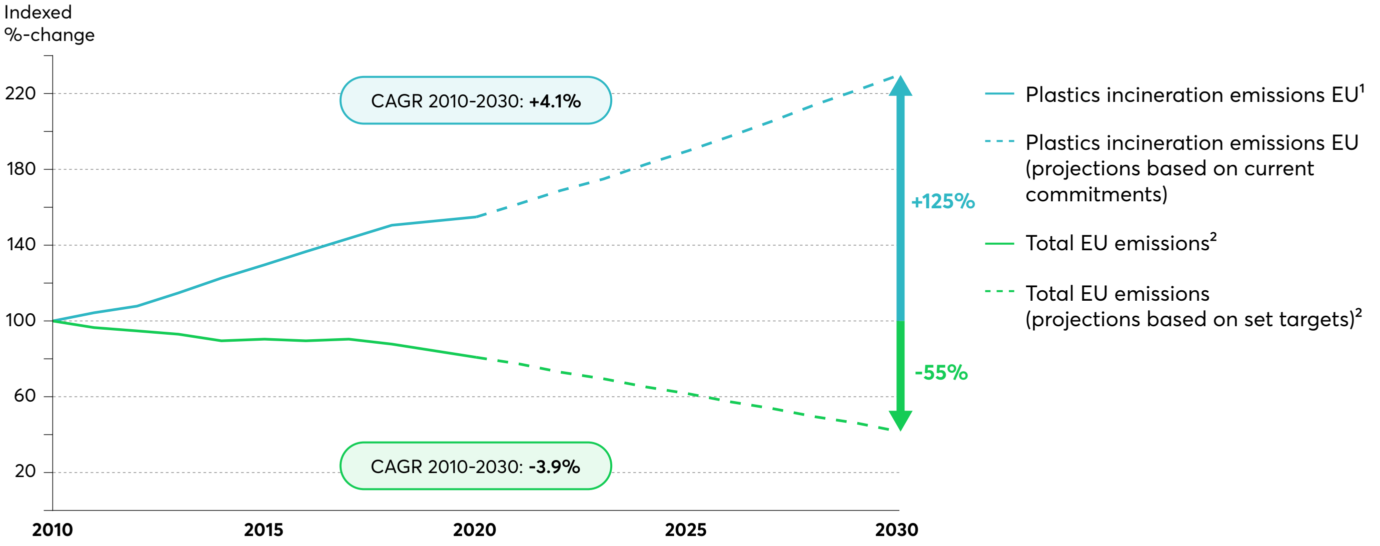
Figure 8 summarizes the overall impact of current actions by policymakers and industry on the in-scope plastics mass flows by 2030, as modelled in the Current Actions Scenario.

The European plastics system GHG reduction targets have not been included in the Current Actions scenario. While some companies[xxxv] have aligned with the EU target of achieving 55% reduction in GHG emissions vs 1990s levels by 2030, and there are multiple pledges to reach net zero emission targets by 2050, as those pledges are often company-wide and spanning a broader system beyond plastic, it was not possible to distil a plastic specific overarching number. For this reason, they were not included in the modelling of this study, but this should not detract from industry leaders that are pioneering GHG reduction.[xxxvi]

Figure 7

Total plastic incineration emissions are trending in the opposite direction of EU emission targets, driven largely by the Landfill Directive which is expected to continue driving waste from landfill to incineration

European emissions from plastics incineration vs. total EU GHG emissions 2010-2030 (indexed to 2010 values)



Notes: [1] As reported by Plastics Europe (2020): Plastics the Facts 2020.
[2] Using data by the EEA (2020): Total greenhouse gas emission trends and projections in Europe.
Note that this scenario only includes the effects of the Landfill Directive.

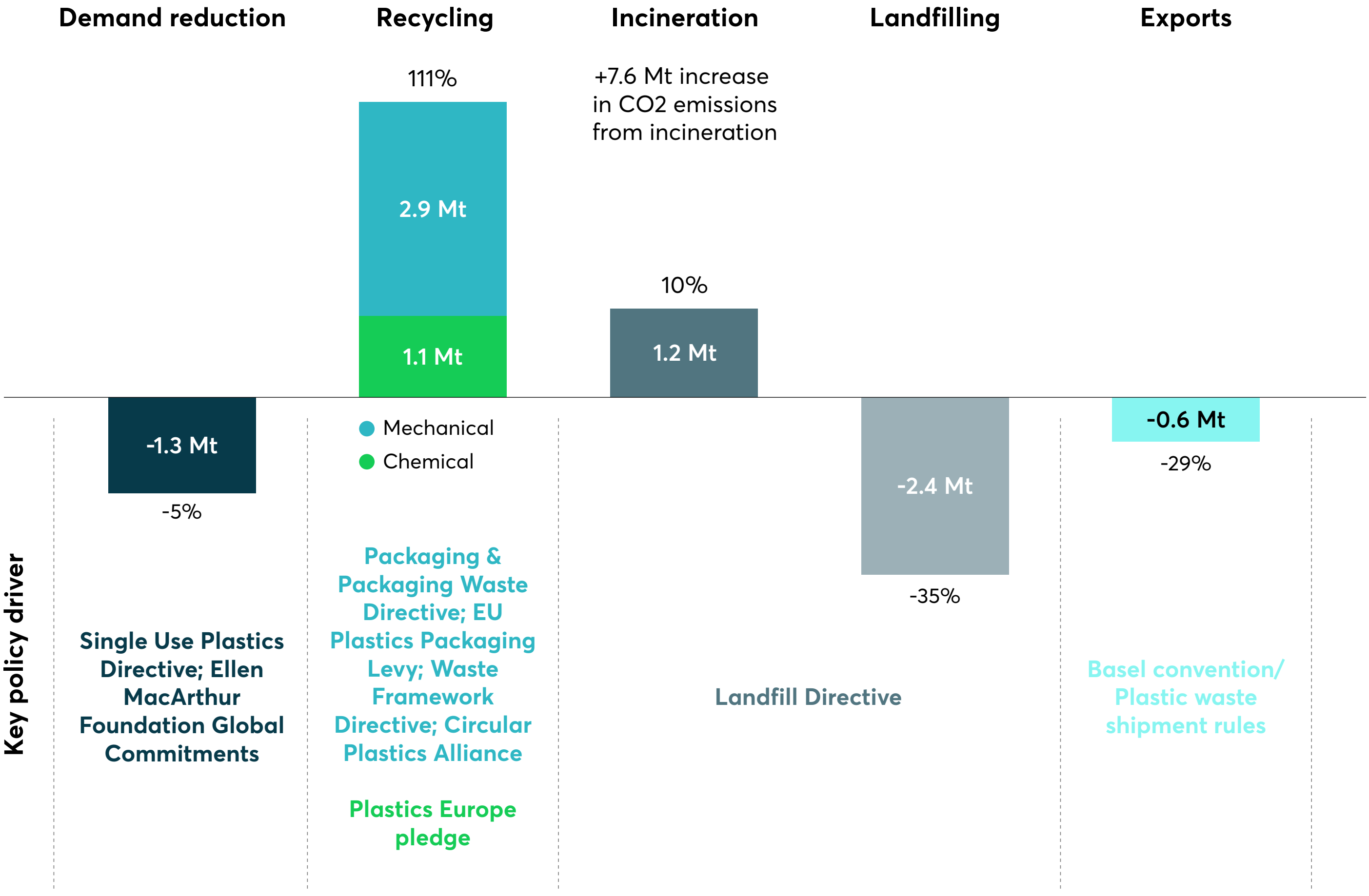
[xxxv] Individual company GHG reduction commitments have been removed from this report in order to avoid creating an uneven distribution of references.

[xxxvi] Current Actions reduce total GHG emissions by 11% by 2030 and by 18% by 2050 relative to the Do Nothing Scenario. These efforts, coupled with macro-decarbonization of the broader economy, could keep GHG levels flat 2020-2050 just above 90 Mt C02e despite the growing system. Some large players have set more ambitious commitments. However, achieving these commitments relies heavily on technologies which are currently very nascent and are yet to be demonstrated commercially, and therefore have great uncertainty for feasibility and effectiveness. Furthermore, there is not a pan-industry GHG active reduction commitments, with the current focus rightly being on driving circularity before investing heavily in GHG reduction technologies.

Figure 8

Current Actions could decrease exports, reduce demand, increase recycling, and divert waste from landfill to incineration by 2030

Impact of Current Actions in 2030 vs 2020 (volumes (Mt) and %-change)



Source: "ReShaping Plastics" model

> ***"Achieving the ambitious outcomes modelled in this study requires substantial changes in the business models of firms producing and using plastics and their substitutes; overhauls to the recycling and waste disposal industries; new investment models and criteria; and the modification of consumer behaviour at scale."***

Box 2:

Implications of incineration with energy recovery and possible alternatives

The current policy environment in Europe means that incineration is likely to continue to be the dominant form of waste disposal for MSW end-of-life by 2050, with landfilling remaining legal only for automotive and construction waste. The Landfill Directive seeks to limit the volume of MSW in landfills, including plastic. Hence, incineration with energy recovery is being increasingly used as an alternative, not least because it can recover the energy within the waste and in doing so displaces emissions related with fossil fuel energy.[27] However, despite the GHG benefits of reducing landfill, as well as broader social and environmental benefits including neutralizing certain toxins contained within waste, incineration with energy recovery is not a climate-neutral solution for end-of-life plastic. It is a partial mitigation of GHG impacts relative to landfilling and is increasingly problematic.

The energy recovery only results in a small offset relative to the emissions generated and even this will decline as renewable energy further decarbonizes the grid[xxxvii]. Incineration with energy recovery (Waste-to-Energy, W2E) is about twice as carbon intensive as grid generation at around 550g CO_2e/kWh[28]. Incinerator construction can also have a "lock-in" effect (i.e., incinerator capex requires long-term contracts for waste supply by municipalities) and an inverse correlation between incineration of MSW and recycling rates in municipalities have been observed.[xxxviii] The incinerator portfolio across Europe does not currently have a clear pathway to emissions abatement and thus climate risks from this end-of-life pathway are escalating driven by: i) increased plastic volumes flowing to W2E at end-of-life; ii) decreased electricity generation offset; iii) risk of higher levels of plastic in residual waste than previous calculated; and iv) growth of the overall plastics system. Two strategic alternatives to the incineration pathway considered in the Current Actions scenario have been identified.

1. **Zero-methane landfilling of residual waste.** The Waste Framework Directive mandates separation of organic waste in the EU by 31 December 2023 (article 22). If organic matter can be removed effectively from MSW and landfilled in higher-quality, controlled sites it may offer the opportunity to return carbon directly to the ground. Opportunities have been identified to create Mechanical Recovery Biological Treatment facilities that introduce equipment to extract additional plastic from residual waste and biologically stabilize fermentable organic materials to avoid methane generation[xxxix] before landfilling. Such a shift would require a policy reframing, careful implementation to avoid perverse incentives, and careful communication, but presents an interesting transition technology alternative to incineration, using known, tested, at scale technology in an economically efficient way. It is worth noting that GHG emissions are not the only environmental metric, and landfills have other negative impacts such as soil pollution, taking valuable urban space, and smell implications.

2. **Gasify all municipal solid waste.** Gasification is a form of chemical recycling that is discussed later in the report in Section 2 b, but theoretically could address the majority of residual waste – assuming issues around sortation and contamination are overcome.

[xxxvii] Calculated as a saving of 0.5t CO_2e per tonne of polymer incinerated, meaning blended emissions from end-of-life plastics incineration increase from 2.4t CO_2e per tonne in 2020 to 2.9t CO_2e in 2050.

[xxxviii] Data presented to the UK Parliament for Communities and Local Government *Waste Strategy: Implications for Local Authorities* by Professor N. Gregson (Recycling & Waste Economics specialist), Durham University on 5 September 2019.

[xxxix] Not for composting.

Methodology and selection criteria of current actions

Commitments are not taken at face value. While numerous ambitious commitments have been made, history tells us that a target set is not always a target met. A set of four criteria were used to assess their likelihood of realization:

- **Adopted legislation**: All EU-wide legislation that was passed by 1 April 2021 was automatically included. National legislation was not considered as the modelling was done at an EU level.[xl]
- **Control over voluntary targets**: for a voluntary commitment to be considered credible, the target setter must have sufficient control over the achievement of the target. For example, while the Circular Plastics Alliance has committed to increasing the market for recyclates to 10 Mt by 2025, only 6.4 Mt has so far been committed to by those who have direct control over the targets. Therefore, the commitment is only partially included in the analysis.
- **Priority for ambitious targets**: Where industry and/or policy commitments overlap, the more stringent target is modelled. Therefore, voluntary commitments are only considered if they are above legislative ambition.
- **KPIs and roadmap**: Voluntary commitments and/or targets are only included if they have clear key performance indicators and an actively managed roadmap.

Applying these criteria led to the inclusion of the following initiatives as "current actions" in this scenario:

- **EU-wide policy**: Single-Use Plastic Directive; Packaging and Packaging Waste Directive; EU Plastic Packaging Levy; Waste Framework Directive; Landfill Directive.
- **International agreements**: Basel Convention.
- **Voluntary commitments from industry**: Ellen MacArthur Foundation Global Commitments; Circular Plastics Alliance commitments; and chemical recycling pledges to Plastics Europe (included one third of pledge total).

Looking forward, an imminent wave of legislation may have a far more substantial impact on the system. It is very likely that the Circular Economy Action Plan 2.0 (CEAP 2.0) has greater potential and impact than existing legislation. Under CEAP 2.0, 39 pieces of legislation will be reviewed, adapted, or added over the course of 2021 to 2023. Of these, nine legislative actions affect the plastics value chain and the in-scope sectors of this study with potentially significant impacts on the plastic waste process chain, from design to collection to end-of-life treatment. Some of these legislations, including a revision of the Packaging and Packaging Waste Directive, have the potential to fundamentally redefine the plastics system. Under advisement from the European Commission, these future commitments have not been quantified in this study, as no binding targets exist yet and accurate quantification would be challenging, but it is notable that the policy landscape is likely about to undergo a major shift.

In summary, current policy and industry commitments, even if achieved in full, are insufficient to achieve a predominantly circular system. This highlights the need for ambition beyond existing pledges in order to align the European plastics system with societal expectations and climate commitments. How this can be achieved is discussed in Chapter 2.

C. Single lever scenarios show there is no "silver bullet"

There is no "silver bullet" solution to significantly reduce plastic waste and GHG emissions. Upstream and downstream solutions are complementary, and are most effective when deployed together. The Reduction and Substitution Scenario demonstrates that without investing in recycling, significant plastic waste and GHG emissions remain in the system. Similarly, the Recycling Scenario shows that we cannot recycle our way out of the problem, as a significant share of plastic is not economically recyclable, even if redesigned.

To date, stakeholders have often focused on either "upstream" (pre-consumer, such as material redesign, plastic reduction, and substitution) or "downstream" (post-consumer, such as mechanical and chemical recycling) solutions.

[xl] Country-level actions are not included as EU policy is leading member states legislation on circularity and GHG reduction. Single member states might deviate and not fully implement EU directives, but modelling this would be too complex. Key policy archetypes have been used to inform system change levers, e.g. France and Germany.

The analysis shows that this is a false dichotomy. None of single-group lever scenarios modelled in this study are adequate to change the system.

Upstream solutions that aim to reduce or substitute plastic use are critical, but will need to be scaled carefully to limit adverse social or environmental effects[xli]. While there are significant opportunities to reduce, redesign or – in some cases - substitute plastic in the system, relying on these solutions alone still leaves substantial waste disposal and GHG emissions. Ambitious upstream reduction, redesign, reuse and substitution levers in isolation could reduce the overall demand for plastic in 2050 by up to 22% (10.6 Mt) and achieve a reduction of up to 26% in GHG emissions relative to current actions. However, these levers only achieve a system circularity of 53% and leave 74% of system emissions unabated by 2050, even when applied very ambitiously.

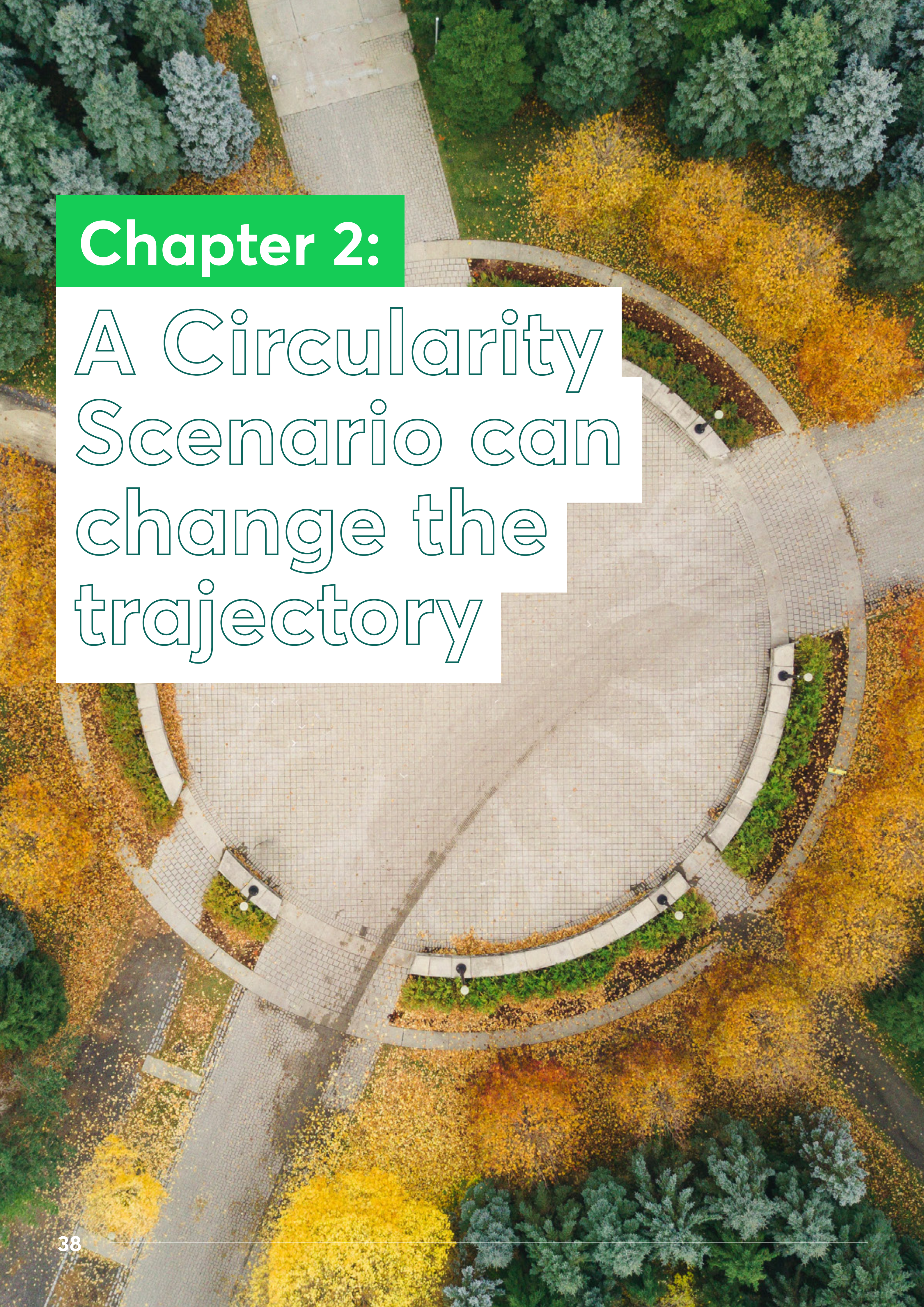
Downstream solutions are also essential but are limited by economic viability and the realistic speed of infrastructure development and feedstock tolerance. Mechanical and chemical recycling levers can achieve circularity levels of up to 69% on their own, with an associated GHG reduction of 55% compared to current actions. However, solely relying on downstream levers is risky given the nascence and uncertainty of scaling chemical recycling technologies and mixed historical successes in scaling mechanical recycling.

Barriers to high-quality plastic recycling include the high variability of materials and plastic being optimized for each application, the dispersal of plastic into millions of households, the huge variety of polymers and additives, and the low value of waste not providing incentives for process optimizations. Mechanical recycling is also limited by the fact that a plastic product can only be mechanically recycled a certain number of times (typically between three and seven, depending on the polymer) before it loses its mechanical properties and can no longer be recycled. Today this may not be an issue as recycling rates are low, but as rates increase it could start to become a limiting factor. Additionally, most extended producer responsibility **(**EPR) schemes incentivize sorting to a minimum purity level and therefore the material sent to recycling facilities often either requires further expensive sorting or is only really suitable for producing low quality recyclate.

Upstream levers decrease the size of the entire plastics system by driving resource efficiency, resulting in lower system costs across the plastics value chain, higher circularity, and lower GHG emissions. Therefore, both upstream and downstream solutions have an important role to play in the future Plastics system, and neither can be left out.

> ***“There is no “silver bullet” solution to significantly reduce plastic waste and GHG emissions. Upstream and downstream solutions are complementary, and are most effective when deployed together. The Recycling Scenario shows that we cannot recycle our way out of the problem, as a significant share of plastic is not economically recyclable, even if redesigned.”***

[xli] Substitution solutions could have unintended consequences and need to be assessed on a case-by-case basis to understand their full impact. For more information, see Section 2 b.



Chapter 2:

A Circularity Scenario can change the trajectory

A. Incorporating both upstream and downstream solutions is fundamental for full circularity

The necessary tools exist today to substantially increase plastics system circularity[xlii] from 14% today to 78% by 2050, while reducing GHGs by 65%, and delivering broader social and health benefits.[29] Achieving these substantial reductions in plastic waste disposal and GHG emissions is a complex challenge that requires system-level interventions. The Circularity Scenario defined in this study sets out a feasible pathway towards meeting these goals while creating co-benefits for health, jobs, and the environment. To realize this transformation, several system interventions need to be implemented concurrently, ambitiously, and immediately. Based on the analysis conducted, an unprecedented level of circularity can be achieved in Europe through proven circular technologies and strategies, namely: elimination, reuse and new delivery models, substitution, better design, mechanical recycling, and chemical recycling.

It is not the lack of technical solutions that is preventing the plastics system from addressing its environmental and climate impacts, but rather the need for different regulatory frameworks, business models, funding mechanisms, and behaviour change. Although the technical solutions exist, the incentives are not always in place to scale-up these changes fast enough.

The analysis shows that creating a resource-efficient, emissions-abating system requires a cumulative (2020-2050) investment of approximately €160-180 billion, but that overall it can reduce system cost by €400-440 billion. At the same time, the growth of labour-intensive sectors and business models, such as recycling and reverse logistics, leads to net job growth of 11% by 2050 compared to today.

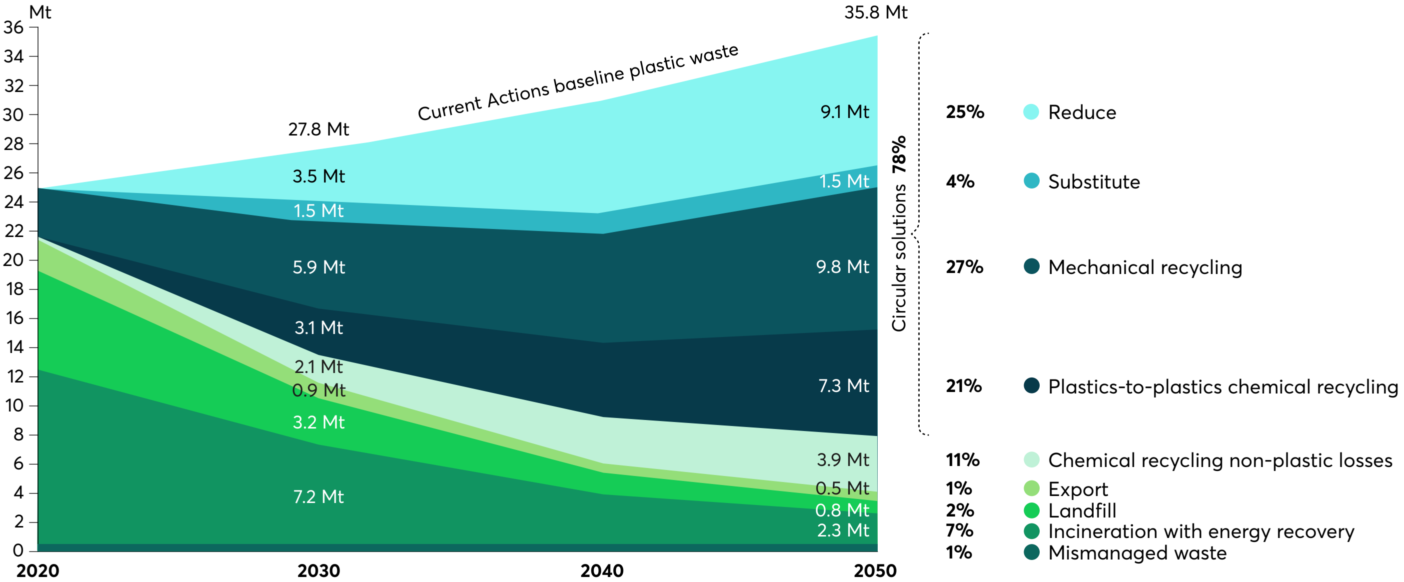
The Circularity Scenario combines proven upstream and downstream interventions – reduction, substitution, mechanical recycling, chemical recycling – and intervention levers that enable them, such as scaling collection and sorting.

Figure 9 shows the relative size of each of the intervention "wedges" that together make up the Circularity Scenario and deliver circular solutions for 78% of plastic waste by 2050, as depicted in Figure 10.

Figure 9

By 2050, the Plastics system could achieve 78% circularity with 30% of waste avoided through reduction and substitution and 48% being recycled, leaving 9% in landfills and incinerators

Physical fate of plastic waste from packaging, household goods, automotive and construction 2020-2050 (Mt)



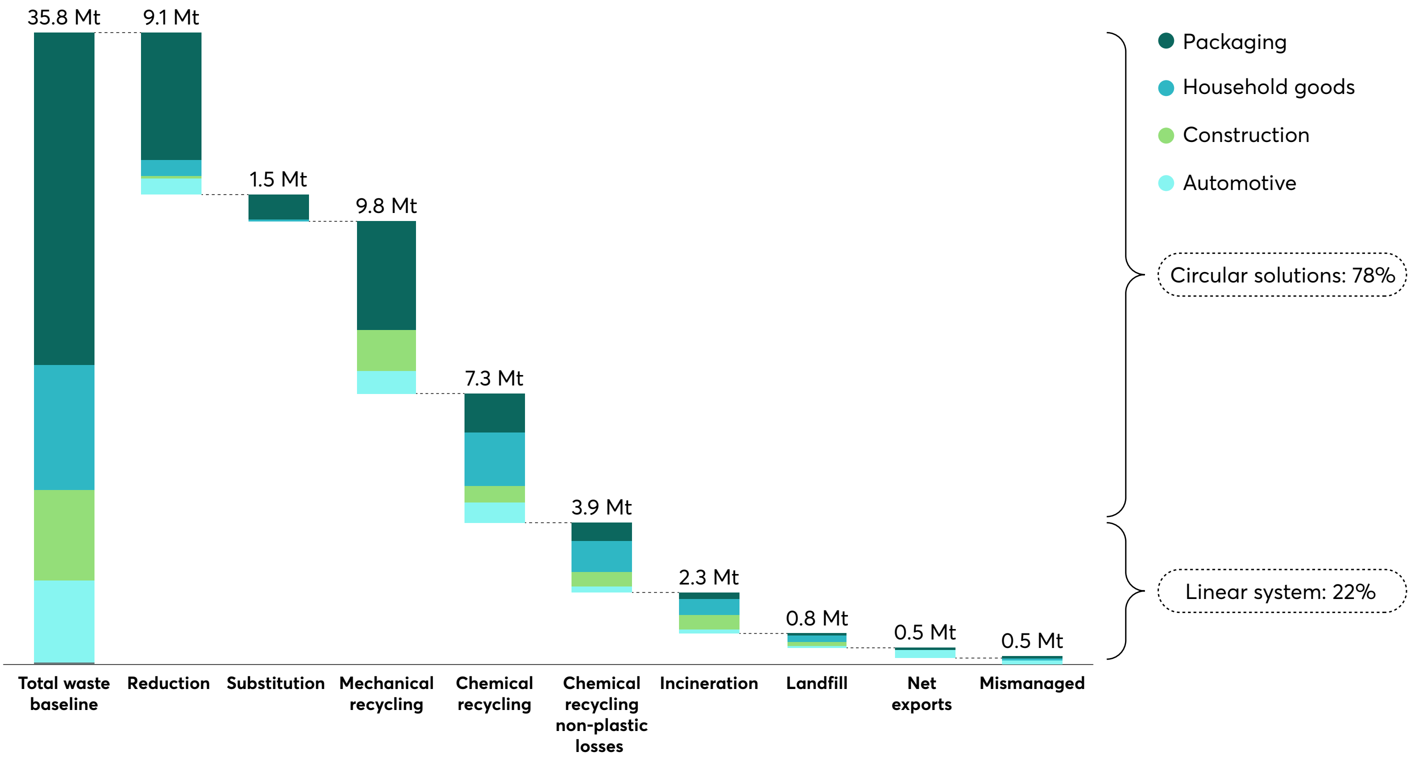
Source: "ReShaping Plastics" model

[xlii] Defined as the share of plastic utility that is treated in any way other than landfill, incineration with energy recovery, exported, or mismanaged.

Figures 10 and 11

By 2050 ambitious application of the circularity levers across the four sub-systems reduces disposal, exports and mismanaged to 22% and increases system circularity to 78%

Physical fate of plastic waste from automotive, construction, packaging and household goods in the circularity scenario in 2050 (Mt)



Note: [1] Chemical recycling non-plastic losses describes gaseous and process losses in chemical recycling (gasification and pyrolysis)
Source: "ReShaping Plastics" model

Four system interventions and corresponding levers improve circularity in the sub-systems with varying applicability

✅ Highly applicable ☑ Partially applicable

System Intervention	System Intervention Levers	Plastics sub-system and applicability of intervention				Main responsible stakeholder
		Packaging	Household	Construction	Automotive	
#1 Reduction	Reduce plastic through elimination	✅	✅			Consumer goods brands; retailers
	Reduce plastic through reuse/ New Delivery Models	✅	☑	☑	☑	Consumer goods brands; OEMs; construction companies
	Reduce plastic through sharing models for vehicles				✅	OEMs
#2 Substitution	Substitute plastic with alternative materials	☑	☑			Consumer goods brands; retailers
#3 Mechanical recycling	Design for mechanical recycling	✅		✅	☑	Consumer goods brands; OEMs; construction companies
	Expand collection for recycling and sorting	✅		✅	☑	Local governments
	Increase mechanical recycling capacity	✅		✅	✅	Waste management companies
#4 Chemical recycling	Scale up chemical recycling	✅	✅	☑	✅	Petrochemical industry

Circularity is the fastest, most cost-effective, and most reliable way to increase resource productivity and drive down GHG emissions before 2040. If applied ambitiously alongside macro-levers such as grid decarbonization, circularity levers can deliver a 65% reduction in emissions by 2050 relative to today.

B. Every sub-system has a role in the transition, but each requires different levers

Figure 11 summarizes the upstream and downstream system interventions and levers that define the Circularity Scenario in each plastic sub-system. It is worth noting that circularity levers in almost any sector of the economy could impact plastic demand because of the ubiquity of plastic in our lives. For practical reasons, this study quantified the levers with the most meaningful and direct impact on plastic, but other broader circularity levers are mentioned qualitatively in the report.

Packaging

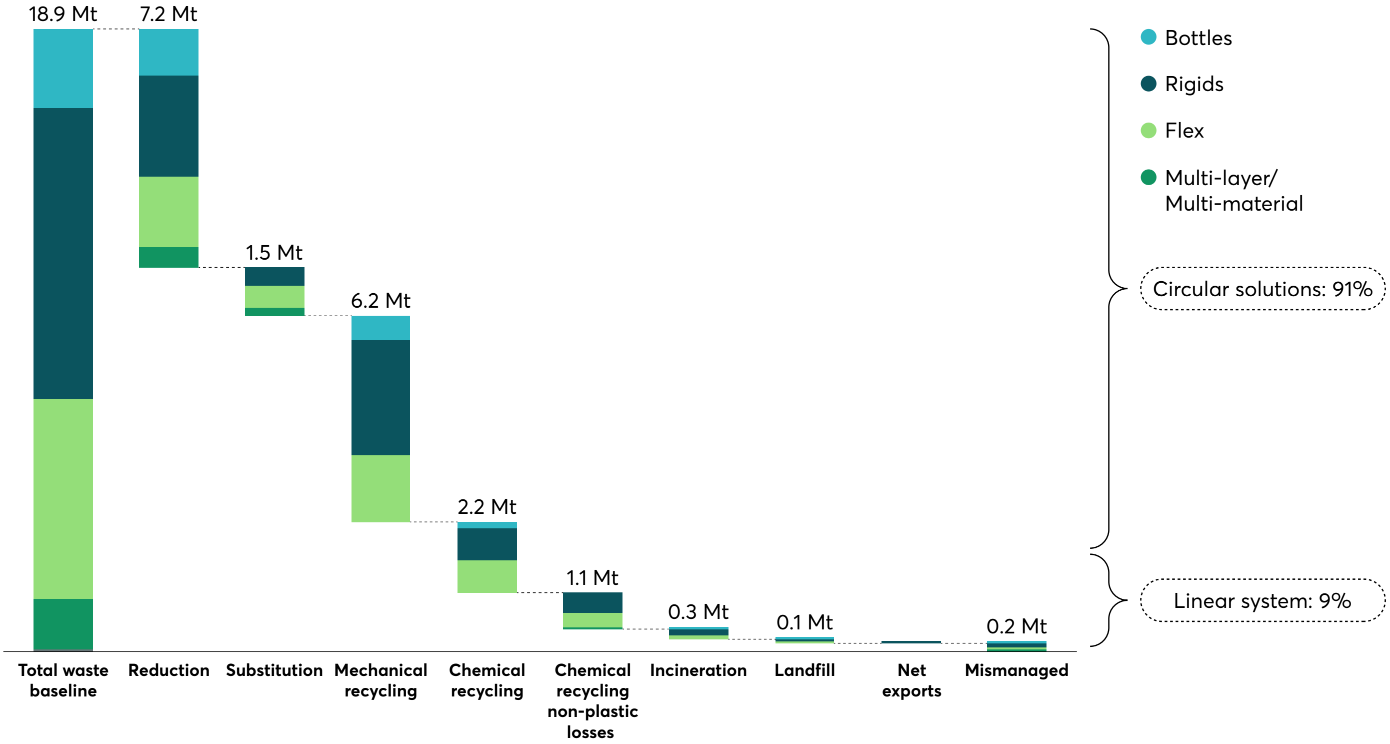
Disposal of plastic packaging waste could decrease from an estimated 11 Mt in 2020 to just 0.5 Mt in 2050 under this scenario, effectively reducing incineration and landfilling by 96%. GHG emissions would drop to approximately a sixth of current levels, making this comprehensive strategy a major cornerstone of GHG reduction pathways. Four system interventions, each applicable to different plastic categories, are deployed simultaneously to provide circular solutions for 91% of plastic packaging waste by 2050, as shown in Figure 12.

End-of-life management of plastic packaging has been a major challenge for the plastics industry in recent years, with pressure stemming largely from the environmental pollution of single-use, disposable plastic. However, given the existing policy ambition, the rise in more sustainable consumption, as well as the industry focus on circularity solutions for plastic packaging, interventions have the potential to be scaled early and rapidly.

Figure 12

Ambitious application of the circularity interventions in the packaging sub-system increases system circularity to 91%

Physical fate of plastic waste from packaging in the Circularity Scenario in 2050 (Mt)



Note: [1] While today very few flexibles are mechanically recycled, this scenario assumes that mechanical recycling of flexibles will improve with better technology, processes and supportive policy
[2] Chemical recycling non-plastic losses describes gaseous and process losses in chemical recycling (gasification and pyrolysis)
Source: "ReShaping Plastics" model

If the design, elimination, reuse, substitution, and recycling levers are all pulled ambitiously and in tandem, plastic packaging can transition from a predominantly linear to a highly circular system as early as 2040 in a best-case scenario.

Packaging System Intervention #1: Reduce 38% of plastic packaging

Upstream innovation can design out plastic waste while retaining the benefits of packaging. This requires rethinking packaging, product design, and business models. The analysis shows that – with appropriate regulatory support, infrastructure investment, and R&D – it is technically feasible and environmentally beneficial to reduce 38% (7.2 Mt) of projected plastic packaging demand by 2050 without compromising on functionality, as shown in Figure 14.

Plastic reduction through elimination of unnecessary packaging and scaling of reuse models are major drivers of resource efficiency as these approaches provide the same utility with less materials required. For each of these reduction levers, alternatives have been tested against five criteria as described in the peer-reviewed “Breaking the Plastic Wave” report: technological readiness, performance, climate impact, affordability, and convenience.[30,31] New delivery models, which focus on reuse and as-a-service strategies, can – if scaled – provide a fundamental reconfiguration of currently linear and wasteful packaging systems towards durable applications. On average, if well designed, these models are more resource productive in terms of the plastic required to meet the same utility by a factor of three to five times, depending on the application.

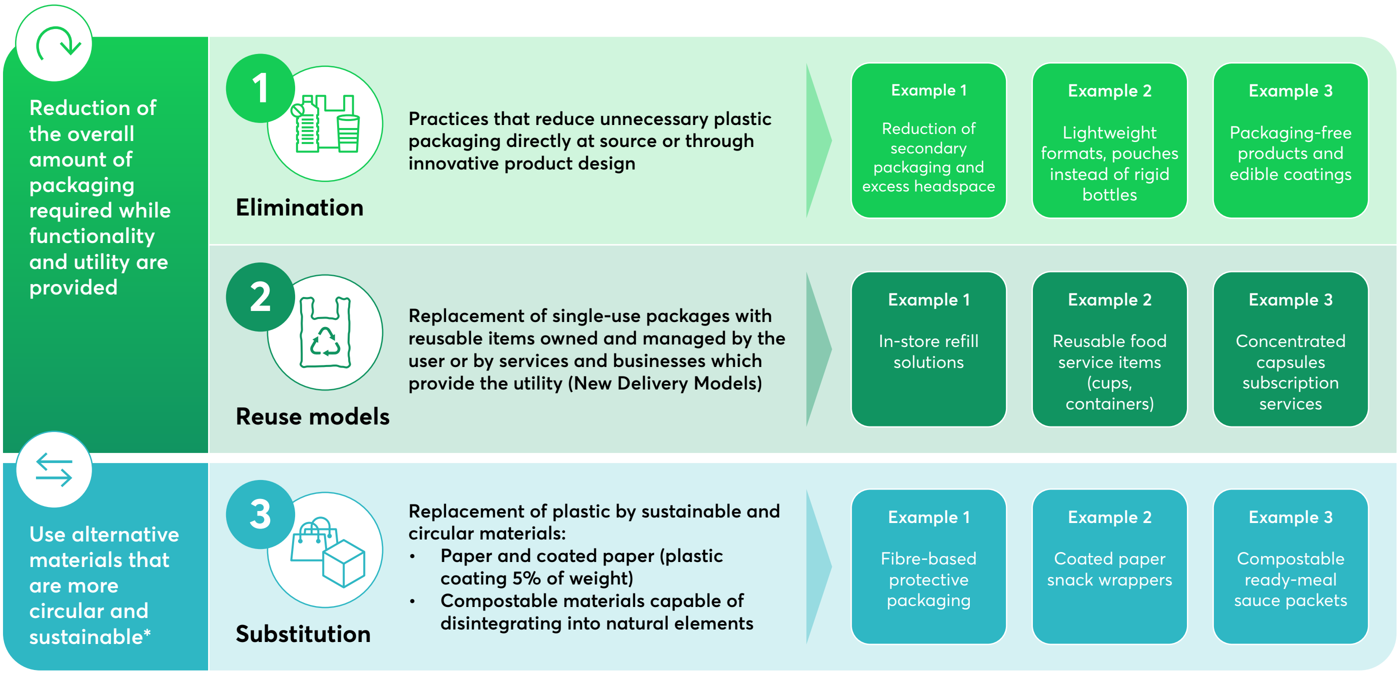
While reduction solutions can appear as a challenge to the plastics industry, new delivery models and technological innovation present a prime opportunity for industry to decouple economic value from plastic waste. Embracing these solutions can help shift towards new value pools characterized by better design, better materials, better delivery models, improved sorting and recycling technologies, and smart collection and supply chain management systems.

Elimination of unnecessary packaging

Elimination of plastic packaging at source provides a low cost, low-emissions strategy to reduce plastic that is already being pursued today. Eliminating unnecessary packaging, such as secondary packaging or excess headspace for marketing

Figure 13

Reduction and Substitution strategies can provide resource-efficient, circular alternatives to Single-Use Plastics Packaging



Reduction of the overall amount of packaging required while functionality and utility are provided	1 Elimination	Practices that reduce unnecessary plastic packaging directly at source or through innovative product design	Example 1 Reduction of secondary packaging and excess headspace	Example 2 Lightweight formats, pouches instead of rigid bottles	Example 3 Packaging-free products and edible coatings
	2 Reuse models	Replacement of single-use packages with reusable items owned and managed by the user or by services and businesses which provide the utility (New Delivery Models)	Example 1 In-store refill solutions	Example 2 Reusable food service items (cups, containers)	Example 3 Concentrated capsules subscription services
Use alternative materials that are more circular and sustainable*	3 Substitution	Replacement of plastic by sustainable and circular materials: • Paper and coated paper (plastic coating 5% of weight) • Compostable materials capable of disintegrating into natural elements	Example 1 Fibre-based protective packaging	Example 2 Coated paper snack wrappers	Example 3 Compostable ready-meal sauce packets

Note: * To avoid inadvertent consequences, a careful case-by-case analysis on product level must be performed for any substitution.

purposes, is easy and fast as it does not provide any consumer benefit. The analysis suggests that direct elimination[xliii] could reduce annual plastic packaging demand by 1 Mt (5%) by 2050, while innovative solutions[xliv] could eliminate 0.5 Mt (2%) in this period. Best of all, almost 70% of this potential can be achieved by 2030 and it is already an essential part of the reduction strategies of many brands and retailers. Elimination solutions also apply to secondary plastic wrappings (overwraps), unnecessary tear-offs, excess headspace, unnecessary films, rigid PTTs, and plastic windows, which can all be easily eliminated. In addition, mesh material secured with straps or solid alternatives can replace business-to-business "B2B" films (e.g., Reusa-Wraps), innovative solutions in the form of edible coatings for vegetables already exist (example providers include Apeel, Mori, Notpla), dissolvable packaging (e.g., by Aquapack or Kuraray), solid products instead of liquid (e.g., Lush), and concentrates replacing rigid non-food grade bottles for cleaning essentials, are all emerging trends raising the elimination potential in this scenario.[32]

Consumer goods companies and retailers play a critical role in driving the implementation of this lever. With the intention to reduce their plastic footprint, many brands and retailers have already committed to reducing (virgin) plastic volumes. This can be accelerated through common standards for what constitutes unnecessary packaging (packaging that can be removed without compromising supply chain or operational efficiencies and without inadvertent consequences such as product waste) and identifying further actions to eliminate it (e.g. via the Consumer Goods Forum's Golden Design Rules). Integrating principles of elimination into the eco-modulation of EPR fees could provide further incentives.

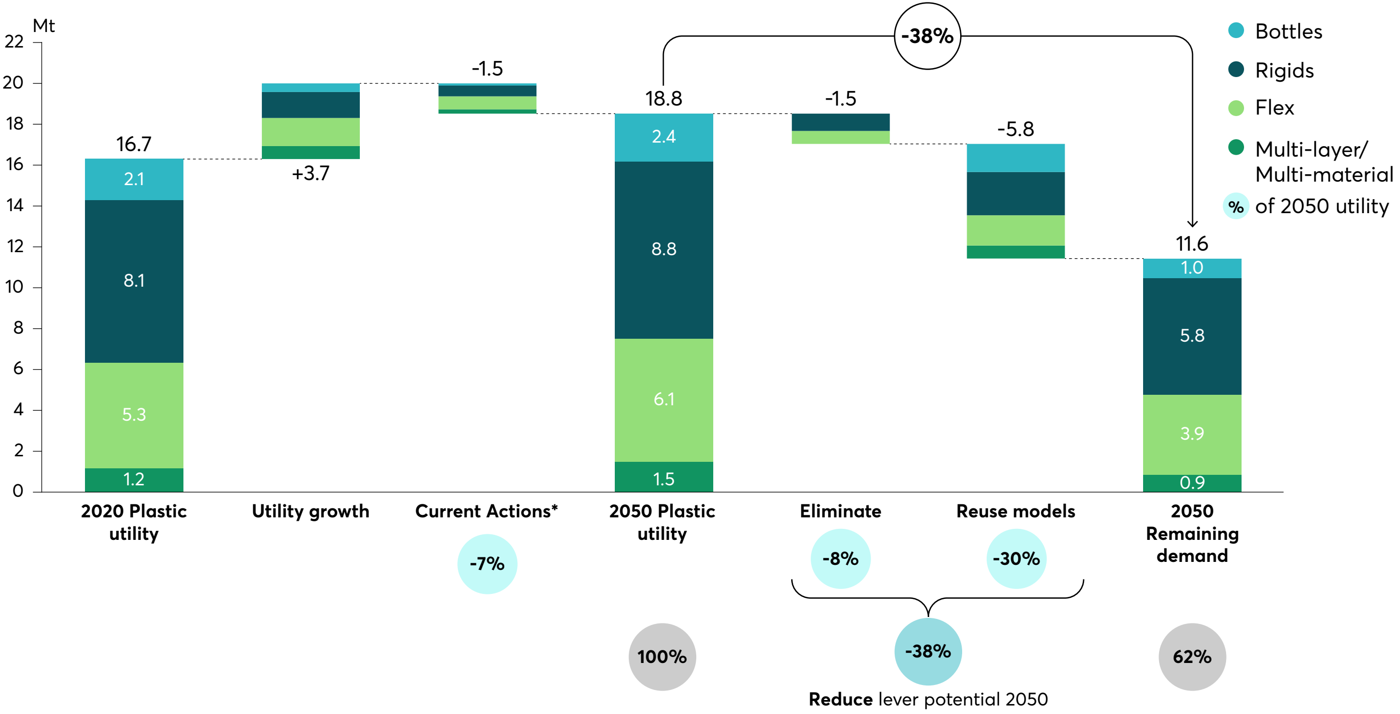
Reporting on plastic footprint and reduction results can also inform the public about progress, incentivizing additional brands and retailers to adopt this strategy.

Reuse models for packaging

The analysis shows that it is technically possible and environmentally beneficial to transform over a third of packaging into reuse systems and new

Figure 14

By 2050, 38% of packaging can be reduced, with reuse models offering the greatest potential impact



*Note: The Current Actions reduction includes the ban and reduction of single use plastics applications as per the Single Use Plastics Directive and the pro-rated Ellen MacArthur Foundation Global Commitment reduction target. Potential deviations are the result of rounding differences.
Source: "ReShaping Plastics" model

[xliii] **Direct elimination**: packaging that does not serve an essential function is directly eliminated. Policy interventions (modelled in the Current Actions Scenario), industry anticipations to reduce over-packaging and consumer behaviour shifts lead to reduced plastic material demand for low-utility plastic.

[xliv] **Innovative elimination**: innovative solutions replace plastic packaging serving an essential function.

delivery models by 2050. Scaling up reuse models is a resource-efficient waste prevention strategy that can effectively decouple utility provision from material use and provide many environmental benefits.[33–38] Provided that reuse cycles and logistics are optimized, this could lead to a net reduction of 13% (2.3 Mt) of packaging demand by 2030 and 30% (5.8 Mt) less plastic packaging and the resulting waste by 2050, while cutting GHG emissions by 26% compared to the packaging baseline. The Ellen MacArthur Foundation identifies four types of business-to-consumer, "B2C", reuse models[xlv] for packaging – from customer-owned models to new delivery models and return systems where companies operate and own the package.[39] Refill at home solutions are cost competitive and already used at scale, while return/refill on the go models entail reconfigurations of existing infrastructure and adjustments in consumption habits.

According to the Ellen MacArthur Foundation, "reuse presents an innovation opportunity to change the way we think about packaging from something that is simply as inexpensive and light as possible to viewing it as a high value asset that can deliver significant benefits to users and businesses", estimating the economic opportunity at USD10 billion.[11] There are multiple benefits of reuse models, such as the creation of new value pools for companies willing to explore new ways of operating. For polymer/plastic producers, reuse models can drive a shift towards more durable plastic products able to generate value over an extended period. For converters, manufacturing-as-a-service can also provide a new form of business model consisting of developing and leasing reusable packaging to be reclaimed and recycled at the end of the life cycle.[40,41] For brands, reuse models can deepen customer loyalty through advanced new services and data optimization through track and trace. They give consumers new touchpoints at which to engage with the company, such as refill stations. For waste management systems, closed loop systems increase the quality of feedstock inflows into recycling streams because service providers consider recycling in the design phase. Additionally, waste management systems may consider extending their business model to provide reverse logistics and cleaning services for reuse model providers, based on their existing infrastructure.

Implementing reuse models and systems at scale will require collaborative action along value chains. To a great extent, the externalization of the costs of single-use packaging has been the primary enabler of linear packaging retail models.[42] A level playing field through investments and policy can induce the infrastructure, effectiveness, and scale needed for the systemic transformation of packaging supply chains. Reuse delivery models require significant re-organization of logistics, which is currently a major barrier as reverse logistics are costly. In the absence of standards for designing reusable packaging and running interoperable reuse systems, companies incur high unnecessary costs that make it difficult to compete with single-use packaging. The move away from current business models that rely on throwaway convenience also requires fundamental behaviour change. This can be enabled by digital technology to enhance the shopping experience, improved functional benefits, and better economics for customers through scaled systems. Simultaneously, some form of consumer guidance may be required to emphasize the benefits of reuse, coupled with smart incentivization mechanisms.

Momentum for reuse models is growing. Established brands and retailers are piloting reusable packaging systems with promising results, innovative companies are pushing into the market, and policy is starting to take reuse as an alternative into account.[xlvi] This provides a fertile ground for the reuse paradigm shift. In the Circularity Scenario, this study estimates the overall reduction potential for plastic packaging at 13% in 2030, 27% in 2040, and 30% in 2050, across the 23 assessed packaging formats. The following three application groups make up the largest share of the reduction potential of reuse models and systems.

[xlv] **(i) Refill at home:** consumers fill their own reusable container at home, refills are either delivered to the door (e.g., a subscription service), or in a shop (e.g. concentrates). **(ii) Refill on the go:** Consumers refill their own reusable packaging at a dispensing point away from home, such as in-store refill stations. **(iii) Return from home:** Users subscribe to a delivery and collection service that allows them to return empty packaging from home which will be cleaned and redistributed by the service provider(s). **(iv) Return on the go:** Users purchase a product in a reusable container and return the packaging at a store or drop-off point after use. The packaging is either cleaned and redistributed where it is returned (e.g. at a retail site) or by a business or service-provider. Additionally, **B2B packaging reuse models**, where individual companies reuse their packaging or industry-wide reuse models operate standardized packaging systems, exist. The Ellen MacArthur Foundation "Upstream Innovation Guide" and Reuse: rethinking packaging" reports provide a comprehensive overview of leading case studies.[32,39]

[xlvi] **Brands and retailers**: see for instance Unilever, Nestlé, Marks & Spencer, Waitrose & Partners, Aldi, Carrefour, Tesco.[37,43–50] **Innovative companies**: see for example Packoorang, recup, Miwa, REATH.[51–54] **Policy**: See notably France Anti-waste Law[25,55], EU Member States implementations of the SUPD[24], and the revision of the PPWD in which the EU Commission potentially includes mandatory targets for packaging placed on the market to be reusable.[56]

- **Beverage bottles:** scaling the share of reusable bottles by implementing reuse targets (e.g., the German 'Mehrwegsystem') and scaling refill at home solutions (e.g. SodaStream) could reduce 59% of beverage bottle waste by 2050 (and 33% by 2030).
- **Transport packaging such as B2B and B2C films and rigids:** operationalizing a standardized B2B system (e.g., Svenska Retursystem) and circulating reusable alternatives for transport (e.g., EnviroWrap) and e-commerce (e.g., RePack) could reduce overall packaging waste by approximately 10% by 2050 (and 3% by 2030).
- **Refill at home and on the go for home care and groceries (non-food grade bottles, sachets/multilayer flexibles, and PTTs):** becoming an integrated part of a smart shopping experience with in-store refill delivery models (e.g., Algramo) as well as reusable (e.g., Loop) and plastic packaging-free (e.g., Everdrop) home delivery solutions could reduce overall plastic waste by approximately 7% by 2050 (and 3% by 2030).

An enabling policy framework is required to achieve the reuse paradigm. In accordance with the Packaging and Packaging Waste Directive, the European Commission will review data on reusable packaging provided by Member States in 2025 to assess the quantitative targets on reuse of packaging and further measures to promote reuse. Further policy support for reuse is therefore expected after 2025, increasing the uptake of reuse models on a European level. On Member State level, the French government for instance aims at 10% of packaging being reusable by 2027. Germany mandates to offer reusability of food service packaging at the point of sales as part of the Single-Use Plastic Directive implementation.[24] In addition, a harmonization of existing standards in the respective categories must follow suit in order for reuse models to comply with them (e.g., hygiene, transport, food safety).

Packaging System Intervention #2: Substitute 8% of hard-to-recycle plastic packaging

Substitution with paper, coated paper, and compostables offers an alternative where reuse models cannot be scaled or applied. They can provide benefits in applications that are hard to recycle or reduce, but can have high GHG emissions due to energy-intensive production and end-of-life incineration/decomposition. Therefore, they must be undertaken carefully to avoid increasing emission or causing inadvertent food waste.[57] Other substitute materials, such as glass and metal, were also considered, but are generally not recommended as due to higher GHG emissions. The applicability of the substitution lever is currently constrained to niche applications due to several boundary conditions, including: technological readiness, performance, climate impact, affordability, and convenience. However, material innovation – especially in the compostables space –could be beneficial to the system overall. This study shows that some substitution of plastic packaging can be performed while accounting for unintended environmental consequences, replacing to 8% (1.5 Mt) of plastic baseline demand by 2050. As the plastics system reduces emissions and becomes more circular, substitutions will become increasingly expensive and GHG intensive, further limiting the applicability of this lever.

Paper and coated paper composites

In this scenario it is estimated that 1.3 Mt (5%) of packaging can be substituted by paper (0.7 Mt) and coated paper (0.6 Mt) by 2030, with environmental benefits, equivalent functionality, and no economic disadvantages. Plastic applications suitable for substitution include vegetable/fruit punnets, food service clamshells, hard-to-recycle composite display trays, blister packs, and dry food multilayer film packaging. Careful deployment of fibre-based alternatives – including (where moisture content is high) coated paper with enhanced barrier properties – can lead to less non-recyclable packaging waste being generated and consequently an increase in plastic packaging recycling rates. Paper and coated paper substitutes are undergoing rapid innovation, resulting in improved barrier properties and cost/weight performance, but substitution by paper and coated paper must be conducted carefully on a case-by-case basis to avoid unintended consequences such as risks of deforestation and GHG emissions, which are both accounted for in this scenario. Fibres should be sourced from certified sustainable biomass or recycled fibres and not compete with other land use systems. To support circularity, paper lined with a plastic coating needs to be acceptable to paper recyclers. Plastic coatings up to a maximum 5% of total weight are considered tolerable to recyclers even in unseparated paper waste streams.[58] However, a significant increase of paper composites in the paper waste stream could potentially lead to problems of impurity and adhesion. Careful consideration should also be given to prevent inadvertent contamination by food substances (especially food attached to the surface or food waste within packaging), as it can compromise the recycling process.

While trends indicate increasing rates of substitution for (composite) paper alternatives, the climate trade-off is not always clear.[59] GHG emissions in paper production can differ widely, depending on the production location, energy mix, type of paper packaging, end-of-life treatment, and other impact factors.[60,61] Paper typically requires at least 50% more material to package the same products as plastic, which increases waste volume. Nevertheless, if fibre-based packaging is made of renewable feedstock, it could become a viable decarbonization strategy and replace fossil-based formats as long as production emissions are addressed and abated faster than those of plastic, sustainable sourcing can be guaranteed, and technical properties are maintained.[62]

Compostables

Composting is considered to be a circular solution for specific, targeted packaging applications rather than a blanket solution, according to the Global Commitment to a New Plastics Economy.[63] This Circularity Scenario defines a narrow use case for compostable materials and projects that just 3% of plastic utility demand across the defined plastic categories will be substituted by compostable materials compared to the current actions baseline by 2050.

Compostable materials considered in the scenario include both natural polyesters such as Polyhydroxyalkanoates (PHA) and new formats under development (including cellulosics, alginates, banana leaves, edible and ephemeral packaging) that comply with relevant international and local compostability standards.[xlvii] These materials can be collected and processed along with food waste, where food waste processing infrastructure exists or will be built. Materials which do not meet all these conditions have been excluded from the scenario analysis. Unlike mechanical or chemical recycling, composting of materials does not generate an economically valuable product or lead to a reduction in virgin material production and the associated GHG emissions.[64,65]

The substitution rate for in-scope materials is low because of the higher cost of compostable materials, limitations in their functional performance for some applications, and potential risk of interfering with the mechanical recycling of plastic. They are primarily considered a potential substitute in applications with low recycling rates due to high levels of food contamination, where they can also contribute to higher recovery rates for food waste, and can be segregated from the plastic recycling stream (e.g., tea bags, compostable bags for compost collection in cities, or fruit/vegetable labels). In many countries in the EU, only compostable bags and some closed loop food service applications are accepted by composters.[66]

The potential growth in demand for such materials has already been noted by the European Commission and market expansion is expected.[67,68] Under the CEAP 2.0, the Commission plans to develop a policy framework on the use of biodegradable/compostable plastic in 2022, which will be included in the revision of the Single-Use Plastic Directive (SUPD) in 2027. This framework is expected to lay out the applications where such materials can be beneficial for the environment, and under which criteria. Biodegradable plastic is currently considered the same as conventional plastic under the SUPD and included in its measures.[69,70]

[xlvii] For example, industrial composting standard EN 13432.

Packaging System Intervention #3: Expand mechanical recycling capacity

Mechanical recycling is an efficient, cost-effective circular technology that is well established at scale in Europe. At a system-wide level, mechanical recycling can save an estimated 1.1 to 3.6 tonnes of CO_2e per tonne of polymer recycled.[71] Plastic recycling is increasingly accepted as a provider of potentially valuable, more environmentally beneficial feedstock, with both governments and major fast-moving consumer goods (FMCG) brands setting targets to increase the recyclability of plastic. Introducing and strengthening mandatory recycling targets and recycled content targets could enable the scaling of mechanical recycling with a market expansion that is expected in the coming decade.[72] Additional action is needed as, despite many years of attempts, European mechanical recycling has not yet scaled sufficiently. Major interventions must overcome structural inefficiencies, from product design through to recycling itself, as well as a lack of investment, to achieve recyclate quality at prices on a par with virgin materials.

The ambitious recycling system intervention presented in this scenario reflects the potential for significantly expanding Europe's recycling infrastructure, with the right support from policy and industry. It shows how policy targets could be achieved through improvements across the entire recycling value chain, encompassing a scale-up in separate collection, sorting and recycling capacity accompanied by design for recycling shifts from multi- to mono-material formats. In this scenario, 5.1 Mt of recyclates are produced from post-consumer packaging waste in 2030 (see Figure 15), 5.3 Mt in 2040, and 6.2 Mt in 2050.

Plastic recycling is not thriving as an industry. Barriers to scaling the mechanical recycling market can be characterized around supply and demand side issues.[73] On the supply side, there is a lack of high-quality waste/recyclate that is certified and traceable through its lifecycle and recycling process. Barriers to high-quality plastic recycling include the high variability of materials and plastic being optimized for each application, the dispersal of plastic into millions of households, the huge variety of polymers and additives, and the low value of waste not providing incentives for process optimizations. Mechanical recycling is also limited by the fact that a plastic product can only be mechanically recycled a certain number of times before it loses its mechanical properties. This is not a major problem today, as recycling rates are low, but as rates increase it could start to become a limiting factor. Additionally, most EPR schemes incentivize sorting to a minimum purity level and therefore the material sent to recycling facilities often either requires further expensive sorting or is only suitable for producing low quality recylate. Many recyclers claim these issues stem from a lack of product standardization, volatile customer demand, and inefficient sortation processes.

On the demand side, recyclates at current output quality are not sufficiently in demand to stir the required market expansion, induced by structural price differences between virgin materials and recyclates.[74–76] Demand for suitable recyclate is expected to increase due to the recycled content quota under CEAP 2.0, and voluntary commitments such as the EMF Global Commitment, but a reliable recyclate economy with stable and scaled supply structures providing high-quality recylates, as well as a level playing field with virgin materials, are needed to supply this growing demand. Recyclability must be optimized from product design to the recovery process itself through market signals and incentive structures.

This scenario shows that achieving significantly higher rates of mechanical recycling of plastic in Europe is possible, but it depends on significant changes in policy, product design, technology, investments, and offtake agreements. Design packaging for mechanical recycling (D4R) A high-quality recycling system depends on materials being designed for recycling. This requires considering the technical and economical recyclability of materials when designing products. According to experts, 90% of multilayer/multimaterial products can shift to rigid-monomaterials (0.2 Mt) or flexible-monomaterials (0.3 Mt) while still maintaining performance demands. For example, removing certain pigments and additives can be crucial for increasing the recyclability of packaging, as these items can either make recycling more difficult or can significantly reduce the value of recycled output. Harmonizing polymers, colours, additives, and closures can all increase the recyclability of packaging. Increasing the amount of recyclable packaging on the market through the widespread adoption of D4R principles will encourage larger collection, sorting and recycling yields and, in turn, increase the quantity and quality of packaging recyclates.

Packaging producers and brands are on track to increase recyclability, and state-of-the-art D4R rules (e.g., RecyClass by Plastics Recyclers Europe, and Golden Rules by the Consumer Goods Forum) can provide guidance towards reaching industry commitments of 100% recyclable packaging.[77,78] The implementation of D4R guidelines should be complemented with recycled content targets, encouraging packaging design to integrate recyclates.[79]

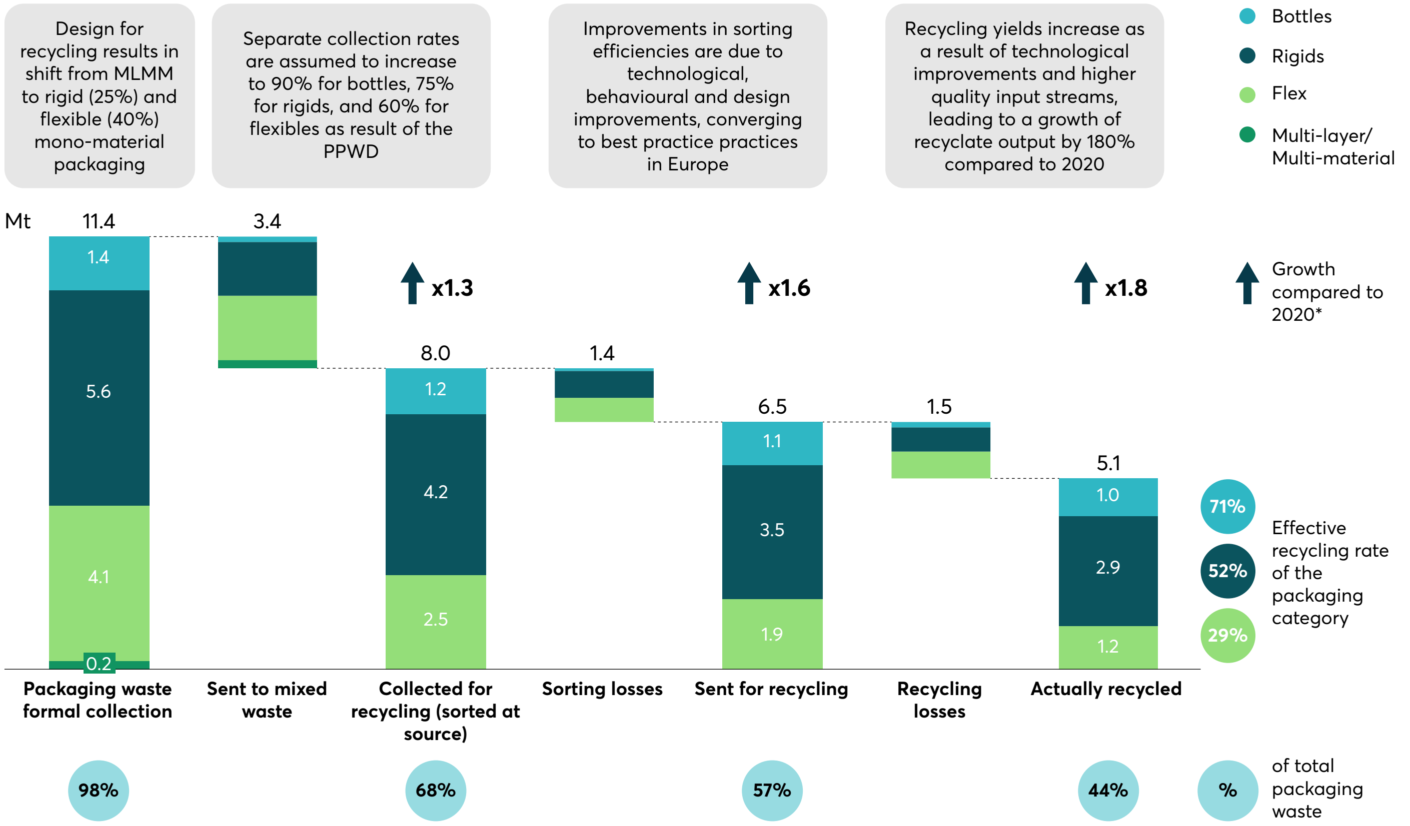
Increase separate packaging collection and improve sorting

Enhancing separation at source increases the quality and quantity of waste streams destined for recycling. To achieve the Packaging and Packaging Waste Directive, separation at source needs to increase from 40% to 70% by 2030. To achieve this, the European Commission envisions a harmonization of separate collection systems, including the separate collection of bio-waste to decrease plastic contamination, coupled with improved consumer awareness. Together, this can lead to higher waste stream purity levels that improve overall post-consumer packaging recycling. At the same time, incentive structures must be put in place to ensure that the extra expense of separate, high-quality collection is reflected in the incomes of both private and municipality-led collection systems. This is especially important for materials that are expensive to collect and historically obtain low market value, such as the flexible plastic that will be the focus of efforts to increase plastic recycling in Europe.

Figure 15

In 2030, increases in separate collection, sorting efficiency and recycling yields lead to an effective recycling rate of 44% for plastic packaging

In the Circularity Scenario, mechanical recycling of packaging waste can grow from 2.9 Mt of recyclates in 2020 to 5.1 Mt in 2030, even with declining waste volumes driven by reduction and substitution



*Note: To illustrate the mechanical recycling output growth in the Circularity Scenario more effectively, the output values are compared to 2020 numbers as Reduction & Substitution reduce overall plastic waste volumes, making a direct comparison to the Current Actions Scenario difficult.
Source: "ReShaping Plastics" model

In parallel, strengthening sortation through advanced sorting technology and improving inefficient sorting processes can further improve the purity of waste streams and separate out polymers/fractions/applications, thus increasing the quality and quantity of waste bales destined for recycling – impacting the process efficiencies at the recycling plant. The implementation of sorting best practices could decrease sorting losses by 50% by 2040.[xlviii] To improve sorting technology, best available technology needs to be employed at materials recovery facilities (MRFs). For instance, investments in state-of-the-art MRF cleaning and sorting equipment could boost sorting efficiencies. Digital innovation and technology, such as the latest Near-infrared/optical sorters, digital watermarking (e.g., HolyGrail 2.0), digital product passports (e.g. R-Cycle)[xlix], or AI-enabled advanced robotic sorting can provide opportunities to increase sorting efficiencies.

Increase mechanical recycling capacity and efficiency

This scenario describes a significant growth in mechanical recycling output – especially until 2030, which requires an expansion of current market structures and practices. To achieve this, the recycling sector would likely benefit from greater consolidation, standardization and process optimization to unlock scale, while external investment could provide access to capital needed to seize the opportunity of a market that is about to expand.[80] Improved recycling yields can be achieved as the purity of input materials increases alongside investments in technologies that improve the quality of recyclates. Recyclers are faced with the challenge of maximizing recycling yields while minimizing costs, which can be overcome once stable recyclate markets are implemented and the industry moves towards stronger industrialization.

Process losses are assumed to converge to European best practices by 2050[l], leading to high recycling yields at the recycling plant level of 83% and a corresponding 1.8 times increase in actually recycled volumes. This in turn could lead to a 90% increase in installed recycling capacity for post-consumer packaging waste by 2050 (and a 60% increase by 2030). Under this scenario, 61% of packaging waste that remains after the reduction and substitution interventions could be recovered as recycling feedstock and displace virgin material. This will require cumulative capital investments of approximately €14 billion for expansion and optimizations along the recycling value chain.[li] In addition, investments in state-of-the-art technology[lii] to improve recyclate quality might lead to additional increases in capex (+50%) and opex (+90%) per tonne of throughput for recyclers. Investments may deliver positive return on investment, given the subsequent improvements to recyclate quality and the expected growth in recyclate demand driven by regulation and voluntary company commitments.

There is limited like-for-like packaging recycling due to quality requirements and stringent health and safety regulations for food grade packaging ('Food Contact Materials') by the European Food and Safety Agency. While the analysis shows that roughly half of all packaging recycled is recycled as closed loop (1.9 Mt) in 2020, and this could increase to an estimated 5.5 Mt by 2050, much of the recycled content is used in lower value applications within the same sub-system (e.g., garbage bags).[liii] Regulatory requirements for the use of recycled content in food grade applications are currently under review and are expected to authorize more recycled food contact applications, which could entail certification standards for recycling processes that reduce uncertainties about the properties of recyclates.[82,83]

[xlviii] The assumptions for sorting yields are based on developments that converge to best practice MRFs in Europe as per Antonopolous et al (2021).

[xlix] Digital product passports or digital watermarking could significantly increase transparency on plastic content and improve the subsequent recycling process.

[l] The assumptions for recycling yields are based on developments that converge to best practice recycling facilities as well as resulting recycling yields in Europe as per Antonopolous et al (2021).

[li] This includes investments in collection and sorting infrastructure.

[lii] Near-infrared pre-sorting, hot wash, de-inking, liquid separation, composition measurement, state-of-the art extrusion and filters to improve polymer melt quality, odour reduction, additives treatment.

[liii] An exception is PET bottles that are collected in separated waste streams, leading to policy and brands increasing recycled content targets, with 18% of rPET currently ending up in new food grade bottles.[81]

Packaging System Intervention #4: Scale chemical recycling capacity for packaging (and other sectors)

Mechanical recycling has the potential to address a larger proportion of waste streams in the future, but a technology with greater tolerance of contamination and complexity is still required to address the harder to tackle waste streams such as contaminated, flexible, multilayer composites, degraded mono-materials, and plastic with small form factors. Chemical recycling is needed to address the past as well as the future of the Plastics system. Globally, only 9% of the plastic ever produced has been recycled[84] and within the scope of this report there is waste from the construction sector made in the 1980s (or even earlier) that was not designed for recycling and will continue to churn from the system beyond 2050.

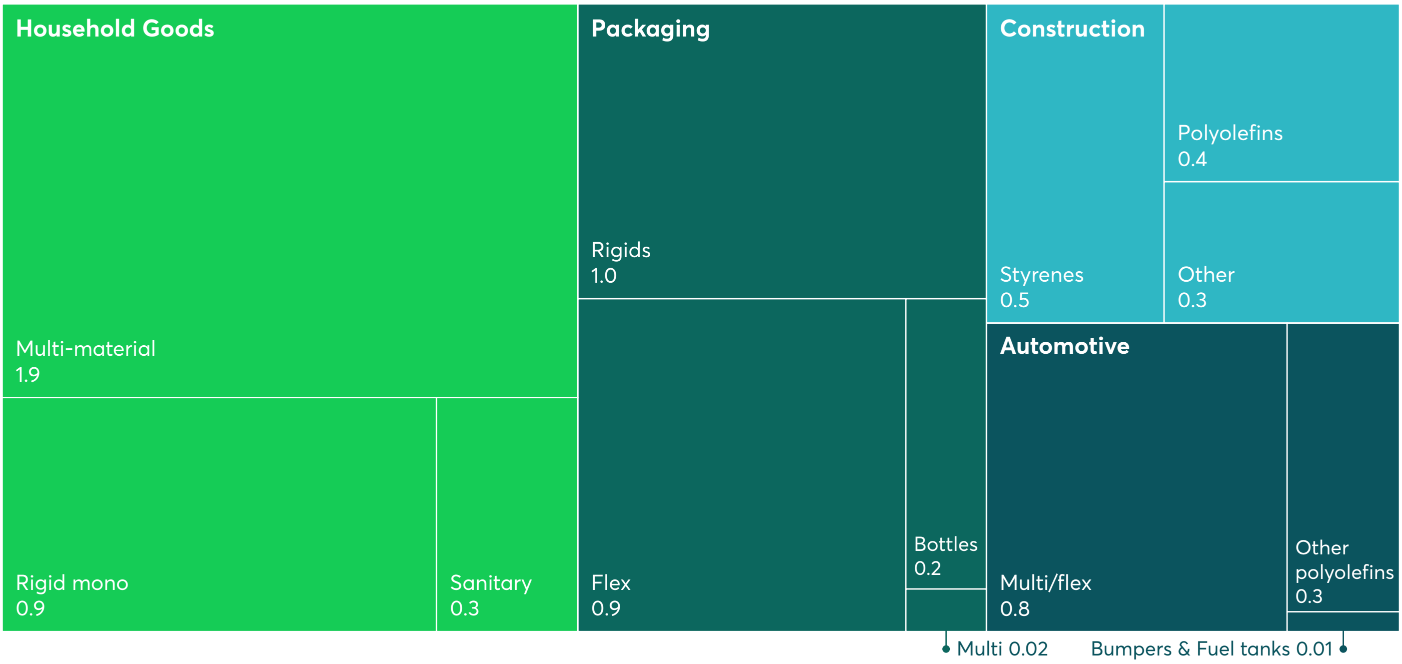
While mechanical recycling is dependent on a range of factors, such as quality feedstocks to achieve high-quality recyclates suitable for food grade applications[liv], chemical recycling technologies have the potential to consistently produce recyclate that is equivalent to virgin polymers.

Given that chemical recycling technologies are still relatively nascent, with only a limited number of commercial-scale plants[lv] operating, and given the uncertainties regarding policy and full value chain economics at scale, chemical recycling remains a big swing factor in estimating the circularity levels of this scenario. The European plastics industry has pledged to invest €7.2 billion by 2030 to produce 3.4 Mt of chemical recyclate per annum, depending on adequate policy support.[85] Assuming continued growth in the market based on the availability of waste feedstock, the chemical recycling market could grow to 7.5 Mt of recyclate by 2050 across household (3.1 Mt), packaging (2.2 Mt), automotive (1.1 Mt) and construction (1.1 Mt), as shown in Figure 16. This would treat a quarter of the total plastic waste generated and help fulfil the demand for plastic utility.

Figure 16

In 2050, 7.5 Mt of plastic could be chemically recycled across under the Circularity Scenario

Volumes of chemical recycling per plastic sub-system and category in 2050 (Mt)



Source: "ReShaping Plastics" model

[liv] CEFLEX exemplifies initiatives to drive greater recyclability of flexible packaging in Europe.

[lv] Plants that have scaled for an economic return rather than a proof of concept. No fixed line has been drawn but 100 kt p.a. is an approximate scale that is considered commercial. SYSTEMIQ bottom-up analysis has identified under 100 active or commissioned facilities across the developed world, with capacities ranging from a few kilotonnes to over 100 kt.

Chemical recycling market growth and feedstock assumptions

Chemical recycling technologies can be classified into four main chemical processes into which industry is investing: dissolution[lvi], depolymerisation[lvii], pyrolysis[lviii] and gasification.[lix] Each of these technologies are characterized by different feedstock tolerances to impurities and organic contamination, yields, emissions factors, costs, levels of maturity, and types of outputs.

Furthermore, their inclusion in the scenario as a "current technology" is controversial among experts. Given the nascence of these technologies, it is not clear which technology type will scale and in what proportions.[86]

While this report approaches the mix of technology pathways with as much agnosticism as possible to avoid influencing investment prospects, the characteristics of each technology impacts yields, feedstock availability (thus potential market size), GHG emissions factors, ability to scale, and economics of the system.

Three waste streams are considered feedstock for chemical recycling in this study: plastic losses from mechanical recycling, plastic losses from formal sorting, and plastic waste collected and sorted from within the mixed waste stream.

The first two streams are generally purer and this study assumes 95% of this waste is suitable for chemical recycling.[lx] It is also assumed that 50-80% of mixed plastic waste is suitable for chemical recycling, but can only be treated by gasification, with the exception of mixed automotive shredder residue, of which 95% is assumed suitable.[87]

Depolymerization and dissolution are preferable to pyrolysis and gasification from an energy efficiency perspective as they yield monomers and polymers, respectively, and thus avoid the more energy intensive, high CO_2 emitting, thermal treatments that convert waste into monomer feedstock. However, due to the emerging nature of these technologies, their ultimate tolerance for accepting mixed streams is currently uncertain. Therefore, while these technologies have been scaled to the full extent of the quality waste streams available for sortation, they play a smaller role in this scenario, and care must be taken to ensure that the growth of chemical recycling does not cannibalize the growth of mechanical recycling as these technologies complement each other.

Gasification and pyrolysis, despite being less attractive from an energy and emissions perspective, play a more dominant role due to their feedstock tolerance for harder to tackle waste streams. Early industry investment in plastic-to-plastic chemical recycling is focusing on pyrolysis, driven by a combination of economics, feedstock tolerances, and this technology's relatively straightforward utilization of the existing fossil system, namely pyrolysis oil displacing naphtha in steam crackers.

While from a production perspective this technology has similar emissions to virgin fossil steam cracking, and only abates emissions at a system level due to avoided fossil feedstock production and incineration, investment in this technology may also be linked to the desire to "sweat" existing steam cracking assets.[lxi] Gasification has higher feedstock tolerances than pyrolysis (particularity with regards to organic waste) and the business case and abatement levels of the technology is expected to improve after 2030. However, there are few at-scale commercial plastic-to-plastic gasification projects operating in the world today, and most rely on coal as carbon feedstock, not plastic waste. Gasification is therefore assumed to address the difficult-to-recycle mixed waste streams that include non-plastic impurities, such as organic waste.

Nevertheless, there are limits to feedstock availability due to constraints on the separation of plastic from other waste through sortation techniques and the corrosion caused by gasifying contaminated waste, which makes the economics of recycling all waste in the stream challenging. Notably, output losses from gasification and pyrolysis processes have significant

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[lvi] Dissolution is often referred to as "physical recycling" rather than chemical recycling as the chemical state of the polymer is not changed through the process; the polymer is merely extracted from other materials through chemical means. However, for convenience, here it has been grouped with other true chemical recycling technologies.

[lvii] Including glycolysis, hydrolysis, methanolysis, aminolysis, and ammonolysis.

[lviii] Including plasma pyrolysis, microwave assisted, catalytic cracking and hydrocracking.

[lix] Including steam reforming and partial oxidation.

[lx] Losses from formal sorting are potentially of much lower quality than losses from mechanical recycling and may be akin to the mixed waste stream. Simultaneously, pyrolysis recycling is =considered by some experts to be less tolerant to feedstocks than advertised, thus a 95% availability is considered generous and based on further technology optimization.

[lxi] Notably, this reinforces the inclusion of the "Retrofit" scenario presented later in this document, which applies a similar investment rationale to "sweating" the legacy fossil system.

mass, are largely gaseous (including GHGs), and have limited recyclability[lxii]. GHG reduction measures, such as electrification and methanol to olefins processes, may need to be applied to chemical recycling technologies (particularly pyrolysis) to place them on a trajectory to net zero emissions in absolute terms. Crucially, only plastic-to-plastic chemical recycling should be considered circular and care must be taken to ensure that this trajectory does not lead to further plastic-to-fuel expansion, which in effect is similar to incineration with energy recovery.

Household goods

Household goods have a more limited potential for elimination, reuse, or substitution than packaging. Due to the nature of these products - mostly multimaterial, bulky, complex, combined with other materials, or contaminated - and a lack of adequate and targeted collection and processing systems, mechanical recycling of plastic household goods is also expected to remain low. Therefore, most system interventions have limited impact. Chemical recycling, however, has the potential to recover 49% (3.1 Mt) of plastic household goods by 2050.

Plastic household goods encompass a variety of use cases and applications. Data suggests that 63% of this sub-system is made up of complex, multimaterial plastic, for example in toys and furniture.[2,3] An estimated 28% is rigid monomaterial plastic in household goods such as pods, buckets, and cosmetics, and the remaining 9% are plastic portions in hygiene and sanitary products, including diapers, wet-wipes, and pads. Complex material composition and a lack of control through the use phase create significant challenges to recyclability. If collected for recycling at all, household goods are often rejected by sorting and recycling facilities. As a result, research indicates that virtually no mechanical recycling of household goods currently takes place in practice.

Household Goods System Intervention #1 and #2: Reduce and substitute 12% of plastic households goods

Due to the technical properties and specific characteristics of plastic household goods, the potential for reduction and substitution is estimated at 12% in this scenario. This is constrained to consumption reductions through service-based, circular business models, and some alternatives to plastic hygiene and sanitary products (e.g., reusable sanitary applications). Circular business models that provide plastic household goods through subscriptions and sharing with an extended lifetime can also decrease excess consumption, as demonstrated by examples like Whirli, a children's toy subscription service in the UK. Substitutions with paper alternatives (e.g. paper-based wipes) or compostables result in a substitution potential of less than 1% of plastic demand in this sub-system.

Household Goods System Intervention #3: Scale chemical recycling to treat 49% of plastic household goods

This scenario models that chemical recycling can address almost 49% of this waste stream by 2050. However, even if chemical recycling technology is scaled up, as discussed in the previous section on packaging, achieving this is limited by the feasibility of sorting out the plastic from the mixed waste. A more prudent approach could be to also explore technologies that codify plastic applications to allow goods to be tracked through their use phase and dismantled/reused/recycled as they become waste. Take-back schemes by providers such as Mattel or Lego could scale on the back of such track and trace technology (secondary markets are already emerging) to improve material productivity and recovery.

[lxii] Varied by process and feedstock but likely water, ash, metals, inorganics, and raw syngas.

Construction

Plastic waste from the construction sector is estimated to increase significantly from 1.7 Mt to 5 Mt by 2050. Without action, this could result in an unwelcome rise in landfilling and incineration, leading to elevated GHG emissions, but with proper measures, 69% of construction waste can be returned to the economy through recycling and 3% through reuse by 2050. Although the longevity of the plastic in this sub-sector creates multiple challenges for circularity, existing solutions allow for 72% plastic circularity to be achieved in construction by 2050, as shown in Figure 17.

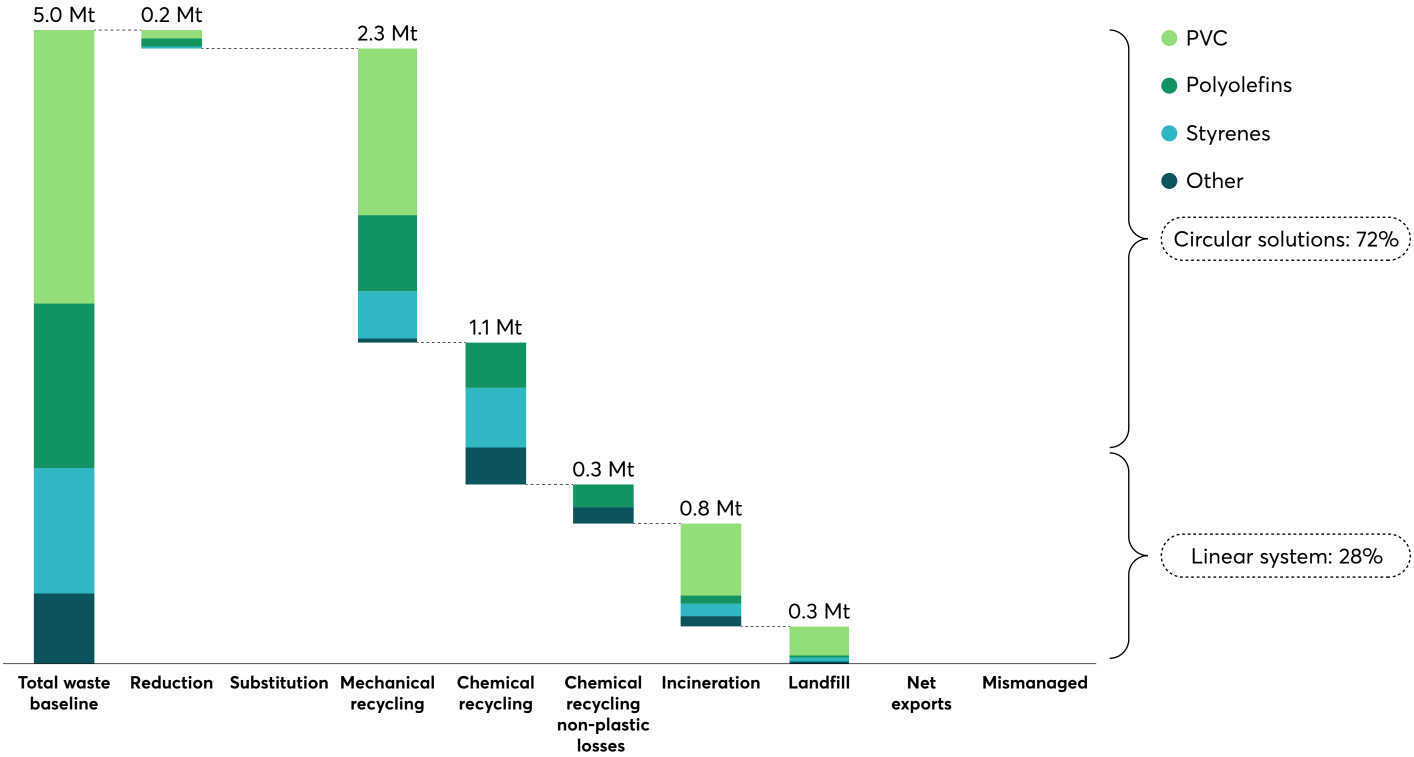
A resistance to change and deep-set norms in the construction sector to date has made it challenging to develop material-efficient practices, improve material recovery in demolition, and enhance waste logistics in the sector. In addition, rising levels of plastic stocks in buildings, as well as in vehicles, are creating a latent store of plastic waste for which the future system must prepare itself. Significant efforts are therefore required to drive a sector-wide transition towards more circular practices; in order for this to happen, both investment and policy support are needed. If significant efforts are made and all circularity levers pulled to their maximum potential, by 2050 the construction sub-system can achieve circularity levels of 72%, up from 20% today.

In the short term, the single most impactful lever is shifting from current demolition techniques towards selective demolition and increasing on-site sorting and separate collection of plastic waste. To date this has been challenging due to the associated economics, the preference for speed of demolition over circularity, and the logistical challenges associated with on-site sorting. This shift will require significant policy support and a dramatic improvement in the economics so that the cost of disposal of unsorted waste surpasses that of selective dismantling and on-site sorting.

Figure 17

Ambitious application of the circularity interventions in the construction sub-system increases system circularity to 72%

Physical fate of plastic waste from construction in the Circularity Scenario in 2050 (Mt)



Note: [1] Chemical recycling non-plastic losses describes gaseous and process losses in chemical recycling (gasification and pyrolysis)
Source: "ReShaping Plastics" model

Construction System Intervention #1 and #2: Reduce, reuse and substitute in construction

Limited potential for reduction and substitution has been identified in this study given the use-phase benefits that plastic delivers in the construction sector, particularly by improving energy and thermal efficiency. Upstream levers, such as design for recycling, modular building design, and component standardization all have limited impacts on system circularity before 2050, given the long lifespans of plastic in construction. Therefore, the reuse potential of plastic components is limited to certain applications where modularity and standardization are feasible. Another potential reduction lever in construction is the shift towards the renovation and refurbishment of buildings, and enabling selective demolition, and thus reducing both the plastic waste generated by the sector and the demand for new components. There is some potential for broader reduction e.g. in floor space usage through efficient building design, but as this is not directly orientated towards the use of plastic it has been evaluated qualitatively. Although substitutes do exist for certain plastic applications in construction, plastic is often the superior choice on a cost, performance, and GHG basis.

It is also important to recognize that there are a number of macro-levers in the construction sector which enable a more intensive use of building floorspace, for example via sharing models, which in turn reduce the demand for construction materials including plastic. While these levers have not been quantified in this analysis, given their nascence and the uncertainty surrounding the impact on total floorspace, it is likely that trends towards peer-to-peer lodging, enabled by service companies like Airbnb, shared housing, and home working/flexible office spaces[88], will continue, resulting in reduced floorspace demand and thus an overall reduction in plastic used in construction.

Construction System Intervention #3: Expand mechanical recycling to 45% of construction plastic waste

When scaled to its technical limits, mechanical recycling in the construction sector can reach 2.3 Mt by 2050, a 475% growth from 2020. However, the growth of mechanical recycling in this sector is limited by the technical challenges associated with recycling polymers that were put on the market several decades ago, namely the presence of legacy additives and the degradation of polymers. Under a fully optimized system, mechanical recycling could account for 45% of total plastic waste generated in the sector by 2050. This growth relies on an improvement in both separate collection rates and sorting and recycling yields, and is predominantly a result of industry actions. An example of such actions are those under the VinylPlus framework, which have seen the introduction of separate collection schemes, improvements in sorting, and higher recycling yields. One innovative collection scheme is REWINDO in Germany, which has been set up specifically to recover PVC window frames and recycle them in a closed loop. Despite these commitments, progress under current actions is incremental and falls short of achieving a fully circular system.

Given that plastic waste from construction and demolition is typically present in large volumes containing much of the same set of polymers, the economics of mechanical recycling are favourable. There is therefore potential for mechanical recycling to play a more prominent role in tackling plastic waste from this sector. Its expansion, however, relies on significant improvement in current waste logistics, demolition practices, and the economics associated with material recovery versus disposal. This requires significant investment in technological solutions such as digitized building passports and robotic sorting, as well as increased policy focus on plastic in construction.

Given the longevity of plastic components in construction, upstream levers such as design for recycling have limited impact on system circularity before 2050. Despite this, it is important that design for recycling is implemented in the near term, in order to overcome the current barriers to mechanical recycling as soon as possible. Plastic used in construction applications are typically incorporated into complex multimaterial products and composite components, presenting significant challenges to mechanical recycling and limiting the quality of the recyclate produced, thus reducing the potential for closed loop recycling. In addition, the issue of legacy additives such as cadmium and lead, which are no longer permitted under current regulation, presents a barrier to achieving higher rates of mechanical recycling. It is therefore imperative that design for recycling is implemented, for example through a shift towards monomaterial components and away from the use of additives that could disrupt recycling, to rapidly drive increased mechanical recycling. By doing so, based on best practices today, it is estimated that losses from mechanical recycling can be reduced to 10%, down from an average of 28% today.

On-site sorting of plastic waste from construction and demolition is the single most impactful lever in the near term. Plastic makes up less than 1% of total construction and demolition waste and thus, without on-site sorting and separate collection, there is virtually no recovery of plastic from mixed waste.[17] It is widely documented that separate collection and sorting of construction products on site leads to cleaner, uncontaminated materials. This is clearly exhibited by the success of separate collection schemes in the industry. According to a report by Plastics Europe[14], separately collected plastic waste is 10 times more likely to be recycled than mixed waste. This is particularly relevant for construction waste, where the concentration of plastic in mixed construction and demolition waste consisting of rubble, bricks, etc., is extremely diluted.

Sorting losses can be reduced through the adoption of advanced sorting technologies (e.g., robotic sorting) but in order to have a notable impact, separate collection rates must increase. Sorting yields improve with larger volumes of separately collected waste and thus with increased on-site sorting there is likely to be a beneficial impact on sorting yields. In addition, as demonstrated by Finland-based ZenRobotics, robotic sorting has significant potential for sorting large and heavy plastic fractions.[89] Commercial plants using these technologies are already operating and have achieved sorting losses as low as 10%. In addition, robots enable uninterrupted sorting and up to 24/7 operations, increasing the capital efficiency of sorting plants. The adoption of these technologies would also make decentralized operations possible, which would reduce transport costs and increase the likelihood of sorting waste in more remote areas. It is estimated that robotic sorting could decrease sorting losses to a minimum of 10% for polymers that achieve separate collection rates of above 50% as higher rates of separate collection allow for more effective sorting. This is the case for PVC, HDPE and EPS insulation.

Construction System Intervention #4: Scale chemical recycling to tackle 23% of construction plastic waste

Chemical recycling plays an important role in the construction sub-sector, dealing mainly with legacy additives and polymers which have degraded during their long use phase due to exposure to UV and wear and tear. Chemical recycling can provide the material rejuvenation step needed as a complement to mechanical recycling, to enable higher rates of mechanical recycling in applications where mechanically recycled content needs to be blended with virgin material for quality/performance consistency. When scaled, chemical recycling could tackle an estimated 23% of total plastic waste generated by the construction sector, producing 1.1 Mt of chemical recyclate by 2050, in addition to the 2.3 Mt of mechanical recyclate, thus unlocking higher levels of circularity.

Chemical recycling is particularly relevant for plastic waste from the construction sector as the impact of design for recycling is limited before 2050 because of the longevity of plastic components in buildings. Therefore, given that there are large volumes of in-stock plastic which either contain legacy additives or are incorporated into complex composite or multimaterial components, the potential for recovery via mechanical recycling is limited. Chemical recycling technologies provide a viable solution for these hard-to-tackle volumes of waste, with a major role for depolymerisation as a means to deal with EPS insulation, as well as for thermal treatments, pyrolysis and gasification to tackle other polymers.

Automotive

Through the ambitious application of circularity levers, namely scaling mechanical recycling, chemical recycling, and modest levels of plastic component refurbishment and reuse[90], the automotive sub-system can achieve circularity levels of 66% by 2050, up from 9% today. As shown in Figure 18, by achieving this circularity, disposal of plastic waste from the sector decreases to just 0.3 Mt, an 83% reduction compared to 2020, despite a 110% increase in the total volume of waste.

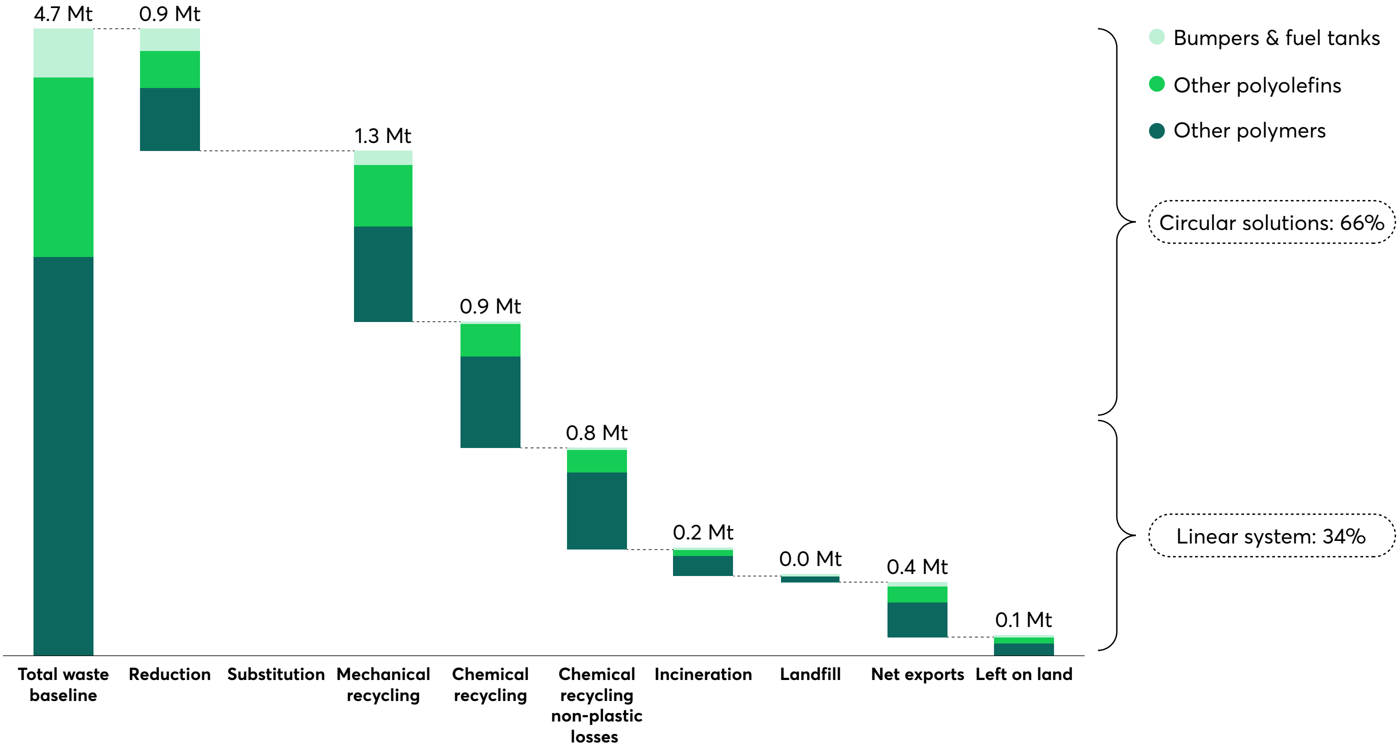
With the rise of digitization, the problem of vehicles with unknown whereabouts and, in particular, the unauthorized treatment and illegal export of end-of-life vehicles, can be mitigated. Through the use of financial incentives, which are already in place in certain EU Member States, and technological solutions to increase vehicle traceability and thus compliance with the ELV Directive, the levels of vehicle mismanagement decline and the proportion of vehicles leaving stock that are received by authorized treatment facilities increases from 59% today to 85% by 2040, with the remainder being exported out of the EU as second-hand vehicles for further use. This increases the potential for plastic recovery within the EU and thus the potential for circularity.

The recycling of plastic components in the automotive sector is currently limited and to date it has not been a major focus for auto-recyclers. However, with an increasing share of plastic in vehicles, the environmental burdens associated with ELV treatment are rising and thus bringing into focus the need for plastic recycling. While this calls for an expansion of mechanical recycling in the automotive sector, there are several challenges, both technical and economic, that must be overcome.

Figure 18

Ambitious application of the circularity interventions in the automotive sub-system reduces disposal, exports and left on land to 34% and increases system circularity to 66%

Physical fate of plastic waste from construction in the Circularity Scenario in 2050 (Mt)



Note: [1] Chemical recycling non-plastic losses describes gaseous and process losses in chemical recycling (gasification and pyrolysis)
Source: "ReShaping Plastics" model

Automotive plastic typically ends up in automotive shredder residue because of the logistical and economic barriers to dismantling. Scaling up advanced post shredder technologies (PST) more widely across the EU should therefore be prioritized in order to recover plastic from shredder residue. While the dismantling of plastic components allows for a clean, uncontaminated plastic stream for recycling, dismantling rates are currently low (4%) with limited potential to scale given the high labour costs of dismantling, the logistical challenges associated with storage and transport of dismantled components, and the technical challenges associated with designing vehicles for dismantling. As a result, dismantling is assumed to only increase to 15% by 2050, with most significant improvement seen in the dismantling of large monomaterial components such as bumpers and, in the case of internal combustion engine vehicles, fuel tanks. However, for advanced PSTs to scale up, policy drivers are required and the costs for incineration and landfilling of the shredder light fraction must increase so that recycling becomes a more economically viable route. These disposal costs are currently comparatively low and thus do not encourage investment in these technologies.

Automotive System Intervention #1 and #2: Reduce, reuse, substitute in automotive plastic

Given the important role plastic plays in the functionality, safety, and emissions performance of vehicles, there is limited opportunity for the elimination or substitution of plastic in vehicles. However, there is the opportunity for reduction of total demand via the reuse of refurbished components. Although small now, by developing more standardized plastic component design with a higher degree of modularity in vehicles, and by creating a re-sale channel for used parts, it is assumed that total plastic demand in this sub-system could reduce by 6% by 2050.

Due to tight weight restrictions, the use of plastic in vehicles has already been optimized with no further opportunities for reduction. The potential for the reuse of plastic components is therefore highly dependent on having modular, standardized vehicle designs, using non-destructive dismantling processes, and relies on re-sale channels for used parts, which currently do not exist in a sufficiently large capacity.

It also requires technical specifications to remain static over the lifespan of the vehicle, or to become more flexible for certain components, particularly for non-safety critical components. For substitution, the cost and weight saving advantages of plastic, compared to alternative materials, means that substitution of plastic is not only unlikely but would be detrimental to the performance of vehicles. In fact, current trends indicate that plastic is likely to continue substituting other materials in vehicle components. Particularly with a shift to electric vehicles, for which lightweighting will allow for a greater range and load capacity, the total volume of plastic in vehicles is likely to continue increasing with very little likelihood of substitution of plastic by other materials.

According to the International Resource Panel[88], sharing models, including both car-sharing and ride-sharing, have the potential to reduce the total European vehicle stock by 13% by 2050.[lxiii] More intensive use of vehicles could decouple car ownership from demand for mobility through, for example, both car-sharing where vehicles are owned collectively but used by individuals through rental, and ride-sharing where vehicles are owned by individuals, but occupancy rates are increased through sharing services. These trends are gaining significant traction and undoubtedly will play a central role in driving the circular economy as the more efficient use of our current vehicle stock, and the materials it is made from, reduces future demand. In turn, according to this study's stock and flow model, this could reduce total plastic demand by 22% and waste by 13% by 2050 relative to the Current Actions Scenario. A modal shift in transportation (e.g., shifts from cars to public transport, bicycles, or other modes of transportation) also have the potential to reduce the number of vehicles on the road and therefore the demand for plastic from the automotive sector. This modal shift has not been quantified in the analysis.

[lxiii] The International Resource Panel analysis estimates a vehicle stock reduction of 13%-57% for G7 countries as a result of car-sharing and ride-sharing, with the lower end of the range applying to European countries.

Automotive System Intervention #3: Expand mechanical recycling in automotive

Mechanical recycling of plastic in the automotive sector is currently very limited for four main reasons:

1. Design choices to date have meant that plastic is typically dispersed throughout a vehicle and incorporated into complex composite components.
2. Dismantling is limited and faces multiple logistical and economic challenges.
3. At end-of-life, plastic is usually shredded up in a mixture of various polymers and other materials from which they are hard to recover.
4. The current material recycling target of 85% introduced by the ELV Directive has had almost no impact on plastic, which makes up only around 10%-15% of current end-of-life vehicles. The focus to date has been on increasing the recycling of metals, particularly steel, as they are present in much larger volumes and are much easier to recycle.

While mechanical recycling is preferable to chemical recycling from both a GHG impact and cost perspective, the challenges listed above limit its expansion. Even if all potential levers are utilized to their maximum potential and best practice is adopted across Europe, it is estimated that only 38% of total plastic waste from ELVs remaining in Europe would be mechanically recycled by 2050, producing 1.3 Mt of recyclate. Therefore, the role for closed loop mechanical recycling is limited. While there is some opportunity to use mechanical recyclate from other sectors, particularly consumable applications, this is also limited in terms of both the quantity and quality of the supply. Despite these challenges, there does appear to be a role for mechanical recycling of plastic in the automotive sector, but this relies on increased investment in post-shredder technologies across Europe, policy incentives to design plastic components in vehicles for recycling and for the uptake of recycled content, and a strengthening of EPR schemes under the ELV Directive. All these criteria need to be realized to achieve the 38% mechanical recycling by 2050 level modelled in this scenario, which is an almost 10-fold increase from 2020.

Although not directly linked to the recyclability of vehicles, the issue of vehicles with unknown whereabouts must be resolved to increase the formal recovery of plastic from ELVs in Europe. Currently a third of the vehicles leaving the European stock have unknown whereabouts and 10% are exported as second-hand vehicles; this results in high levels of leakage of plastic from the European automotive sector which could otherwise provide recycled content. There are a variety of reasons for these missing ELVs, some of which pose greater environmental risks than others. These include illegal treatment of vehicles by unauthorized facilities, illegal or unreported exports of vehicles, and vehicle abandonment. To ensure the environmentally sound treatment of ELVs, as well as support the economics of the formal recycling market, the illegal exports and treatment of vehicles must be minimized if not completely eliminated. This relies on the establishment of effective vehicle deregistration frameworks, tamper-proof technological solutions and unique identifiers to keep track of a vehicle during its life, and strengthening EPR systems via the ELV Directive.

Similar to construction, upstream levers to drive circularity in the automotive sub-system will have limited impact in the short term, given the 10-15 year lifespan of vehicles.[91] Nevertheless, early adoption of such levers is critical to allow their benefit to be felt as soon as possible. Widespread adoption of design for recycling of vehicle components could reduce losses from mechanical recycling to a minimum of 15%, down from 27% today, according to current best practice.[8] In recent years, the increased use of reinforced plastic containing fillers and additives has made plastic components in vehicles virtually impossible to mechanically recycle. By choosing monomaterial designs, avoiding the use of paint, using fewer and more common polymer types, and, where possible, avoiding the combination of incompatible polymers, much higher yields could be achieved in mechanical recycling and higher quality recyclates produced, driving a greater share of closed loop recycling. This relies heavily on the formulation of industry-wide standards for design for recycling of plastic vehicle components, which must be adopted consistently and strictly adhered to. It is important to note that in some cases design for recycling could increase a vehicle's emissions during the use-phase, hence a full life cycle assessment is needed on a case-by-case basis.

Through the adoption of best practices at authorized treatment facilities, and some degree of design for disassembly, it is estimated that the total share of plastic that could be recovered prior to shredding is 15%, up from 4% today. Dismantling of plastic vehicles parts is thus likely to remain relatively limited due to technical limitations on design, logistical challenges, and the lack of necessary channels to support the reuse and recycling of plastic components. Currently, under best known practices, around 10-11% of total plastic can be dismantled with current vehicle design.[92] But in reality, only around 4% of plastic components are dismantled prior to shredding[22,90,92], as the dismantling process – being both time and labour intensive – comes at a high cost and requires significant storage space, but with almost no pay back. Similarly, the opportunity to increase the share of plastic that can be dismantled from a vehicle is also relatively limited as this requires a greater modularity of vehicles, which would result in additional vehicle components and thus added vehicle weight. Therefore, in order to achieve the 15% dismantling rate that is estimated to be possible by 2040, a degree of design for disassembly is important, but a significant improvement in the economics associated with dismantling and the establishment of channels to support the resale and recycling of plastic vehicle components are critical.

Automotive shredder residue is a growing waste stream and, as the opportunities to scale up dismantling are limited, PSTs have significant potential to become the main means of recovery. By 2050, it is estimated that recovery of plastic from shredder residue could increase from an average of 13% today to 50% by 2050. The recycling sector still favours advanced PST over dismantling[91] , and investment in PST would make more economic sense in terms of plastic quantities to be recovered and further recycle.

However, at present, the use of advanced PSTs to recover plastic from shredder residue is minimal and restricted to only a few Member States, such as France and the Netherlands. To achieve higher recovery rates of automotive plastic from shredder residue, as demonstrated by best practices today, widespread adoption of advanced PSTs is required across Europe such that it becomes the dominant treatment route of the shredder light fraction. This requires significant investment in these technologies, which relies on an improvement in the economics of recycling engineering plastic, as well as strong policy incentives, which are expected to be introduced in the upcoming revision of the ELV Directive and which will likely include material-specific recycling targets. At the same time, alternative disposal routes (i.e., landfilling and incineration) must become less attractive economically and/or be more strictly limited by regulation.

Automotive System Intervention #4: Scale chemical recycling in automotive

Given these technical challenges and the suitability of the shredder light fraction to thermal treatment, it is expected that chemical recycling will play an increasingly significant, yet still complementary, role in the sub-sector. In this scenario, it is estimated that, by 2050, 0.9 Mt of automotive plastic waste could be chemically recycled via either gasification or pyrolysis and recirculated back into the automotive sector, satisfying 20% of total demand for plastic in the sub-sector.

> ***“The interventions modelled in the Circularity Scenario are all current technologies – as such they can be relied on more confidently to deliver change. These current technologies do not preclude the possibility that further breakthroughs may be achieved in circularity technologies that could drive circularity towards even higher rates.”***

C. The Circularity Scenario has economic, climate and social benefits

Circularity levers have a strong potential to drive the transformation of the European plastics system across all in-scope sub-sectors while delivering economic, climate and social benefits – including the creation of new jobs. These levers offer the potential to achieve high levels of circularity as well as over 60% reduction in GHG emissions by 2050. They are the fastest, most certain method for driving change, and have the largest impact on the system. Best of all, they can deliver bulk of the essential systems changes required by 2040.

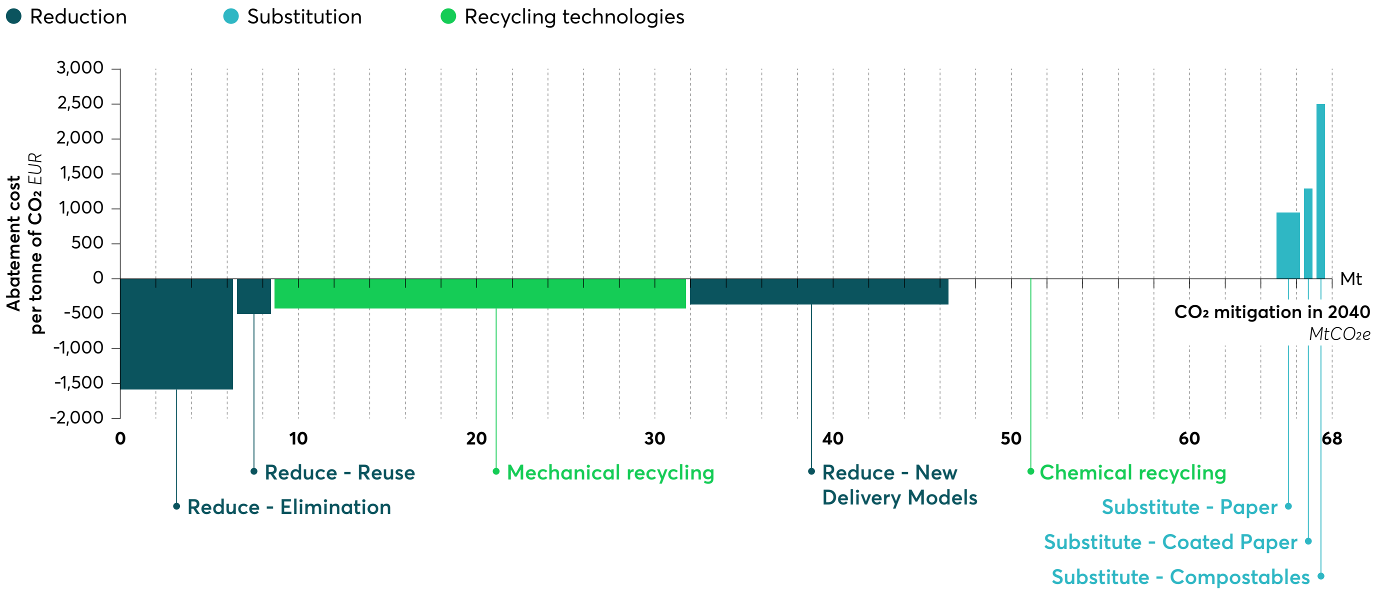
The costs at which circularity levers drive the abatement of GHG emissions varies significantly. The most cost-effective forms of abatement are the elimination of unnecessary plastic and the introduction of customer reuse models.

Mechanical recycling and new delivery models are on a par, assuming the best-in-class mechanical recycling infrastructure is purchased and supportive policy is put in place. Chemical recycling delivers GHG reductions at a system level[lxiv] but at a cost that nets off against existing systems production savings, while substitution is significantly more costly but does not abate large volumes of GHGs. The focus of the marginal abatement cost curve in Figure 19 is in 2040, when the majority of circularity levers have reached maturity, and together have reduced GHG emissions in the European plastics system by 48%

The interventions modelled in the Circularity Scenario are all current technologies – as such they can be relied on more confidently to deliver change. High levels of resource efficiency through circularity are a pre-requisite for the European plastics system to establish a long-term sustainable model within a broader resource efficient and low-carbon economy. These current technologies do not preclude the possibility that further breakthroughs may be achieved in circularity technologies (e.g., AI sorting technology, enzymatic recycling, digital watermarking, and more) that could drive circularity towards even higher rates.

Figure 19

Marginal Abatement Cost Curve – Circularity Scenario in 2040: Circularity interventions offer low-cost CO_2 reduction strategies, abating 48% of CO_2 at a net economic saving.



Note: By 2040, most circularity solutions are expected to be fully scaled. Therefore, total emissions abated and avoided/added cost to the system are compared for this year. The cost include fully loaded CAPEX and OPEX and are compared to the cost of not having implemented the respective solution (i.e. virgin plastic production and end-of-life). For instance, mechanical recycling includes CAPEX and OPEX to produce one tonne of recyclate, the cost of additional investment to produce high-quality recyclates as well as collection and sorting costs. Cost avoided are the cost of producing an equivalent virgin polymer as well as cost of disposal.
Source: "ReShaping Plastics" model

[lxiv] Weighted GHG emissions value for the system calculated using total mass recycled per pathway multiplied by emissions factor, then offset by avoided production and end-of-life emissions.

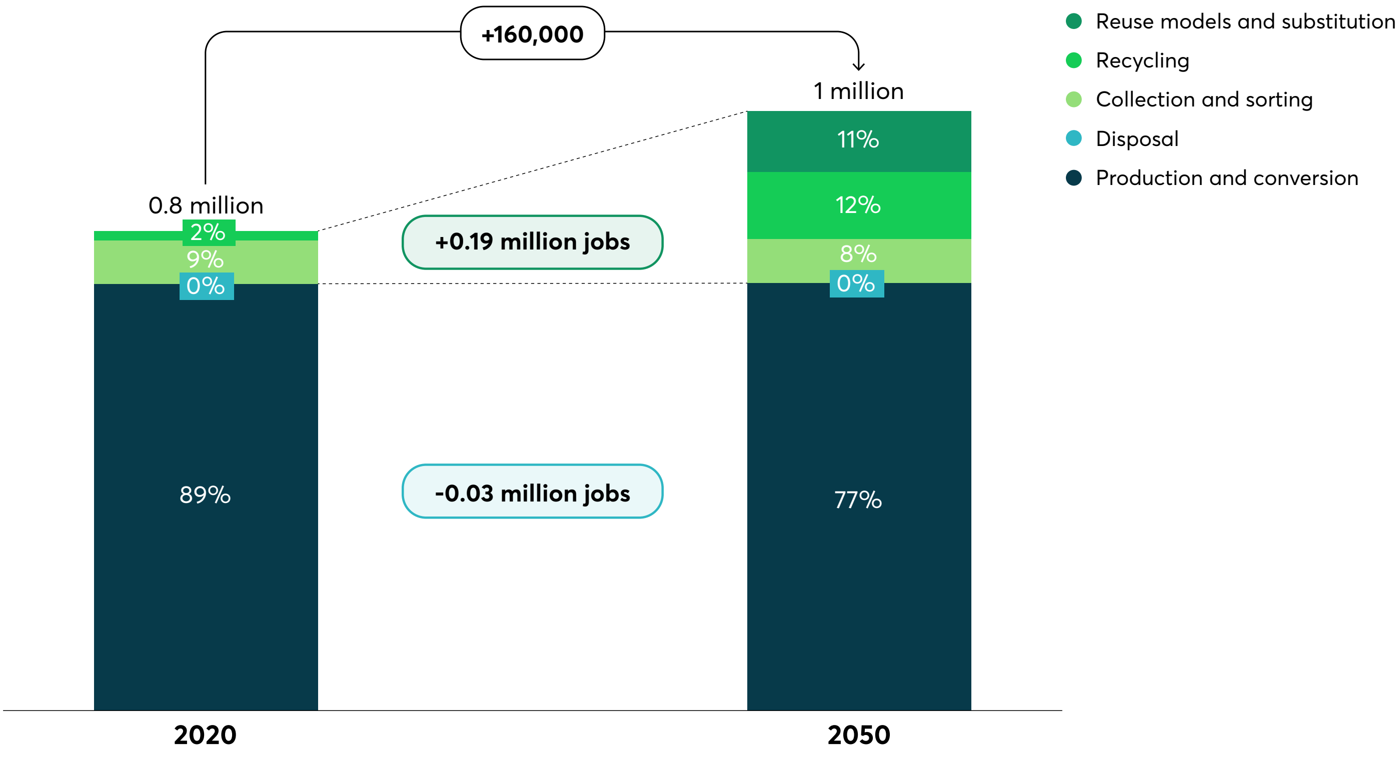
At the same time, implementing a circular plastics economy can be a net job creator for Europe. In the Circularity Scenario, employment grows by 11% from 2020 to 2050. Approximately 160,000 jobs could be created, as shown in Figure 20, especially as labour-intensive sectors such as recycling and reuse models – which tend include a service component – scale up due to market expansions. These can offset jobs losses in earlier stages of the plastics value chain, notably in production and conversion as virgin production decreases due to increased circularity. In light of projected European population and plastics sector growth, this is unlikely to result in any major loss of employment but may require some natural shifting of roles and retraining schemes, the latter of which come at a social cost. Care must also be taken to maintain job quality through this transition, for example ensuring that high-paying jobs in the petrochemical industry are not replaced with lower paying jobs in the service industry. The jobs impact of individual levers in the Circularity Scenario have not been quantified due to data scarcity and complexities around the calculation of the net jobs impact of GHG reduction levers.

After implementing all known circular solutions at an ambitious yet realistic level, 33 Mt (or 36% relative to Current Actions) of CO_2e emissions remain in the system by 2050[lxv]. The next chapter describes additional levers that could be implemented to further decrease GHG emissions beyond the Circularity Scenario.

Figure 20

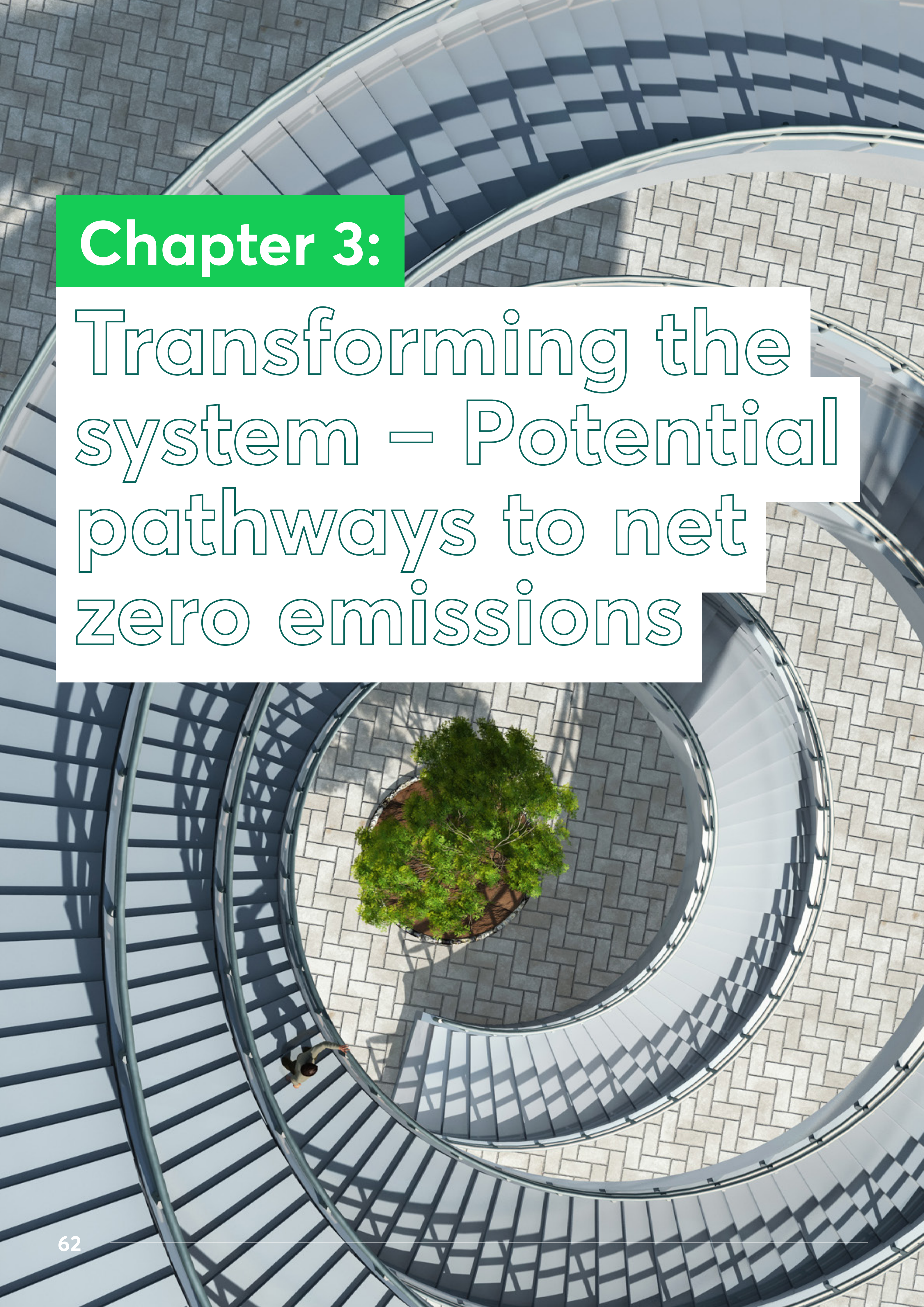
160,000 new jobs could be created by 2050 in the Circularity Scenario

Sources of employment in the Plastics system in the Circularity Scenario 2020 vs 2050



Source: "ReShaping Plastics" model

[lxv] "Known solutions" here excludes the use of bio-based feedstock even though it is a known solution because, while this lever has a positive impact on reducing GHG emissions from the system, it does little to impact system circularity, which has been the focus of this chapter. The use of bio-based feedstock is explored in more detail in Chapter 3.



Chapter 3:

Transforming the system – Potential pathways to net zero emissions

A. A bold innovation agenda is needed to reduce GHG emissions further

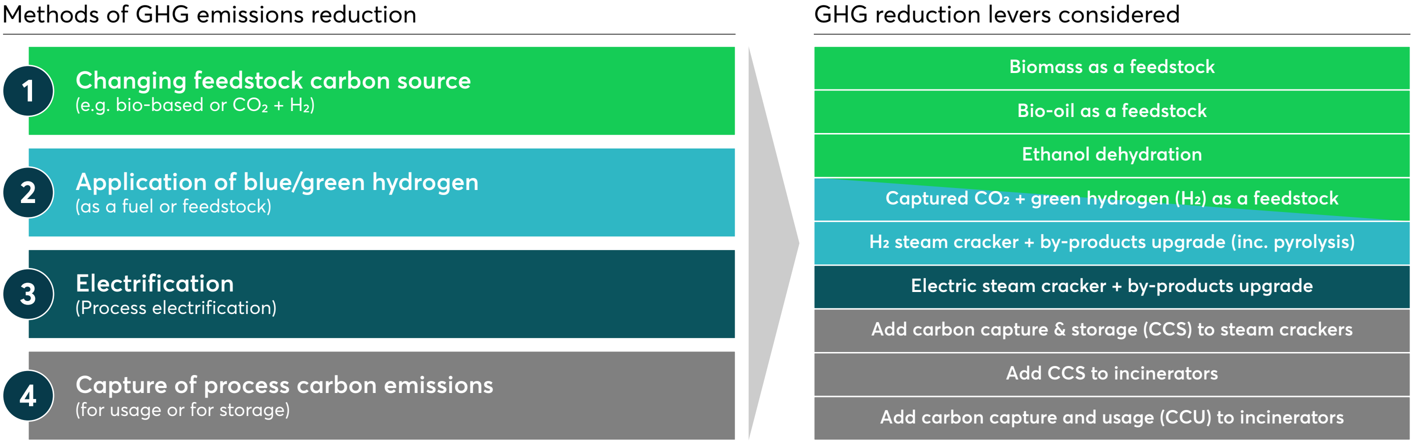
As shown in the previous chapter, the Circularity Scenario has a significant impact on plastic waste reduction and resource productivity, but it still leaves 33 Mt of GHG emissions in the system. Additional, direct GHG reduction system interventions are required to reach net zero emissions by 2050, building on the circularity system change levers. This chapter explores two scenarios, the Retrofit Systems Change Scenario (RSCS) and the Net Zero Systems Change Scenario (NZSCS), which have been developed to gain insight into the implications of using emerging technologies to identify a pathway to a net zero emissions plastics industry. The RSCS aims to retrofit the existing system infrastructure and operating model with low-emissions fuel and carbon capture, and achieves a GHG reduction down to 25 MtCO_2e per year by 2050. The NZSCS adds to the RSCS approach by displacing some fossil feedstock with alternative sources of carbon and employs direct electrification in production. It shows that reaching net zero emissions in the European Plastics system by 2050 is possible, but requires bold innovation, significant investment, targeted policy support, technological advancement, and new business models. Many levers described in this chapter are at a very early stage and have not yet been proven at scale. As such, the conclusions presented need to be treated as informed but speculative, recognizing that there are high degrees of uncertainty surrounding the possible costs and technological development, especially in the later years of the analysis.

This report focuses on GHG reduction in Scope 1, 2 and 3 across the plastics system value chain for in-scope plastic (but excludes quantifying GHG impacts in the use-phase). Four main methods to reduce GHG emissions have been identified, as shown in Figure 21, all of which require significant innovation.

1. **Changing the feedstock's carbon source:** Hydrogen and carbon feedstocks for plastic production have generally been sourced from crude oil fractions as an affordable, abundant hydrocarbon. As the world moves away from oil as a source of energy, its continued usage as a feedstock may become increasingly challenging due to the limits of abating production emissions (0.4 tonnes of CO_2e per tonne of polymer). Therefore, non-virgin fossil sources of feedstock are likely to be required by the future plastics system in the form of either bio-based sources or captured carbon[lxvi]. Plastic can be made from biological feedstocks, such as sustainably grown biomass (e.g., wood or sugar cane), as well as from bio-waste.

Figure 21

We have identified 4 approaches to reduce GHGs in the Plastics system, which have been combined to form a shortlist of potential GHG reduction levers



Note: Increased circularity via recycling and R&S is also a means of GHG reduction but is not included explicitly as a GHG reduction lever.

[lxvi] N.B. captured carbon will probably have originated from a fossil source, but in the process of capture is essentially being recycled. Arguably, captured fossil carbon is a transitional source of feedstock as the global economy decarbonizes until a fully circular carbon economy can be established, but there is likely to be an oversupply of captured carbon towards a net zero emissions future and a lack of demand for commercially viable applications.

These substitutions need to be made carefully on a case-by-case basis while considering their broader environmental impacts. Equally, carbon captured from the process emissions of the plastics sector (or other sectors) is likely to become an increasingly abundant feedstock towards 2050. These technologies are starting to reach commercial scale and offer an opportunity to make plastic from sustainable and emission abating sources, as they both reduce the level of carbon in the atmosphere.

2. **Application of low-carbon hydrogen:** Low-carbon hydrogen is a critical component of a net zero emissions system. Hydrogen is already used as a fuel and feedstock in industrial processes around the world, but is typically manufactured from fossil sources in an energy and emissions-intensive process. However, hydrogen can also be produced from electrolysing water using renewable energy sources, referred to as "green hydrogen"[lxvii]. This process is equally energy intensive, and requires expensive electrolysers, but offers the means of producing a zero-carbon, high-temperature fuel, as well as a critical base feedstock for many chemical products. "Blue hydrogen" is another form of low-carbon hydrogen produced using the standard grey hydrogen production process with carbon capture and storage (CCS) applied, which may play a role as a transition technology due to the near-term economics and infrastructure.[lxviii] Green hydrogen is currently very expensive (~€4-6/kg) and has multiple technical barriers around transportation and storage to be overcome. However, the expected level of industrial activity around this opportunity in the transition to a net zero emissions system could place it on a pathway to scale by the end of the 2030s. This could substantially reduce its costs (potentially to <€2/kg), thus placing it on a path to compete with blue hydrogen in the long run.[93] Low-carbon hydrogen[lxix] may be used across the plastics system as a feedstock (e.g., in gasification of waste as a feedstock to supplement syngas composition), and can be combined with captured carbon to make low-GHG emission virgin plastic. It may also be used as a zero-carbon fuel, for example in this study it is used to retrofit existing crackers and displace fossil as a fuel. The plastics system is assumed to be a service taker of the low-carbon hydrogen economy rather than a first mover, thus this report does not discuss the substantial challenges of this method's build out.

3. **Electrification:** Electrification of processes using renewable energy is a more direct way of reducing emissions by removing fossil fuels as sources of energy required to create heat. In this report, electric steam crackers have been explored as a lever whereby the steam cracker is electrified to generate heat and the by-products, usually used to fuel the cracker, are either sold to displace other fossil fuels or upgraded if sale is not possible or appropriate.

4. **Capture of carbon process carbon emissions:** Process carbon emissions are often very hard to avoid but may be captured for storage or usage. CCS usually requires the captured carbon to be transported from the point of capture to a port via ships or pipes, then fed out to saline aquifers in the North Sea, where it can be stored indefinitely. Global annual capacity to sequester CO_2 through this technology amounted to about 40 million tonnes of CO_2 in 2021, making it a proven technology.[94] While considered a viable solution to addressing hard to reduce emissions, CCS is contested by some stakeholders, has technical challenges and risks associated with moving carbon to off-shore storage, and requires massive investments. The nature of CCS also means that it faces geographical constraints as it is uneconomical to transport carbon very far. Alternatively, carbon capture and usage (CCU) is a more nascent set of technologies whereby captured CO_2 is used as a feedstock to make carbon-based products such as cement, aggregates, methanol or polymers. Cement and aggregates are currently viewed as the most viable, at scale methods of carbon usage for high volume sequestration. CCS has been applied to both production (steam crackers) and end-of-life incineration in the levers, with CCU used to simultaneously abate end-of-life emissions and act as an alternative feedstock.

[lxvii] This study assumes the use of green hydrogen rather than blue hydrogen (produced using non-renewable sources of energy but with CCS) throughout due to the projected long-term economic superiority of green hydrogen (see ETC report on the green hydrogen economy[93]).

[lxviii] The emissions factor of blue hydrogen is contended at present.

[lxix] The systems change levers in this report have used the economics and process inputs/outputs of green hydrogen due to a combination of long-term economics and emissions risks, but this is a scenario decision and does not exclude the validity of blue hydrogen as GHG emissions reduction technology. Furthermore, the application of blue hydrogen to crackers has been excluded due to the rationale that CCS would be applied directly to crackers if available, excepting when blue hydrogen could be transported to fire crackers not accessible to carbon storage, which presents logistical complexities around the rollout of CO_2 vs hydrogen transportation infrastructure. Notably, blue hydrogen may represent a pathway to build out the infrastructure for a green hydrogen economy.

Macro-levers were also modelled to create a baseline that shows a decarbonizing Europe on a journey to net zero emissions. One example of this is the decarbonization of the electricity grid in Europe, which could drop from approximately 258g CO_2/kWh today to close to zero by 2050 as the grid shifts to renewable energy. Other examples include the reduction of methane leakage from natural gas supply chains, electrification of natural gas boilers, and GHG-reduction in upstream oil and gas exploitation.

Decarbonization levers can be broken down into two major conceptual approaches to changing the system. On one hand, the European plastics system has invested hundreds of billions of Euros into infrastructure orientated towards processing fossil feedstocks into plastic, and thus there is a strong incentive to decarbonize while retaining this system model as far as possible. On the other hand, the rise of alternative feedstocks presents the opportunity for the plastics system to partially decouple from the existing fossil system, which will require a significant shift away from legacy infrastructure, but may strategically reposition the European plastics system for long-term growth and stability. That is why two scenarios have been developed by this study, the Retrofit Systems Change Scenario (RSCS) and the Net Zero Systems Change Scenario (NZSCS). Figure 22 shows which GHG reduction levers are included in each scenario (all Circularity Scenario levers are included in both):

Figure 22

Full list of levers applied in the Retrofit and Net Zero Systems Change Scenarios

System change lever groups	System change lever groups	Retrofit Systems Change Scenario	Net Zero Systems Change Scenario
Policy & industry actions	All current policy & industry actions	✓	✓
Reduction & substitution levers	Eliminate	✓	✓
	Reuse and New Delivery Models	✓	✓
	Sharing models for vehicles	✓	✓
	Substitute – paper, coated paper, compostables	✓	✓
Recycling levers	Design for recycling	✓	✓
	Expand waste collection and sorting	✓	✓
	Increase mechanical recycling	✓	✓
	Increase chemical recycling	✓	✓
GHG reduction levers	Add carbon capture and storage to steam crackers (inc. pyrolysis oil)	✓	✓
	Green H_2 steam crackers + by-products upgrade (inc. pyrolysis oil)	✓	✓
	Apply carbon capture and storage to incinerators	✓	✓
	Apply carbon capture and usage to incinerators		✓
	Captured CO_2 + green hydrogen as feedstock		✓
	Use electricity as a heat source for steam crackers		✓
	Use sustainable biomass as a feedstock		✓

The objective of these scenarios is to answer two key questions:

- Can retrofitting the existing fossil-based system to "sweat" legacy assets achieve net zero emissions?
- Can a net zero emissions European plastics system be reached, and if so, how and by when?

B. The Retrofit System Change Scenario – reducing emissions while maintaining existing assets

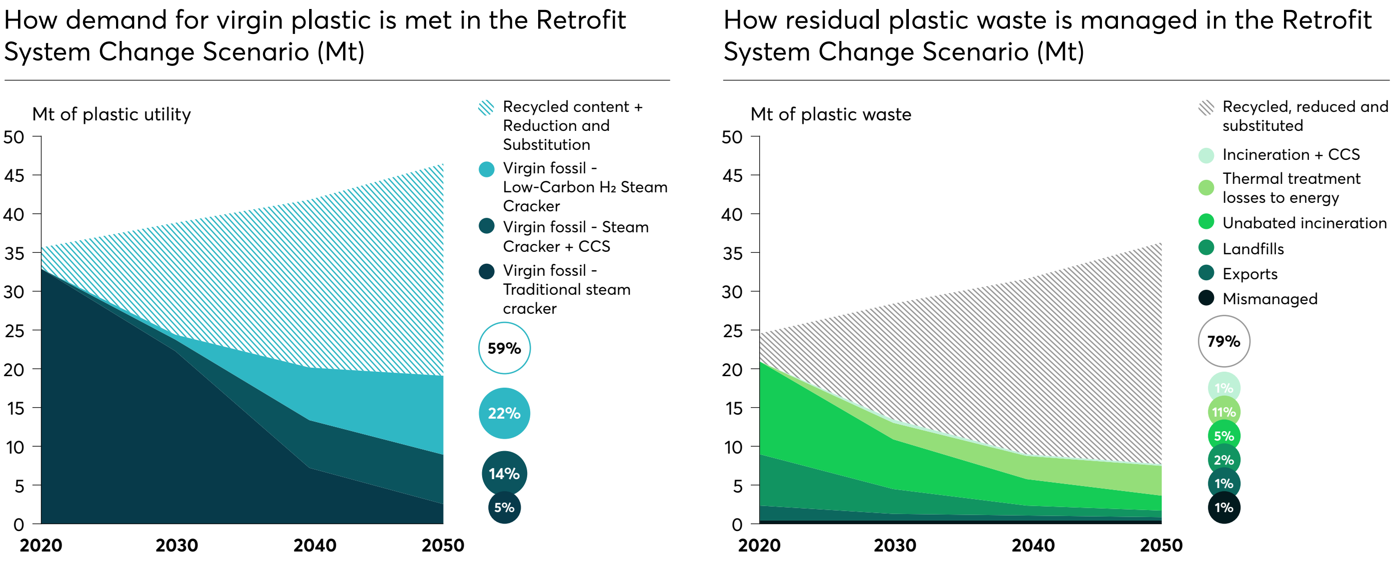
The Retrofit System Change Scenario results in a 72% reduction in GHG emissions vs the Current Actions Scenario by 2050, down to 26 $MtCO_2e$. In 2050, virgin fossil plastic production still represents the largest emission category at approximately 11 $MtCO_2e$, followed by end-of-life incineration at approximately 5 $MtCO_2e$. In this scenario, only 2.7 Mt of virgin fossil polymer production remains unabated (13%) by 2050, with remaining virgin production abated through low-carbon hydrogen crackers (11 Mt, 53%) and CCS, (7 Mt, 34%), while 16% of the incinerator portfolio is abated through CCS. Figure 23 shows how the demand for virgin plastic is met and how the residual plastic waste is managed in the Retrofit System Change Scenario.

Three levers are applied in this scenario, building on top of the circularity levers already applied in the Circularity Scenario:

1. Replace steam cracker fuel with green hydrogen where and when possible, then upgrade by-products into plastic
2. Apply carbon capture and storage to steam crackers
3. As per 1 & 2 but applied to pyrolysis oil in steam crackers instead of virgin fossil feedstock
4. Apply carbon capture and storage to incinerators

Figure 23

In the Retrofit System Change Scenario, as little as 5% of plastic demand could be met with unabated virgin fossil steam cracker production by 2050



Note: All Circularity Scenario levers (Reduction and Substitution, and Recycling) are included, as well as application of Carbon capture and Storage to Steam Crackers and Waste Incinerators and the application of Hydrogen Steam Crackers
Source: "ReShaping Plastics" model

Box 3:
Green Hydrogen Firing vs Electrification of Steam Cracking

One way of reducing emissions is to remove fossil as a source of fuel in production. Two approaches to this have been considered: electrification and green hydrogen firing of steam crackers. The Retrofit System Change Scenario assumes no electric steam cracking, but does include 11 Mt of virgin fossil production through green hydrogen fired crackers. This may seem counter-intuitive, as electrification typically has greater energy efficiency transfer than green hydrogen. Furthermore, the sector already has a high-profile electric steam cracker project led by BASF, SABIC and Linde and targeting a launch by 2023.[95] So why does the scenario include it?

In the Circularity Scenario, total demand for virgin fossil plastic drops from 34 Mt in 2020 to around 21 Mt in 2050, driven by increased circularity. Considering the decreased demand for production, the most capex efficient approach has been taken to abating production in the Retrofit Scenario. Electric steam crackers will probably require either greenfield build or a significant infrastructure overhaul, presenting both technical and capex challenges. Converting furnaces to hydrogen firing, while not a trivial process, has been practiced at scale in Europe for many years.[lxx] The sector already has a major gas cracker project, "Project ONE", which aims to use carbon capture and storage (CCS) and is designed for retrofit to low-carbon hydrogen as a means to produce monomers with low-emissions. Crackers have lifespans of up to 60 years, thus a large upfront investment in electric steam crackers may in some circumstances lock in virgin fossil production capacity past 2050[lxxi], versus hydrogen firing which could reduce stranded asset exposure after 2050 and arguably may be able to facilitate transition to an abated production portfolio faster. The cost of abatement is estimated to equalize between these two routes by 2050 (at €1,800 per tCO_2e)[87], but prior to 2050 green hydrogen fired crackers are estimated to have a 2x lower cost of abatement.

Nonetheless, this is just one scenario, and as with all the projections in this chapter contains uncertainties as well as known and unknown barriers. Electric steam crackers are an equally valid approach to abatement due to their independence from the availability of affordable green hydrogen and their more efficient use of renewable electrons, assuming renewable generation cyclicality issues can be overcome. As such, they are included in the Net Zero System Change Scenario (covered in the next section) to satisfy any additional greenfield production capacity required.

[lxx] Based on expert interview with major oil company Director of Research

[lxxi] While electric crackers can bio-based oils as feedstock, it is currently unclear if there will be sufficient volume of this feedstock to feed many electric crackers, hence there is a potential risk to lock in virgin fossil production.

The role of carbon capture and storage in production and end-of-life

Carbon Capture and Storage is a highly contested technology in Europe. While there are over 18 projects currently under way globally and an additional 12 in the pipeline to 2030, massive geological resources in Norway and the North Sea, and over 10 industrial hubs under development, CCS still faces some major barriers to scale.[96] A conservative approach has been taken in the lever generation, using geospatial analysis to apply CCS to crackers and incinerators within 100Km of the industrial hubs currently under development, and excluding the possibility of massive pipelines across Europe, shipping CO_2 from other ports, or CCS growth in the Mediterranean. There are only around 80 ethylene steam crackers in Europe in 50 locations[97] today, but over 500 incinerators[98] evenly distributed across Europe located where the waste is generated; crackers are thus much more geographically concentrated than incinerators and are often located near to or in industrial clusters, making them more suited to CCS than incinerators. Therefore, in the Retrofit Scenario, CCS has been applied to 33% of the cracker output by 2050 vs only 16% of the incinerator portfolio, leaving the majority of the end-of-life incineration emissions unabated. Massive government subsidies have also been assumed to be necessary to scale these technologies – unless a high market price for carbon is established - and given the current reticence of various governments to commit to this pathway, we estimate that full scaling will be delayed until the late 2030s.

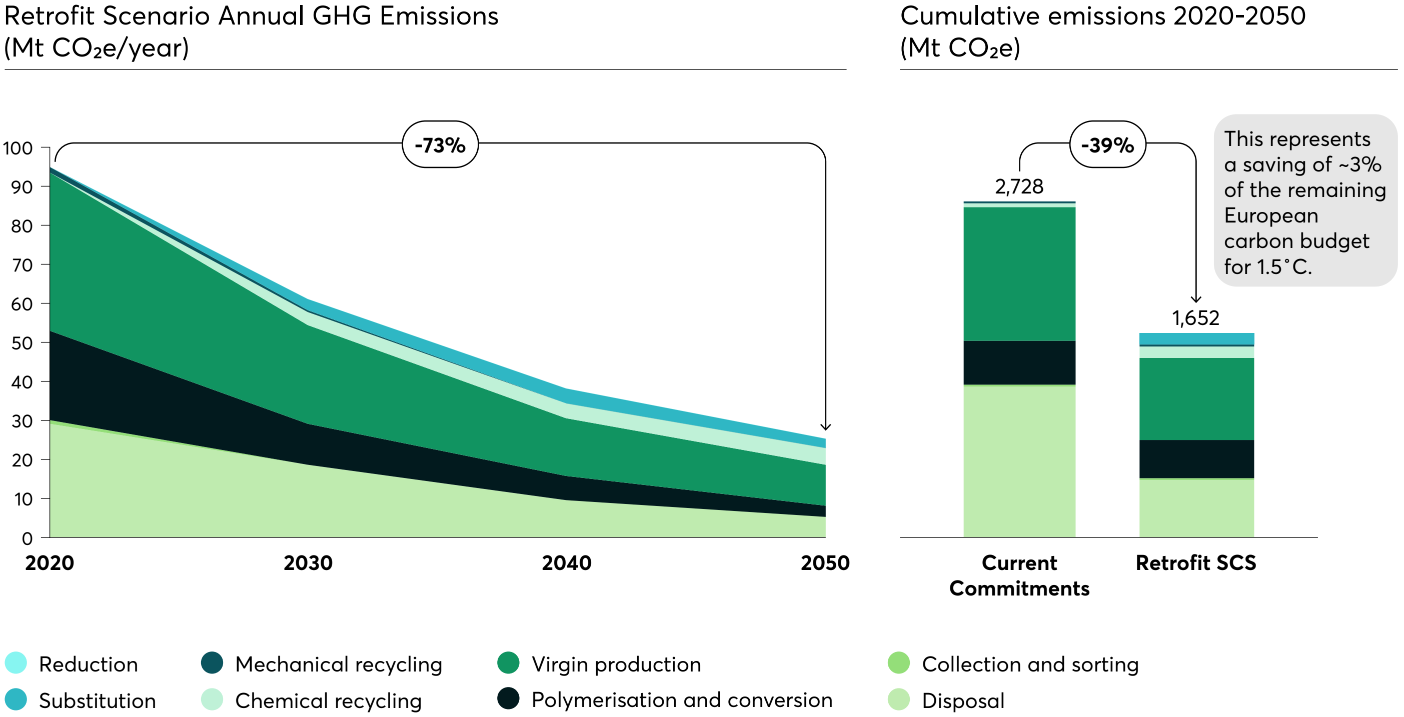
According to the modelling, the RSCS requires an estimated €10-20 billion capex, in addition to the estimated €170 billion capex required for the Circularity Scenario. However, indirect capex also increases by €20-40 billion compared to the Circularity Scenario due to the cost of green hydrogen and CCS services, making the total scenario capex approximately €200-230 billion cumulatively (2020-2050). This makes the total incremental cost of the RSCS – on top of the Circularity Scenario – approximately €30-60 billion, to achieve a further 137 MtCO_2e cumulative emissions reduction between 2020 and 2050.

That could be considered a bargain to reduce emissions by 73% compared to today, 39% lower than the Circularity Scenario, and save 3% of Europe's total remaining 1.5 degrees carbon budget, but it is still not net zero, as shown in Figure 24.

Retrofitting the system, while a financially logical approach that delivers significant decarbonization, ultimately does not achieve a net zero emissions world on its own and could present a strategically challenging outlook in a net zero emissions world in 2050. The next scenario explores what it would take to really achieve net zero emissions for the European Plastics system.

Figure 24

Retrofitting the system reduces GHG emissions by 73%, to 25 Mt CO e per year


Retrofit Scenario Annual GHG Emissions (Mt CO_2e/year)

Cumulative emissions 2020-2050 (Mt CO_2e)

This represents a saving of ~3% of the remaining European carbon budget for 1.5˚C.

Source: "ReShaping Plastics" model

C. A Net Zero System Change Scenario – what will it take to achieve net zero emissions?

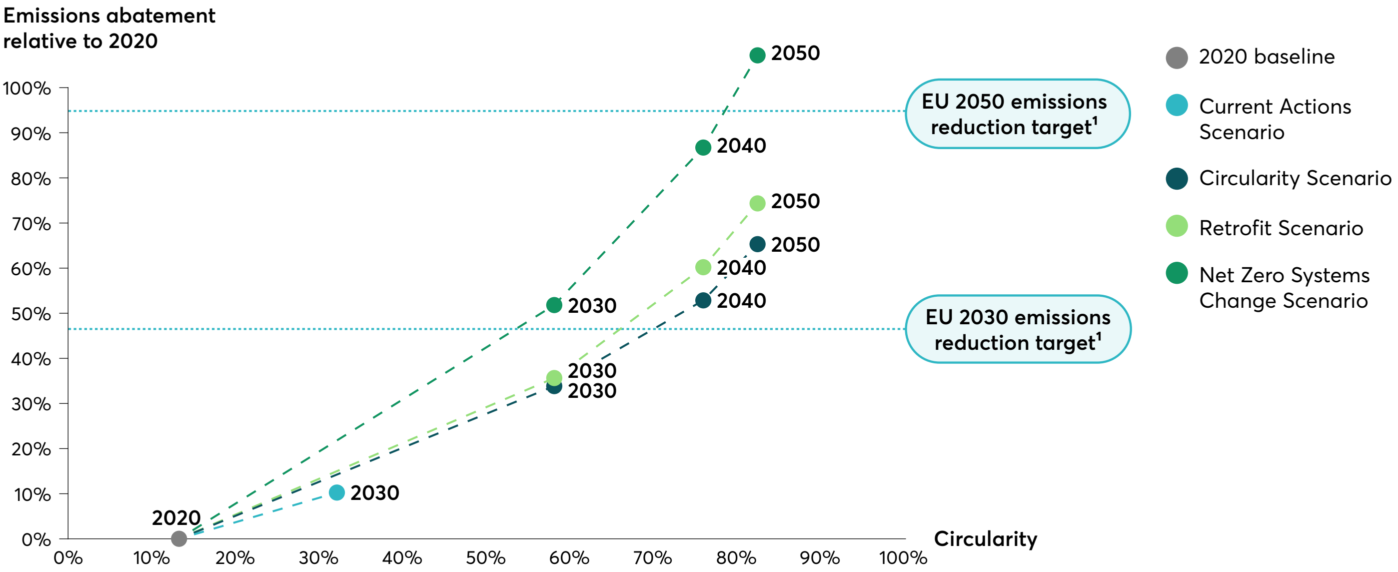
Reaching a net zero emissions Plastics system in Europe, as described in the Net Zero System Change Scenario (NZSCS) will probably require decoupling plastic from the fossil system to source carbon from alternative sources such as biomass and captured carbon, as well as a major infrastructure overhaul. In this scenario, only 12 Mt of virgin fossil plastic are required by the system by 2050, and all the GHG emissions are abated. Greenfield cracking capacity requirements are also limited, due to reductions in virgin polymer demand, but 1.5 Mt is still produced through this low-emissions approach. Alternative feedstocks (biomass and captured carbon) provide 9 Mt of virgin polymer to the system - signalling a decoupling from the use of fossil sourced feedstocks.

The NZSCS will require an additional €80-110 billion of capex[lxxii] on top of the Circularity Scenario, largely driven by the cost of building out alternative feedstock infrastructure, but has a significant GHG reduction potential due to avoided virgin fossil production emissions and utilizing carbon already in the system that would otherwise be in the atmosphere. Similarly, remaining end—of-life incineration is abated across three quarters of the remaining portfolio through carbon capture and recycling back into virgin polymer, meaning the 2.3 Mt of plastic incinerated in 2050 will generate only 1 Mt of emissions. As Figure 25 shows, this scenario sees net GHG emissions from the European plastics system fall below zero by 2050, exceeding the EU emissions reduction targets. It is important to note that this is not the only pathway to a net zero emissions plastics system in Europe, but it is the one that this study found most illustrative.

Figure 25

The Net Zero Systems Change Scenario brings the European plastics industry on a pathway to meet the EU's emissions reduction target by 2030 and 2050

A comparison of emissions abatement vs. circularity[2] achieved in each scenario per decade



Notes: [1] The EU climate law (55% emissions reduction by 2030 compared to 1990 levels; climate neutral (95% reduction) by 2050) has been calculated to match the required reductions compared to 2020 levels (2030: ~48%; 2050: ~94%) using data by the EEA (2020): Total greenhouse gas emission trends and projections in Europe.
[2] Circularity is a measure of resource efficiency, i.e. the degree to which (re)used materials replace new virgin materials. In this study, the circularity metric is defined as the share of plastic utility that is either reduced, substituted by circular materials, or recycled mechanically or chemically excluding plastic entering stock.
Source: "ReShaping Plastics" model and EEA (2020)

[lxxii] Direct capex and indirect capex paid through opex for the build out of alternative feedstocks and green hydrogen infrastructure

The Net Zero System Change Scenario builds on the Retrofit Scenario levers by adding the following 3 levers:

1. **Carbon recycling:** capturing carbon from incineration at end-of-life and combining it with green hydrogen to make methanol, and then create more polymer through the methanol to olefins (MTO) process.
2. **Electric steam crackers:** abating remaining virgin fossil production by building electric steam crackers that replace fossil as a fuel source with renewable sources of energy, and then upgrade the off-gasses through the MTO process.
3. **Use of biomass as feedstock:** displacing virgin fossil carbon feedstock with sustainable biomass feedstock sources by gasifying woody biomass to create syngas, and subsequently produce methanol then olefins.

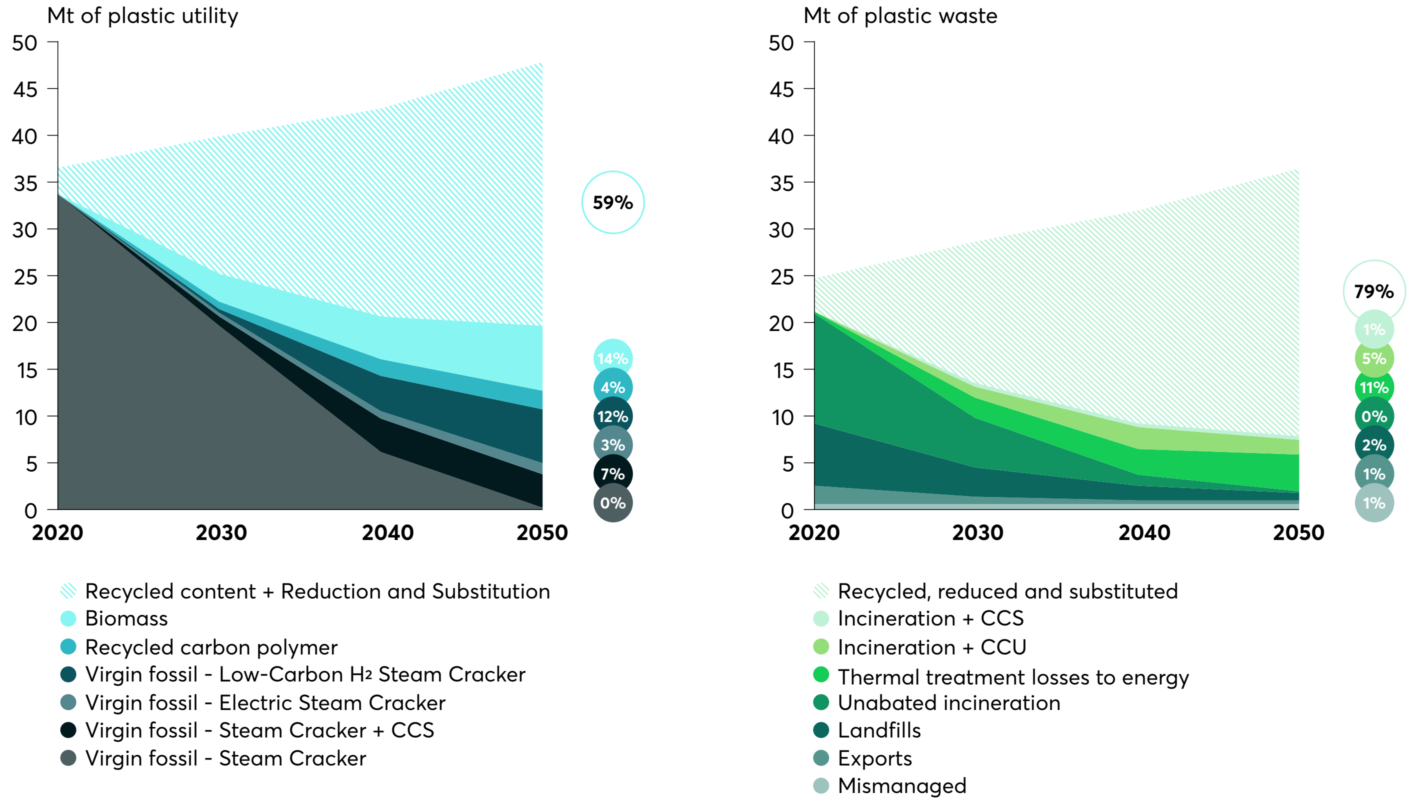
There are multiple inherent risks and uncertainties in realizing this scenario, and a significant research and innovation agenda is needed. Moreover, it represents just one potential pathway to net zero emissions and it is vital that industry and policymakers remain flexible to adapt to evolving circumstances around performance, cost and scale of different technologies. Closing the gap to net zero emissions is not within full direct control of the plastics value chain, and requires close collaboration with adjacent sectors such as energy production, hydrogen, and CCS technologies starting this decade to shift trajectory towards a fully abated system. Figure 26 shows how demand for virgin plastic is met and how the residual plastic waste is managed under the NZSCS.

Figure 26

The Net Zero Systems Change Scenario solutions could lead to no unabated virgin fossil production remaining by 2050

How demand for virgin plastic is met in the Retrofit System Change Scenario (Mt)

How residual plastic waste is managed in the Retrofit System Change Scenario (Mt)



Note: Includes all levers from Retrofit Systems Change Scenario plus alternative feedstocks to displace virgin fossil, incineration + carbon capture and utilization and electric steam crackers.
Source: "ReShaping Plastics" model

Carbon recycling

In the Net Zero System Change Scenario, all systems change levers are assumed to be already maximized to reduce waste incineration, reducing it from 18 Mt in the Current Actions Scenario down to only 2.3 Mt in the NZSCS by 2050. Under NZSCS, it is assumed that residual unabated incinerator emissions are captured and converted into 2 Mt[99] of plastic to displace virgin fossil plastic relative to 20.7 Mt virgin plastic demand and 48 Mt of plastic utility in 2050. This "carbon recycling" represents just 4% of plastic utility demand in 2050, but although it is not the cornerstone of future production methods, it plays a key strategic role in beginning to decouple the plastics system from fossil feedstocks as well as fuels.

European waste incineration capacity has doubled[100] in the past 25 years to reach 90 Mt of waste-to-energy capacity today[98], with long-term contracts locking municipalities into this disposal route for decades to come, with an associated reduction in recycling activities[101]. Therefore, until a breakthrough technology is discovered or there is significant policy change, incineration is still the most likely end-of-life for the harder to recycle, contaminated plastic waste. In the Retrofit System Change Scenario, incineration remains largely unabated (84% of the portfolio resulting in 10.2 $MtCO_2e$ in 2050) and considering the potential risk of "unaccounted for" plastic missing from the waste statistics flowing through mixed waste (see Box 1), these emissions could be even higher. In light of these factors, the abatement of incineration at end-of-life is of paramount importance as a backstop for the system to de-risk the unknown quantities of carbon that may be emitted from incinerators, but should be carefully applied to avoid disincentivizing investment in circularity levers.

Analysis has explored carbon capture and usage as a pathway by which the plastics industry can address its end-of-life abatement issues (after all other measures have been exhausted), while simultaneously engaging in the new carbon usage economy. Plastic-to-plastic carbon recycling is a future technology that will require a major R&D budget and significant innovation. Nevertheless, several publications[102–104] the socioenvironmental problems resulting from the linear economy model have been widely discussed, especially regarding plastic pieces intended for single use and disposed improperly in the environment. Nonetheless, greenhouse gas emissions caused by inappropriate disposal or recycling and by the many production stages have not been discussed thoroughly. Regarding the manufacturing processes, carbon dioxide is produced mainly through heating of process streams and intrinsic chemical transformations, explaining why first-generation petrochemical industries are among the top five most greenhouse gas (GHG have focused on using waste carbon capture for polymer manufacture. These reports outline the growing focus on using carbon from waste to be recycled through a range of pathways back into the base chemicals (i.e. methanol) required for plastic production.[lxxiii] Examples of this pathway already exist at a commercial scale. for example Carbon Recycling International produces 110 kt of methanol per year by utilizing geo-thermally produced green hydrogen as feedstock in Iceland.[105]

In the NZSCS, a closed system approach to carbon recycling is assumed instead of purchasing carbon from other sectors to offset emissions, because the latter is likely to lead to cherry picking the most attractive carbon streams and leaving the hardest to use carbon streams (e.g. incinerators) unabated. A closed system approach is pursued because: i) the plastics system is more directly in control of both demand and supply side levers; ii) it addresses both end-of-life and feedstock emissions simultaneously; and iii) it strategically repositions the European plastics system to play a broader strategic role by using CO_2 from other sectors as feedstock in the post-net zero economy beyond 2050.

Abatement of remaining fossil steam cracking through electric steam crackers

Demand for virgin plastic is significantly reduced from 2020 to 2050 from 34 Mt in 2020 to approximately 20 Mt in 2050 under the NZSCS. The reduction in the steam cracker base is assumed to churn unabated brownfield crackers as ethylene demand reduces. Where crackers remain unabated, the residual cracker base is replaced with greenfield electric steam crackers, amounting to a 1.5 Mt (3% of plastic utility) portfolio, equal to approximately two or three electric crackers. As such, the entire virgin fossil cracker base is abated to the maximum possible degree by 2050, with 11 Mt out of the 20 Mt abated through virgin fossil polymer production (by electrifying steam crackers, using hydrogen as

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[lxxiii] Noting that the methanol-to-olefins route only satisfies olefin production and other chemical processes will be required to convert the carbon into the full spectrum of polymers.

feedstock, and using CCS in steam crackers) and 2 Mt (4%) through recycled carbon polymer from end-of-life. This leaves just 7 Mt unabated virgin fossil plastic production in the system in 2050, which still requires addressing through an GHG abatement lever.

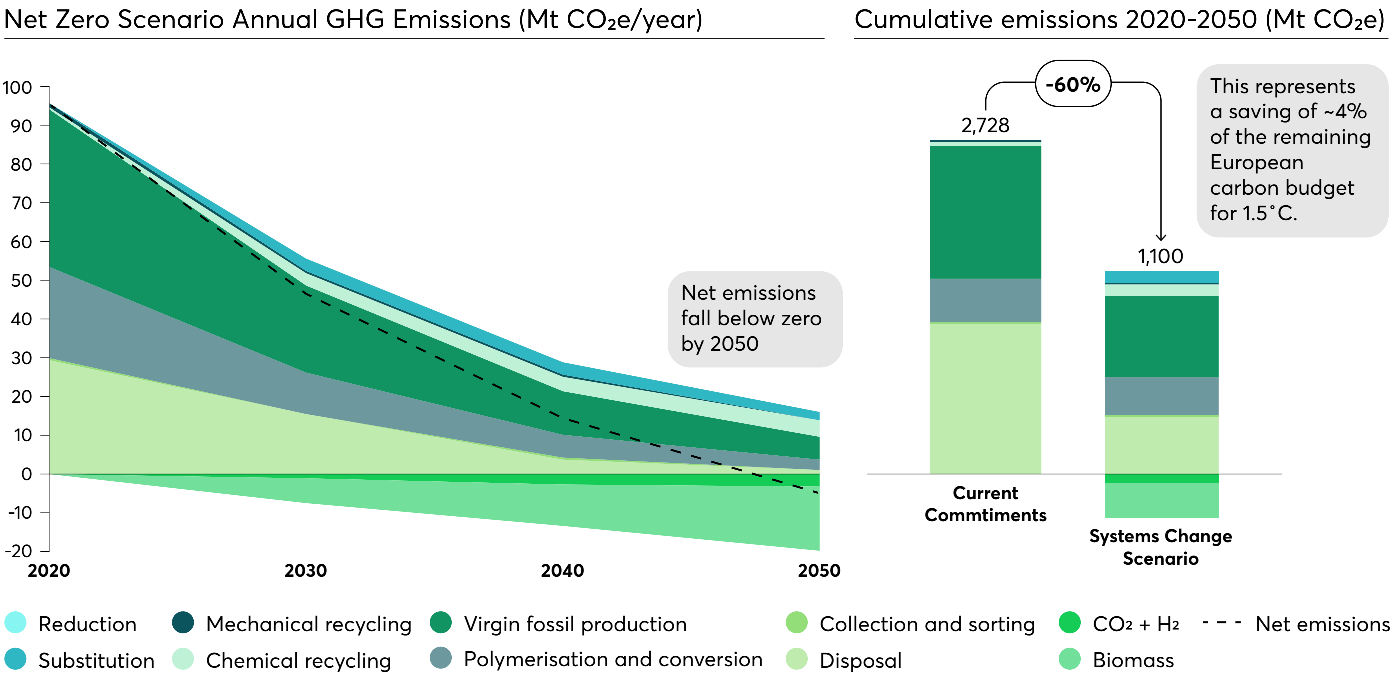
Use of biomass as feedstock

Shifting the source of carbon from plastic manufactured from fossil to sustainable forms of biomass offers the system an opportunity to sink carbon[lxxiv] from the atmosphere into plastic in a commercially viable way. Bio-sources include biomass (e.g., from sustainably managed forests), bio-waste (e.g., waste vegetable oils), and energy crops (e.g., sugar cane) for dehydration of ethanol. Under the presumption of high levels of circularity achieved within the Circularity Scenario, this carbon from bio-sources is used at maximum efficiency and only re-released in small volumes to the atmosphere through inevitable systems leakage.[lxxv] This has a neutral or negative GHG footprint on the system depending upon end-of-life, and can be used to net off emissions from residual GHG leakage. A range of factors should be considered in the selection of biomass pathways, predominantly, avoidance of competition with the food chain; avoidance of dependence upon a waste generating, inefficient economy; and avoidance of geo-political risks. The estimated potential for biomass in the Net Zero System Change Scenario is approximately 7 Mt (14% of plastic utility).

There are an estimated 1-1.3 exajoules of sustainable biomass suitable for use by the European plastics sector, and plastic is considered one of four sectors[lxxvi] for which biomass should be reallocated. Of this total, woody biomass has been selected in this scenario as it is transportable and carbon dense, and thus not in competition with the supply chain. This displaces the remaining unabated virgin fossil production within the system, and in doing so creates a carbon negative wedge that brings the system to net zero emissions by 2050. This approach reduces the cumulative carbon emissions 2020-2050 by 60% relative to the Current Actions Scenario, as shown in Figure 27.

Figure 27

Shifting away from fossil production to alternative feedstocks achieves net zero GHG emissions by 2050



Source: "ReShaping Plastics" model

[lxxiv] This is a temporary sink into a circular economy. Permanent sinking has been defined as sequestration in the ground for >100 years, but irrespectively, carbon is removed from the atmosphere for a time.

[lxxv] Or, if strategic zero-methane landfilling is legalized, plastic could become a form of profitable controlled disposal of carbon to rival CCS given its carbon density meaning almost 3 tonnes of CO_2 can be sequestered per tonne of plastic.

[lxxvi] Others being i) aviation ii) wood products and iii) pulp and paper

Box 4:
Dehydration of Ethanol

Braskem, the major Brazilian petrochemical conglomerate, has been pioneering the production of over 200kt/year of bio-plastics using dehydration of ethanol as a route. Building on the established ethanol industry in Brazil, this approach repurposes land for sugar cane production while avoiding encroaching on sensitive biospheres, including the Amazon. Production estimates indicate that there is adequate land available for re-pasture to sustainably generate feedstock for several million tonnes of bio-plastics without exhausting available arable land or causing deforestation. This technology for plastic production is already at commercial scale, and – while this lever is not applied in the Net Zero System Change Scenario due to the conservative selection criteria – it provides a commercial scale example of how the growth of bio-plastics may represent a much larger proportion of plastic production in coming years.

Strategic positioning of the Plastics system reaching net zero in 2050

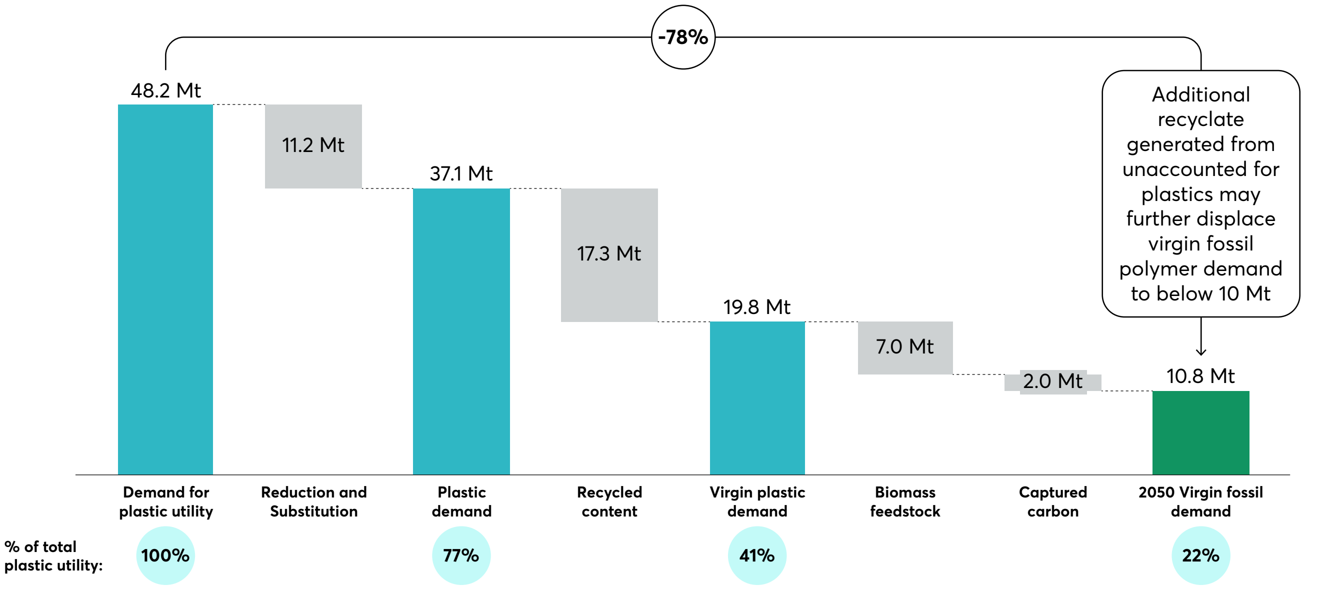
The Net Zero System Change Scenario describes a significant reduction in the demand for fossils, through the combination of circularity and alternative feedstock systems change levers, as highlighted in Figure 28, 78% of plastic utility is supplied by alternative fuels by 2050.

Strategically, experts suggest that fossil as feedstock is problematic in a net zero emissions system in the longer term due to abatement of upstream oil and gas production emissions being extremely hard to deliver and highly expensive to achieve. Coupled with residual emissions from Scope 1 and 2 inefficiencies (e.g. in carbon capture technology), the NZSCS leaves an unabated GHG emission factor of just 0.4-0.7 $MtCO_2$ per tonne of polymer[lxxvii] associated with using fossil sources[lxxviii].

Figure 28

12 Mt of virgin fossil remain in the system in 2050 in the Net Zero Systems Change Scenario – to what extent should a complete disengagement be considered?

By 2050, 78% of plastic utility is supplied by alternatives to fossil fuel in the Net Zero Systems Change Scenario (Mt)



Source: "ReShaping Plastics" model

[lxxvii] 0.4 t refers to upstream emissions and the additional 0.3 t refers to the residual emissions from abated Scope 1 and 2 production as abatement is not 100% efficient and there are, for example, tertiary emissions after off-gas upgrade or less than 100% efficient carbon capture.

[lxxviii] Other high value chemicals are produced from fossil steam cracking, e.g. butadiene, for which alternative methods of production are more problematic.

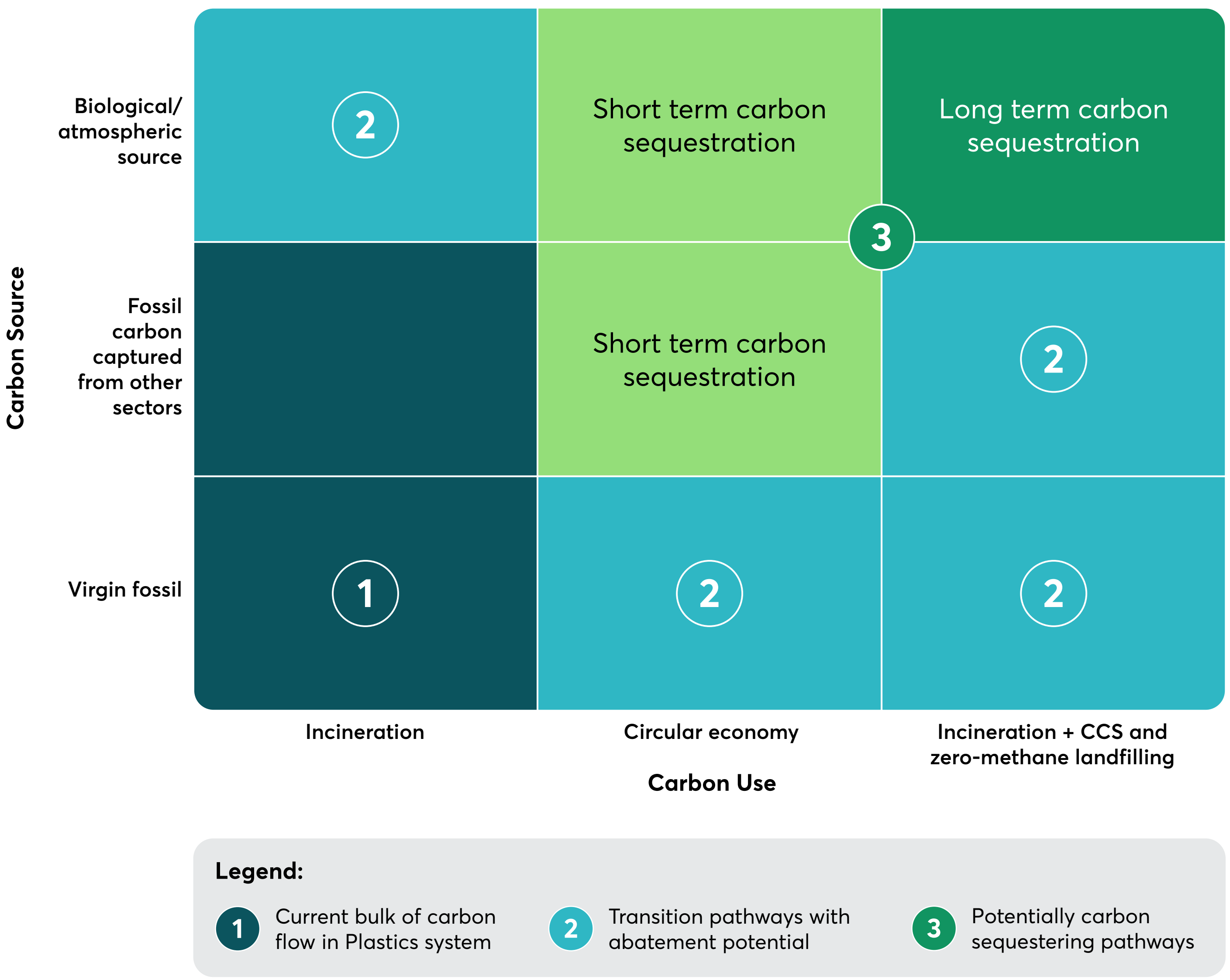
A more aggressive shift towards alternative feedstocks, particularly carbon capture and usage, may offer the plastics system a growth opportunity to play a broader role in the transition of the European economy to net zero. Plastic is carbon dense and requires around 2.9 tonnes of CO_2 per tonne of polymer produced. Towards 2050, low-carbon hydrogen is projected to become far more affordable than today (from >€4/kg today to possibly €1-2/kg in the future[93]) and depending on carbon price, carbon usage may even become a revenue generator for the plastics system, potentially bringing alternative production economics on par with virgin fossil production.

Embracing the opportunity to act as a destination for captured carbon has the potential to invert the operating model of the plastics system and strategically reposition the plastics system from a climate challenge to a climate solution, as can be seen in Figure 29, although this will require major innovation and infrastructure overhaul.

D. Transformation costs are comparable but require a significant redirecting of capital investment to higher risk assets

Figure 29

Current and future carbon pathways through the Plastics system



Carbon Source	Incineration	Circular economy	Incineration + CCS and zero-methane landfilling
Biological/ atmospheric source	2	Short term carbon sequestration	Long term carbon sequestration
Fossil carbon captured from other sectors		Short term carbon sequestration	2
Virgin fossil	1	2	2

Legend:

- 1 Current bulk of carbon flow in Plastics system
- 2 Transition pathways with abatement potential
- 3 Potentially carbon sequestering pathways

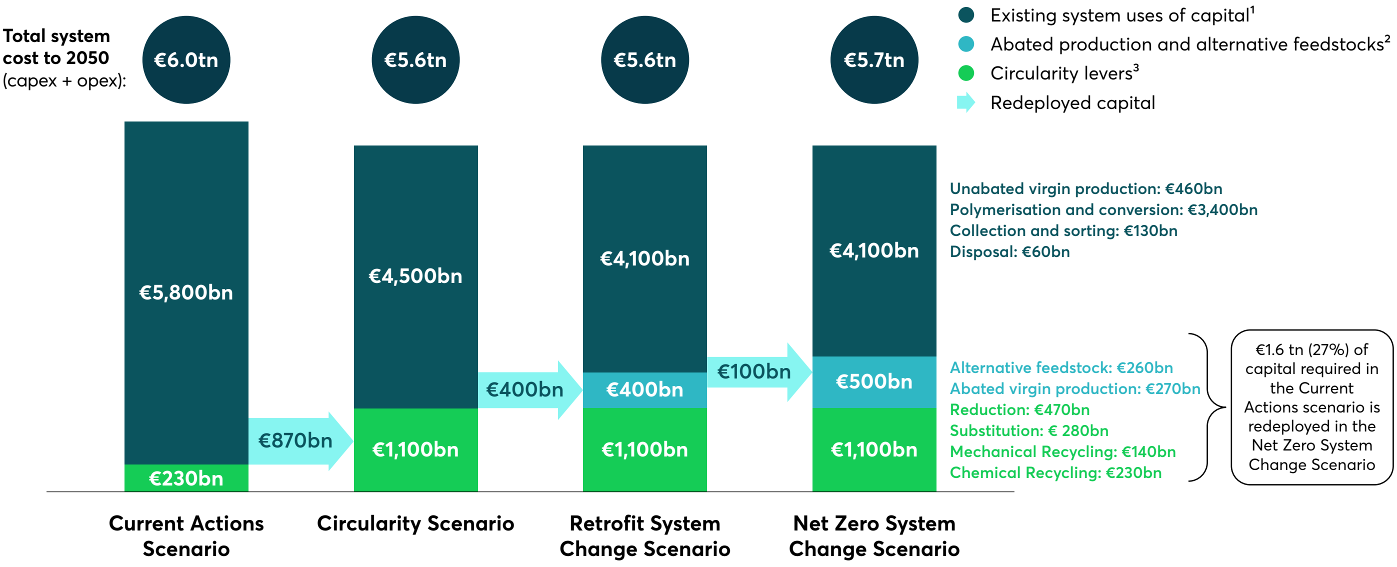
The Net Zero System Change Scenario presents a cumulative system cost of €5-6 trillion[lxxix] (2020-2050), which is comparable to the total cost of the Current Actions Scenario, as shown in Figure 30. This reflects increased system efficiency through avoidance of capacity increases end-to-end balancing out with increased capital investments in new technologies and business models. However, around 1 in 4 Euros will need to be redeployed to these new, less mature and commercially unestablished technologies and models, thus requiring the associated development of suitable intermediaries and financial instruments to de-risk innovation and large-scale capital in this space.

Scaling circularity interventions – namely reuse models, substitution, mechanical recycling, and chemical recycling – requires a large capital investment in the system. At the same time, however, these levers improve system efficiency, reducing costs elsewhere in the system, particularly as a result of avoided virgin production and end-of-life disposal. For example, the cumulative capex and opex cost (2020-2050) of elimination, reuse, substitution, and mechanical and chemical recycling is approximately €1 trillion, but by reducing the demand for expanded linear system capacity from virgin production to disposal in current actions, they deliver a cost reduction above €1 trillion (irrespective of alternative costs of production). The net effect is therefore an overall system saving. Nevertheless, capital expenditure in the NZSCS increases by at least 20% compared to the Current Actions Scenario by 2050 and would be even greater when scaled to cover the transition of the full European plastics system, of which this analysis covers only 75%. Half of this spending is in reuse and new delivery models, while the other half is directed towards scaling both mechanical and chemical recycling technologies and substitution.

Figure 30

27% of the capital required in the Current Actions Scenario is redirected to new uses in the Net Zero System Change Scenario

Cumulative system cost and redeployment of capital per scenario in 2050 (€bn)



Notes: ¹ Existing system uses of capital include conventional steam cracker production, polymerisation, conversion, collection, sorting and disposal (including costs for CCS/CCU applied to incinerators in the NZSCS) .
² Abated production and alternative feedstocks includes abated virgin production (H_2 + CCU, steam cracker production + CCS) in the RSCS; the NZSCS adds cost for electric steam crackers for abatement of remaining fossil steam cracking as well as the use of alternative feedstocks from both biological sources (bio-based methanol-to-olefin) and carbon dioxide capture + H_2 (carbon recycling, fossil methanol-to-olefin).
³ Circularity lever costs include system cost for mechanical and chemical recycling (all scenarios), and for the reduction and substitution levers (in the Circularity Scenario, RSCS, and NZSCS)
Source: "ReShaping Plastics" model

[lxxix] Scenario cost is calculated at incremental capex requirement plus opex cumulatively over the 2020-2050 time series. Costs are gross system costs, not net of revenues i.e. each cost along the plastics value chain is aggregated and not netted off with revenues to calculate margin and value creation.

While there is only a relatively minor fluctuation in total system cost over the time series, the Net Zero System Change Scenario requires significant capital re-allocation from mature, low risk-return business models to less tested, higher risk-return business models. More than 1 in 4 Euros (approximately €1.5-1.8 trillion until 2050) in the system will need to be redirected to circularity or GHG reduction over the next three decades in order to drive towards a fully circular net zero emissions system. While learning curves have been applied to try and capture the higher cost of capital associated with these ventures, additional investments could be made in areas that prove to be unsuccessful further increasing the total amount.

Retrofitting the existing system with CCS and green hydrogen-powered steam crackers diverts an additional estimated €400 billion from conventional steam cracker production towards emissions abated production; a small proportion of this is the capital investment required for the physical assets, while the vast majority (95%) is operating expenditure for carbon storage and green hydrogen, which is paid to service providers through long-term contracts – in part a form of indirect capex by the Plastics system for infrastructure build out.

Given this shift in risk profile as a result of redeploying capital from current, well-established technologies to less proven business models and more nascent technologies, the structure of capital required will be very different compared to the Current Actions Scenario. Different kinds of financial instruments will need to be leveraged and different sources of capital engaged, including venture capital, private equity and debt, green/social/sustainability transition bonds, and concessional and blended finance. Policymakers will also be relied on to create an enabling legislative environment to support and de-risk this transition, and strong collaboration between the plastics value chain and with other sectors will be essential. The net effect of improved system efficiency and large capital expenditure in nascent technologies and new business models will result in a 20-30% increase in the per-tonne cost of plastic relative to today. In the near term, however, the large capital investments required from the European plastics system presents a risk to the competitiveness of Europe against global plastics markets, meaning that policy mechanisms must be put in place to protect against correct action being punished by the market.

Finally, given the scale of transformation called for by the Net Zero System Change Scenario, there is an implicit cost to society that should not be ignored. The circularity interventions, and in particular the reuse and new delivery models of plastic utility, call for considerable behavioural change regarding how the public consume, use, and dispose of plastic and rely strongly on consumer education. Similarly, scaling mechanical and chemical recycling requires an expansion of collection and sorting infrastructure and implies a significant time cost, potentially relying on households to spend more time on sorting waste[lxxx] and demolition workers to spend more time on non-destructive deconstruction and on-site sorting.

E. The time to act is now

The next five years are a critical window for action. Long technology maturity cycles and capex lock-in for large infrastructure investments mean that the decisions taken in the 2020s will determine whether it is possible for the system to its reach waste reduction targets and net zero GHG emissions by 2050. The time to act is now.

The plastics industry is currently targeting pyrolysis as the dominant pathway for chemical recycling in the 2020s. This example implies continued reliance on steam cracker production, the need to further invest in steam cracker capacity, and the implementation of decisions on major decarbonization infrastructure with long-term ramifications. Given the lifespans of these assets, the long technology maturity cycle, and the capital investment required, there are imminent infrastructure lock-in implications. Recycling plants, incinerators, and steam crackers all have lifespans of 20 years or more; hence, investment decisions made throughout this decade, and particularly in the next three to five years, will determine what the European plastics system in 2050 looks like. Similarly, given the nascence of the technologies and the plastic-to-plastic chemical recycling industry, data shows that it takes an average of 17 years[1] from the concept stage for technology providers to reach growth scale., Capital investments made today will have a lasting effect.

[lxxx] Some experts argue that future technologies may not require households to sort waste at all as automated sorting will be more efficient and effective.

Chapter 4:

Making progress requires collaboration and an ambitious action plan

The degree of systems transformation achieved by 2050 depends to a large extent on the decisions taken, the level of ambition, and the degree of collaboration shown by the plastics industry, policymakers, investors and consumers in the next three to five years. Breaking away from the status quo and transforming the currently linear European plastics system into a circular, low-emissions system calls for a pragmatic and collaborative system transformation approach along the entire value chain – which is presented as a new System Change Action Plan. Policymakers and industrial players alike need to help set the enabling conditions for action, while investors, civil society, and consumers all have a role to contribute towards realizing this vital transformation and action must start now.

The upcoming wave of legislation in the CEAP 2.0, and the rise of circularity as a key priority within industry narratives indicates that the next five years will be fundamental in shifting the trajectory of the plastics system away from its current linear model.

Additionally, the longevity and potential lock-in effects of capex investments, and the timescales associated with deploying new infrastructure and maturing technologies, mean that decisions made by the industry in the near term will set a systems trajectory from which it will become increasingly difficult to deviate. Bearing this in mind, consideration should be given to investing in a future of long-term sustainable growth beyond 2050 – after net zero emissions have been achieved.

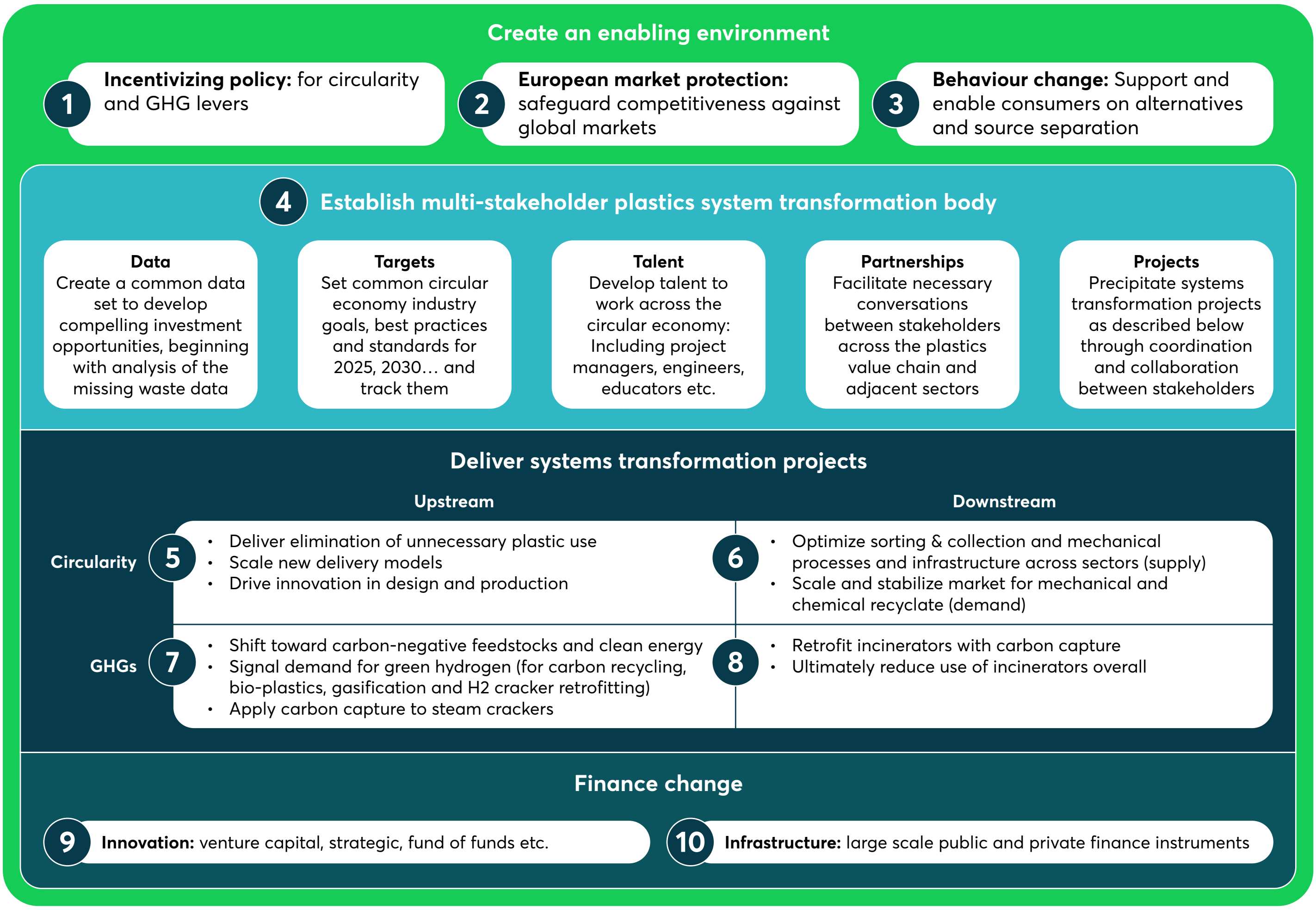
A. The system change capability framework

A systems change capability framework is required to deliver this transformation of the European plastics system. The framework in Figure 31 presents the 10 key capabilities needed to transition towards a circular, net zero emissions system, as laid out in this report.

The systems change capability framework consists of a mix of measures to set the right incentive mechanisms for achieving a circular plastics system:

Figure 31

Systems change capability framework



Create an enabling environment

1 **Incentivizing policy:** for circularity and GHG levers

2 **European market protection:** safeguard competitiveness against global markets

3 **Behaviour change:** Support and enable consumers on alternatives and source separation

4 **Establish multi-stakeholder plastics system transformation body**

Data	Targets	Talent	Partnerships	Projects
Create a common data set to develop compelling investment opportunities, beginning with analysis of the missing waste data	Set common circular economy industry goals, best practices and standards for 2025, 2030… and track them	Develop talent to work across the circular economy: Including project managers, engineers, educators etc.	Facilitate necessary conversations between stakeholders across the plastics value chain and adjacent sectors	Precipitate systems transformation projects as described below through coordination and collaboration between stakeholders

Deliver systems transformation projects

	Upstream	Downstream
Circularity	5 Deliver elimination of unnecessary plastic use Scale new delivery models Drive innovation in design and production	6 Optimize sorting & collection and mechanical processes and infrastructure across sectors (supply) Scale and stabilize market for mechanical and chemical recyclate (demand)
GHGs	7 Shift toward carbon-negative feedstocks and clean energy Signal demand for green hydrogen (for carbon recycling, bio-plastics, gasification and H2 cracker retrofitting) Apply carbon capture to steam crackers	8 Retrofit incinerators with carbon capture Ultimately reduce use of incinerators overall

Finance change

9 **Innovation:** venture capital, strategic, fund of funds etc.

10 **Infrastructure:** large scale public and private finance instruments

1. **Policy frameworks – create an enabling policy environment that accelerates the transition to the system change scenarios through incentive mechanisms.** ***Responsible actor: Governments***

   Policy is required to provide the necessary incentive structures that drive the system change envisioned in this study. While most technical solutions are available today, the incentives are not always in place to scale-up these changes fast enough and a lock-in of prevailing solutions can decrease the competitiveness of important new ones. Therefore, to implement non-competitive technical solutions and achieve the high level of European circularity and GHG reduction ambition, legislation needs to incentivize circular products and net zero emissions technologies. This includes mandatory targets for the use of recyclates to spur high quality mechanical and chemical recycling, new and improved harmonized collection and sorting infrastructure, the rapid scale-up of renewable energy, and support for a low-carbon hydrogen economy.

2. **Regulatory protection – maintain the competitiveness of the European plastics industry in the global market during its transition towards a circular, net zero emissions system.** ***Responsible actor: Governments***

   A more circular, low-emissions European plastics system must not be disadvantaged in global competition. Rules for plastic imports into the European market should reflect the carbon intensity of all plastic products, without being protectionist. The European plastics system has the opportunity to become a leader in circular, sustainable plastic products, which should become economically competitive in their own right within and outside the EU through the right policy mechanisms, following an adjustment period. For example, the carbon border adjustment mechanism (upstream from consumers) has supported the transition of other sectors. A similar economic mechanism, coupled with a progressive intra-EU policy regime that incentivizes circularity, could create the requisite enabling environment for system transition.

3. **Consumer behaviour change – enable the public to play their role in consuming and recycling in an efficient and system compatible manner through multiple channels.** ***Responsible actor: Consumer goods companies, retailers, consumers.***

   An important pillar for making circularity work is consumer behaviour. Consumer decisions and behaviour should be supported through awareness campaigns and appropriate product information that reflects the social benefits of sustainable alternatives, and is supported by price signals and incentives that make sustainable alternatives competitive. This enables the market to adjust to changing patterns of consumption and allows for proper handling at end-of-life. Consumers have an active role to play, whether through engagement with deposit return schemes and reuse models, contributing to proper waste disposal, or supporting the recycling process through sorting/washing waste prior to collection. Waste should be seen as a resource of value and the social cost of improper disposal needs to be communicated.

4. **A multistakeholder plastics system transformation body.** ***Responsible actor: Industry, government, civil society and investors.***

   Systems change requires collaboration and alignment across a wide variety of sectors and stakeholders – the establishment of a (non-regulatory) stakeholder body that represents the entire system can facilitate this alignment. For example, bodies like the Energy Transition Commission have proven to be effective coordinators and help set the agenda for transformation. For the plastics system, a similar body might enable the transition through five key functions: facilitating dialogue, setting and monitoring the system of transformation targets, collating essential opensource systems data to inform aligned decision making, cultivating talent within the system to deliver change, and incepting system-level projects critical to overcoming tragedy of the commons.[lxxxi] These functions could be carried out by a newly created entity or by expanding existing platforms.

[lxxxi] The tragedy of the commons is a problem in economics that occurs when individuals neglect the well-being of society in the pursuit of personal gain.

5. **Upstream circularity – implement upstream commitments and develop further lighthouse projects. *Responsible actor: Plastic producers, converters, consumer goods companies, innovators*.**

   Some actors in the plastics industry are already committed to making packaging recyclable, reusable, or compostable. As per policy developments, more stringent targets are to be expected, for instance with respect to reusable packaging and recycled content in the automotive and construction sectors. To leverage upstream circularity, best practice sharing and reporting could facilitate the more widespread and rapid implementation of such optimizations – from the elimination of unnecessary packaging, to scaling reuse models and improvements in design that reflect recycled content quotas and implementation of design for recycling guidelines. Cross-functional teams across multiple entities can create a pipeline of financed initiatives that are actively managed and delivered to help catalyze progress throughout the system.

6. **Downstream circularity – optimize downstream processes through collaboration with standard setters and end-of-life organizations. *Responsible actor: Collectors, sorters, recyclers, governments*.**

   From collection to material recovery, downstream circularity can be optimized if data and incentives are aligned along the process chain. A stable market for recyclates could increase the value of plastic waste and spur needed investments, which require that material specifications and quality are set. Data availability from source to end-of-life, through technical solutions for tracing material flows to enable improved waste sorting and high-quality recycling, requires participants across the value chain.

7. **Upstream GHG – scale renewable energy and low-carbon hydrogen for decarbonizing plastic production. *Responsible actor: Plastic producers*.**

   Collaboration with the energy sector will be critical for decarbonizing the upstream plastics value chain and achieving system change. Renewable energy must be sufficiently scaled and - in the mid-term - a green hydrogen economy secured as part of government priorities. So far, multiple strategies and commitments have been proposed and about 390 projects are currently being developed to provide hydrogen-based energy.[107] But these still fall short of the pathways laid out in the International Energy Agency roadmap that provides a key pillar to guide decarbonizing industry.[107,108] International cooperation is crucial to accelerate the uptake of hydrogen – just as it is for the expansion of renewable electricity.

8. **Downstream greenhouse gases – reduce incineration-related emissions by increasing circularity measures and retrofitting incinerators with CCS/CCU. *Responsible actor: Incinerators and consumer goods companies*.**

   Increasing circularity in the system through expanding the reduction of unnecessary plastic through elimination and reuse, as well as mechanical and chemical recycling, will decrease waste flows into incinerators and cut associated GHG emissions. While residual waste destined for incineration will remain, in the mid-term, incinerators could be retrofitted with carbon capture technology, once it is proven to be commercially and technically viable. This will require greater investment into this still nascent technology to increase rates of carbon capture from the plastics system.

9. **Innovation – finance innovation for the transition through venture capital, strategic investments, and a fund of funds. *Responsible actor: Investors, academic institutions and innovators*.**

   A huge innovation agenda is needed to help deliver this system transformation by translating promising technologies into scaled, commercially viable breakthrough solutions that can build on the efficacy of the levers identified in this report. A combination of suitable intermediaries, investment vehicles, and local talent across Europe will be required to deliver this innovation. Current volumes of capital in this space are insufficient by an order of magnitude, and significant de-risking of investment into this space by concessional capital and public funds would facilitate engagement by private pools of capital focused on the circular economy.[109]

10. **Infrastructure – provide funds for the required circular infrastructure build-up.** ***Responsible actor: Investors and governments.***

The systems overhaul requires significant infrastructure build up, as reverse logistics and increased recycling capacity are crucial to implementing reuse models and scaling up recycling. Where circularity solutions are proven to be beneficial from social and environmental perspectives, large scale debt-based finance instruments with appropriate de-risking are needed to enable the essential large pools of capital to enter the space with a suitable risk-return profile.

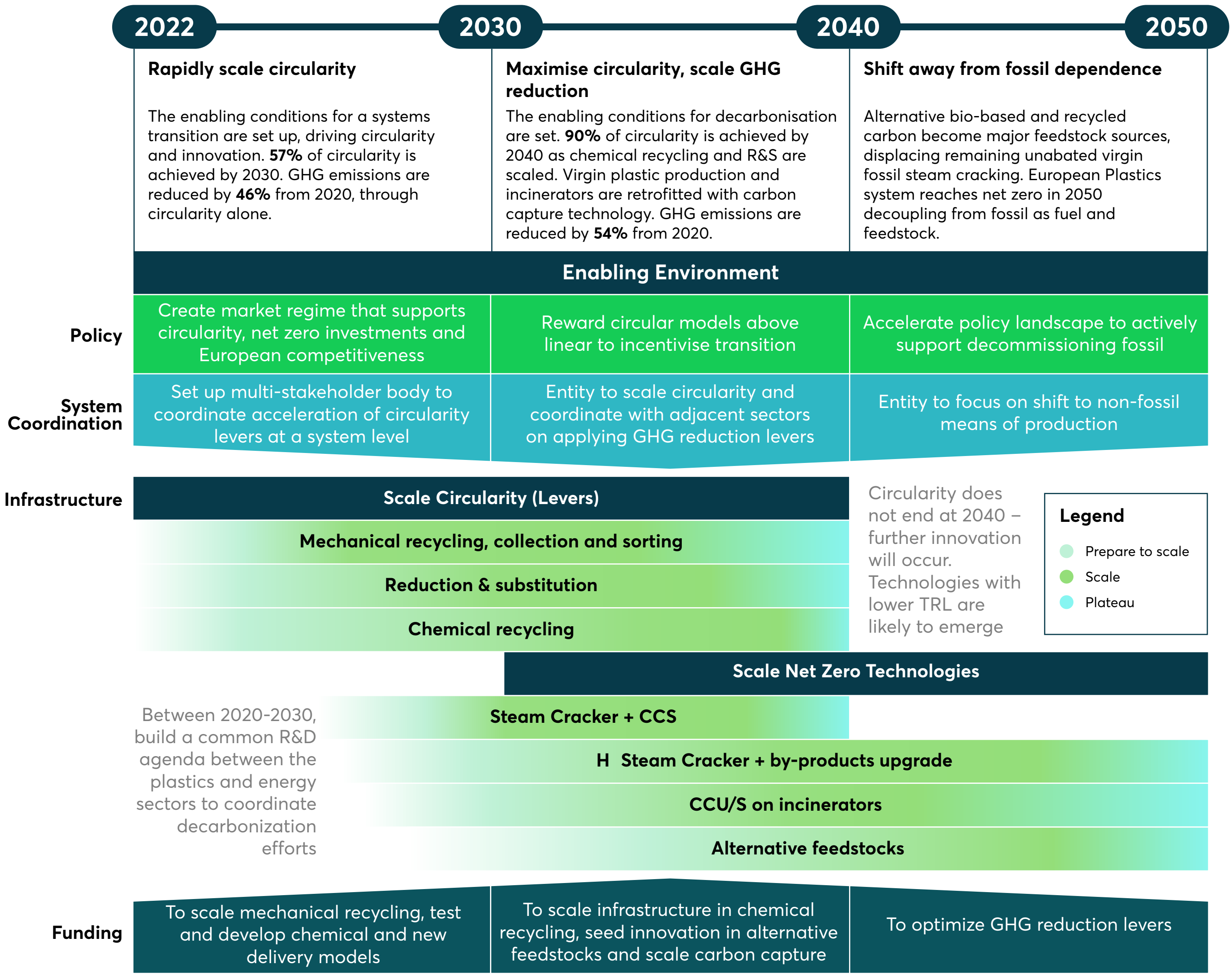
B. Putting it all together: Introducing a systems change action plan

The capabilities highlighted in the previous section need to be established over the next 10 years and then matured throughout the following two decades. Certain levers are already more mature than others, and therefore the phasing of the major levers has been structured over the Systems Change Action Plan time series, reflecting the study assumptions, to identify when most of the changes need to take place, as described in Figure 32.

The circularity levers should be applied immediately and continue over the next two decades, while the GHG reduction levers will begin to scale more aggressively in the 2030s before the plastics system begins switching to alternative feedstocks in the 2040s.

Figure 32

Systems change action plan



	2022	2030	2040
	Rapidly scale circularity The enabling conditions for a systems transition are set up, driving circularity and innovation. **57%** of circularity is achieved by 2030. GHG emissions are reduced by **46%** from 2020, through circularity alone.	**Maximise circularity, scale GHG reduction** The enabling conditions for decarbonisation are set. **90%** of circularity is achieved by 2040 as chemical recycling and R&S are scaled. Virgin plastic production and incinerators are retrofitted with carbon capture technology. GHG emissions are reduced by **54%** from 2020.	**Shift away from fossil dependence** Alternative bio-based and recycled carbon become major feedstock sources, displacing remaining unabated virgin fossil steam cracking. European Plastics system reaches net zero in 2050 decoupling from fossil as fuel and feedstock.
	Enabling Environment		
Policy	Create market regime that supports circularity, net zero investments and European competitiveness	Reward circular models above linear to incentivise transition	Accelerate policy landscape to actively support decommissioning fossil
System Coordination	Set up multi-stakeholder body to coordinate acceleration of circularity levers at a system level	Entity to scale circularity and coordinate with adjacent sectors on applying GHG reduction levers	Entity to focus on shift to non-fossil means of production

Infrastructure

Scale Circularity (Levers)

- **Mechanical recycling, collection and sorting**
- **Reduction & substitution**
- **Chemical recycling**

Circularity does not end at 2040 – further innovation will occur. Technologies with lower TRL are likely to emerge

Legend
- ● Prepare to scale
- ● Scale
- ● Plateau

Scale Net Zero Technologies

- **Steam Cracker + CCS**
- **H Steam Cracker + by-products upgrade**
- **CCU/S on incinerators**
- **Alternative feedstocks**

Between 2020-2030, build a common R&D agenda between the plastics and energy sectors to coordinate decarbonization efforts

	2022–2030	2030–2040	2040–2050
Funding	To scale mechanical recycling, test and develop chemical and new delivery models	To scale infrastructure in chemical recycling, seed innovation in alternative feedstocks and scale carbon capture	To optimize GHG reduction levers

Circularity is a pre-requisite; if circularity is not sufficiently scaled by the end of this decade, the efficacy of GHG reduction levers are unlikely to be sufficient to reach net zero emissions by 2050. Therefore, our current decade (the 2020s) is critical to making the vital decarbonization phase of the roadmap possible.

C. All stakeholder groups must play a role if progress is to be made

Despite progressive policies and a controlled flow of waste, recycling rates across Europe are still very low and there is a continued linear flow of plastic from virgin production to disposal. This intransigence stems from several barriers, including insufficient policy support, a lack of clarity around goals, paucity of available data, insufficient investment into new systems, misaligned incentives, and incomplete consumer awareness. However, significant changes over the last few years are beginning to build the necessary momentum to create the required conditions for systems change. Breaking away from the status quo and transforming the currently linear plastics system into a circular one calls for a pragmatic and collaborative system transformation approach along the entire value chain. Policymakers and industrial players alike need to help set the enabling conditions for action, while investors, civil society, and consumers all have a role to contribute towards this vital transformation.

The role of governments and the public sector

The changes required under the Circularity Scenario and the future-looking system change scenarios are enormous. They include massive shifts in the business models of companies creating plastic, ambitious capital investments across the value chain, large changes in procurement and delivery models for consumer goods companies, redesigning parts of the recycling and waste disposal industries, adaptations to investment criteria used by investors, and changes in the behaviour of consumers. Although these changes are all feasible, they are unlikely to materialize unless governments and regulators create the conditions and provide incentives for more sustainable business models and level the playing field in which virgin plastic feedstock currently has a cost advantage over recycled materials.

Tinkering around the edges and incrementalism will not suffice. All players have a role, but policies that create a clear and stable set of incentives, targets, and definitions are the lynchpin that will make the conditions required under these scenarios possible.

Given the ubiquity of plastic in all aspects of our economic system, and the complexity of addressing plastic waste, it is difficult to see how the voluntary actions of consumers and companies alone can achieve anything like the Circularity Scenario or the system change scenarios. Governments at all levels play a key role in creating the policy framework for social and environmental protection and legal accountability, as well as incentivizing innovation and investment. While "ReShaping Plastics" is not a comprehensive policy review, to enable and accelerate the transition towards the circular economy policymakers can:

- **Incentivize and facilitate solutions that reduce the total volume of material in the market:**
    - Stronger incentives for reuse and new delivery models across all EU countries
    - Incentives and support for deposit return schemes (DRS) to increase capture rate and quality
    - Public procurement of reusable and/or durable items
    - Funding of consumer education and training to encourage adoption of circular solutions and playing their role in waste sortation
    - Incentives for shared ownership models for vehicles and housing

- **Support companies that transition to recyclable plastic and/or plastic with recycled content:**
    - Incentivize and set guidelines for design for recycling to help make recycling easier and more affordable, and harmonize between different design for recycling guidelines
    - Incentives to increase recycled content and/or recyclability of products (not only packaging)
    - Set material specific recycling targets for each sector, including construction and automotive, as a way to support sectors with high plastic volumes but relatively low recycling rates
    - Use economic instruments to incentivize source separation and limit alternative disposal routes, i.e. landfilling and incineration

- **Improve the system overall:**
    - Harmonize collection for recycling systems and eco-modulated EPR criteria throughout the EU
    - Include all recycling technologies for the purpose of fulfilling recycling targets, including plastic-to-plastic chemical recycling and mass balance approach, under the necessary level playing field conditions
    - Enshrine design rules to enable better tracking of materials and units produced, used, and sold
    - Establish effective vehicle deregistration frameworks and levy taxes to incentivize the transfer of ELVs to authorised treatment facilities and minimize the number of vehicles with whereabouts unknown
    - Support blended finance mechanisms to lower capital costs and attract more investments
    - Harmonize and simplify recycling labelling and help educate consumers on what and how to recycle
    - Provide clear and unambiguous legal definitions for key terminology like “recyclable”, “recycled content”, “collection rates”, “recycling rates”, etc.
    - Introduce transparency and traceability to help consumers and companies make more educated choices
    - Ensure competitiveness of the European plastics system relative to regions that maintain a linear, carbon-emissions-intensive Plastics system

To be effective, policy solutions need to be appropriately enforced, and their outcomes amplified through better integration across government departments. While most policies aiming to support the recycling industry have so far focused on the supply (e.g., through EPR schemes), it is important to also support the demand side of the equation.

The role of resin producers and converters

Today, 92% of plastic demand is fulfilled by virgin plastic. Under the Circularity Scenario, this number could be 63% by 2030 and 41% by 2050 (and even lower under the System Change Scenarios), due to the significant reduction potential as well as an increase in recycled feedstock from both mechanical and chemical recycling. To help achieve these transformative changes, resin producers and converters can:

- **Embrace the new system by preparing for a plastic world which uses increasingly more alternative and/or recycled feedstocks in its production and less virgin input:**
    - Ensure any new capacity to produce plastic is accompanied with corresponding investments in sustainable feedstocks to decrease the share of virgin fossil feedstock over time
    - Enter new value pools, such as recycling, more aggressively
    - Work with chemical and mechanical recycling companies to incorporate recycled content into products
    - Be early movers and advance certification and regulation on recycled content, food safety, and recycling definitions

- **Radically innovate for more recyclable and recycled plastic:**
    - Design products for recycling, including reconsidering additives, pigments, adhesives, labels, and/or inks that make recycling more difficult or less economical
    - Develope new materials, barrier coatings, and recycled content tracking systems
    - Proactively produce products that meet recycling specifications without sacrificing product safety

The role of brand owners, fast-moving consumer goods companies and retailers

Brands are under mounting scrutiny to improve today’s Plastics system. There are huge opportunities for companies that can translate today’s costs into tomorrow’s new markets. In the face of rising consumer pressure and policy action, some businesses are already showing that they can shift to alternative feedstocks or new delivery models that require less physical material. Seizing these opportunities, many of which require new business models, may require a significant shift in mindsets and leadership. Brand owners, FMCGs and retailers can:

- **Lead the transition to new delivery models:**
    - Commit to reducing plastic demand (and physical material demand in general) through elimination, reuse, and new delivery models by embracing product redesign and supply chain innovations

  - Signal a shift in demand towards new delivery models, deposit return schemes (DRS), and refill models to disrupt and catalyse investments across the entire value chain
  - Enhance disclosure to enable better tracking of materials and units produced, used, and sold
  - Advance the global uptake of innovative models by leveraging global reach and R&D budgets to facilitate change across geographic archetypes and industry sectors
  - Work across supply chains on sustainable sourcing, effective end-of-life recycling, and composting of substitutes

- **Reduce and redesign for packaging-free products, maximum recycled content, and recyclability:**
  - Redesign products and packaging to minimize the volume of materials used for the required utility
  - Design out excess material and weight and eliminate avoidable packaging
  - Restrict small formats where possible and apply EU harmonized standards on design for recycling, including intuitive labelling providing clear sorting guidance
  - Set ambitious recycled content targets in packaging and other products

- **Facilitate consumer action and provide accessible, cost-effective alternatives:**
  - Facilitate new delivery models and integrate these in-store or through home deliveries for reuse
  - Incentivize shifts in consumer behaviour and consumption patterns by aligning marketing efforts towards more circular solutions, leveraging product placement, and improving labelling for recycling
  - Create packaging that is 100% reusable, recyclable or compostable
  - Leverage the transition to online shopping by utilizing reverse logistics, and—particularly for food retailers—investing in food preservation technology and removing packaging where shelf-life requirements decrease

The role of the automotive industry

The automotive sector is facing significant pressures to improve the circularity of vehicles and the materials they are composed of, including plastic. A greater commitment to circularity and investment in solutions today could translate into significant future savings and the creation of an optimized, resource-efficient automotive industry. Alongside this, as new models of vehicle ownership and the provision of mobility as a service increasingly gain traction among consumers, Original Equipment Manufacturers (OEM) are presented with fresh opportunities to embrace new business models and expand their presence along the supply chain. To seize these opportunities, OEMs can:

- **Support the transition towards new models of vehicle ownership:**
  - Work with downstream players to support and invest in the creation of carsharing services, as many OEMS are already beginning to do
  - Optimize vehicle design and increase standardization and modularity of components to support the transition towards more intensive vehicle use
  - Shift to new business models whereby mobility is sold as a service and OEMs retain ownership of the physical vehicle
  - Advance the global uptake of innovative models by leveraging global reach and R&D budgets to facilitate change across geographic regions and industry sectors

- **Facilitate the recovery of end-of-life vehicles and the materials they are composed of:**
  - Leverage the rise of digitization and invest in tamper-proof technological solutions to improve traceability of a vehicle over its lifetime and mitigate the issue of vehicles with unknown whereabouts
  - Form supply chain partnerships with recycling facilities to drive improvements in the quality of recyclates from mechanical recycling, secure a supply of mechanical recyclates, and thus increase the share of closed loop mechanically recycled content
  - Invest in technological solutions, such as post shredder technologies and chemical recycling, and encourage greater adoption of these solutions across the EU
  - Shift towards new component design standards which facilitate recovery from post shredder technologies

The role of the construction industry

According to current trends, plastic consumption and waste generation in the construction sector is projected to increase significantly over the next three decades. Players in the industry have significant opportunity to divert away from these trends, and in so doing to respond to shifting consumer demand, by rethinking the way floorspace is used, transitioning towards more resource-efficient practices, and designing and constructing buildings with their end-of-life in mind. Innovative industry players can:

- **Shift away from conventional design and construction:**
  - Transition towards design for deconstruction practices including a greater degree of modularity, standardization, and the use of dry connections
  - Opting for higher quality components with longer lifetimes
  - Encouraging and supporting selective demolition practices and transitioning towards the refurbishment and renovation of old buildings instead of constructing new buildings

- **Design buildings to optimize the use of space:**
  - Support the shift towards the more intensive use of buildings by designing adaptable floor plans and facilitating trends such as peer-to-peer lodging and more compact living

- **Facilitate the recovery of materials at demolition:**
  - Adopt and support the industry-wide adoption of digital material/building passports to allow for fast and efficient dismantling and on-site sorting
  - Encourage the digitization of these passports to improve our ability to keep track of the material composition of buildings over their long lifespans during which replacements of components and renovations are likely to take place

The role of sorters and recyclers

Under the Circularity Scenario, demand for recycled content is expected to grow by 2.7 times (see Chapter 2, System Intervention #3), creating an immense business opportunity for the entire waste management industry. With space for landfills increasingly limited, rising opposition against incineration, and growing demand for circular systems, the recycling industry is optimally positioned to plug the gap. With increases in capacity, recycling has the potential to double the volume of plastic waste it handles compared with today. To maximize this opportunity, the recycling industry can:

- **Facilitate source separation in collection systems:**
  - Use incentives and improved standards aimed at decreasing contamination and maximizing recycling yields
  - Collaborate with producers/retailers to create standardized labelling in line with local recycling capabilities to maximize consumer participation

- **Scale up and expand recycling systems:**
  - Expand separate organic waste treatment capacity and ensure that it accepts compostable packaging
  - Expand infrastructure capacity to enable the recycling of waste locally or regionally

- **Improve efficiencies in the new waste system through technological improvements:**
  - Improve sorting and separation technologies that reduce losses and create a higher-quality, safer output
  - Develop and scale up chemical recycling technologies to meet the growing demand for recycled content in food-grade applications (often jointly with plastic producers)
  - Deploy targeted pre-treatment to increase purity, remove impediments to recycling (e.g., labels and inks) and generally achieve higher output quality of recycling processes
  - Advance certification and regulation of recycled content

The role of investors and financial institutions

Investors should seek out opportunities in the changing plastics economy and address any potential risk exposure related to assets in the "old" plastics economy. Otherwise, if policies, technologies, brand owners, and consumer behaviour continue to shift rapidly towards new delivery models and new materials, investors run the risk of being exposed to overvalued or stranded assets.

This report shows that while the total capital investment requirements from 2021 to 2050 under the Circularity Scenario and the System Change Scenarios is comparable to those under the Current Action Scenarios, the portfolio of investments is completely different. Specifically, investments shift away from mature technologies towards new, less-mature investments in new delivery models, chemical recycling plants, and others. It is important to acknowledge that many of the new investments required under the system change scenarios—mainly alternative materials and new delivery models—have market, technology, and regulatory risks associated with them, although new policies can help de-risk the investments needed to achieve the Circularity Scenario.

Attracting finance into recycling and new delivery models can be challenging, partly because of the paucity of investable projects and perceived poor risk/return profiles. To overcome this challenge, investors can:

- **Focus on developing a robust investment pipeline**
  Arguably there is sufficient capital to fund proven technologies and business models in Europe. The challenge is to find investors prepared to nurture and develop projects from the early ideas stage. The common refrain is that there is a "lack of pipeline" and that the new business ventures are premature and not ready for commercial finance. But the pipeline will not appear overnight. Many promising start-ups get stuck at the *entrance* to the "valley of death," the no man's land between developing an idea and actually getting it on the market. Seed funding in the form of grants, technical assistance, introduction to industry players, and guidance on which markets/solutions to prioritize can help scale innovation.
- **Develop specific investment vehicles**
  The type of investment vehicle will depend on the type of assets targeted (e.g., early stage technology with venture capital, or waste management infrastructure with institutional or development capital). The amount of capital required will depend on the strategy. Vehicles can combine blended/concessional capital (from development agencies, donors, climate funds, or philanthropy) to mitigate investor risk or to develop pipelines through project preparation facilities and technical assistance grants.
- **Analyze the commercial feasibility of various business models**
  A thorough review of credit profile, new technologies, and commercial market potential can help demonstrate the attractiveness of the solutions proposed under the Circularity Scenario, compared with traditional products and infrastructure.

Achieving the investments required under the ambitious scenarios presented in this report will require all types of investments. This includes public investments, such as government funding, donor capital, and development banks, as well as private investments including philanthropy, impact investments/blended funds, commercial finance, and institutional investors. Different types of investors and sources of funding are required due to the different asset types requiring investment.

The role of civil society

Civil society can play several important roles, including: acting as watchdog to hold governments, business, and institutions to account; conducting advocacy, setting agendas, raising awareness, and lobbying for stronger regulation; and coordinating research. Specifically, to support the transformation of the plastics system civil society can:

- **Research and monitor**
  Academic scientists are essential for building the evidence base for policy and corporate action.
- **Incubate and accelerate new solutions**
  Civil society campaigns have helped prompt retailers and brands to adopt new reduction and recycling targets and spurred trials of new delivery models. Scaling action on reduction, substitution where appropriate, and design for recycling will be essential to implementing the required interventions. Academia and civil society can act as expert and technical partners, conducting the necessary research and advocacy to support corporations and entrepreneurs in rolling out new solutions.
- **Run communication campaigns**
  Civil society, academia, and media have led the way in making plastic pollution a high-profile issue for policymakers and businesses alike. Sustained

communication campaigns can help build even stronger, more informed consumer engagement on a practical level and support the shifts necessary to transition to the Circularity Scenario and beyond.

- **Champion grassroots community action**
  Flagship zero-waste communities and cities have not only directly reduced the production of plastic waste and leakage into the environment, they also serve as models for other regions. They can also help mobilize assistance and resources for communities impacted by plastic pollution. Inspirational early adopters provide a platform to share and disseminate best practices and will be vital, particularly in rural areas, in helping support the rolling out of community waste reduction and management schemes.

The role of consumers

Consumers today have a fairly limited set of truly circular choices, hence the majority of the responsibility to drive change lies with other stakeholder groups. However, the changes modelled under the Circularity Scenario will require changes to consumer habits and behaviour. The scenario shift towards more durable items, more reuse, and more separate collection of recyclables requires consumer acceptance and participation. Facilitating and enabling such consumer behaviour change, in turn, needs coordinated government policy, education, and industry provision of accessible new products and services – as described above.

Consumer demand has played and should continue to play a catalytic role in accelerating this change. For example, consumers expressing preferences for more sustainable products or services help build the business case for scaling plastic reductions and increasing recycling, and can catalyse businesses to go above and beyond their legal and regulatory responsibilities in addressing the plastic waste challenge. There are already strong signs of strong consumer demand for products with less packaging, more recycled content, and sustainably branded products.

Conclusion

The European plastics system faces the dual, deeply intertwined environmental challenge of cutting greenhouse gas emissions and reducing waste disposal. The solutions require vast coordination, increased resources, transformative innovation, and close collaboration among governments and industry, as well as the ongoing engagement and vigilance of consumers and communities.

“ReShaping Plastics” outlines a feasible, practical, and inexpensive way to significantly reduce the amount of waste and GHG emissions generated by the plastics system, while decoupling plastic from fossil-based fuels and feedstocks, to align it with Europe’s climate change and circular economy commitments and the growing concerns of its citizens. The report demonstrates that it is not a lack of technical solutions that is preventing us from transforming the currently linear, inefficient plastics system, but rather inadequate regulatory frameworks, business models, and funding mechanisms. The findings show that, although solutions exist, the incentives and capacity are not always in place to scale them up fast enough.

But the publication of this report is itself a testament to the rising level of ambition across all stakeholders in the European plastics system, who have worked closely to make this study a reality.

Many of the findings will require the less easy path to be taken in the near term to retarget the system onto a long-term sustainable trajectory. The existence of this publication signals a willingness for cross-sector stakeholder collaboration to take place and it aims to provide the data driven, scientific platform around which the key strategic conversations can take place. To help get this process started, the report identifies priority areas for policymakers, industry leaders, and civil society to focus on to make the biggest possible impact.

The scenarios contained herein aim to illuminate potential pathways leading to a resource efficient, low-carbon emitting plastics system in Europe, and highlight that continued innovation, investment and flexibility will be required to adapt successfully to the changing economic, political, social, and environmental landscape.

While the time series of this model runs for three decades, the pathways described will only be possible if significant changes are made well before the end of the 2020s. This is the decisive decade to achieve waste and GHG emission reductions in the European plastics system. The faster and more ambitious the action taken, the more likely the system can move from a pathway of risk mitigation to one of sustainable growth. The next three to five years are critical to achieving this goal.

Glossary

Additives
Plastic is usually made from polymer mixed with a complex blend of materials known as additives. These additives, which include flame retardants, plasticisers, pigments, fillers, and stabilisers, are used to improve the different properties of the plastic or to reduce its cost.[110]

Automotive shredder residue (ASR)
Automotive shredder residue is an automotive waste stream that results from shredding automobiles. It includes a mixture of ferrous and non-ferrous metals and plastics.

Baseline
The baseline (scenario) serves as a primary point of comparison for an analysis. In this study, the outputs of the Current Actions scenario are referred to as the baseline.

Bio-based (materials)
A material wholly or partly derived from biomass.

Biodegradable (materials)
A material that can, with the help of microorganisms, break down into natural components (eg. water, carbon dioxide, biomass) under certain conditions.

Capex (Capital expenditures)
Funds used by an organization to acquire or upgrade assets such as property, buildings, technology or equipment.

Carbon capture and storage (CCS)
Use of carbon capture technology to extract CO_2 from potential system emissions streams, followed by transport and storage of CO_2 long term in underground saline aquifers.

Carbon Capture and Usage (CCU)
Use of carbon capture technology to extract CO_2 from potential system emissions streams then use it, in this case through the Methanol-to-Olefins process to make new polymers.

Hydrogen (colours)

- **Green:** hydrogen manufactured using renewable energy exclusively by electrolysing water
- **Blue:** hydrogen manufactured through steam methane reforming to split natural gas then sequester the CO_2 in saline aquifers through CCS
- **Grey:** hydrogen manufactured through steam methane reforming without any carbon capture

Carbon recycling
Capturing CO_2 at end-of-life incineration that would otherwise be emitted into the atmosphere then using it in a closed loop through the Methanol-to-Olefins (MTO) process to make new polymer.

Chemical recycling
While the term is used in different ways, in this report, chemical recycling refers to processes that break down polymers into individual monomers or other hydrocarbon products that can then serve as building blocks or feedstock to produce polymers again. Four chemical recycling technologies are considered in this study:

- **Dissolution**: Dissolution describes a process where plastic waste is dissolved in a solvent-based purification process to separate polymers from additives and contaminants. Note that dissolution is often referred to as "physical recycling" rather than chemical recycling since the chemical constitution of the polymer remains intact throughout the process.
- **Depolymerization:** Depolymerization is a chemical process that requires different combinations of chemistry and heat to break up the polymer into monomers or shorter fragments.
- **Pyrolysis**: Pyrolysis is the thermal process of breaking up plastic molecules under the absence of oxygen. It converts polymers into a range of simpler hydrocarbon components in the form of pyrolysis oil.
- **Gasification**: Gasification is a process where mixed after-use materials are heated in the presence of limited oxygen to produce syngas that can be converted into polymers again.

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

Collection separated at source
The collection of individual components of solid waste (such as plastic) separated into different collection containers by the user, in order to recover the material or to facilitate its collection and disposal. Separate collection of plastic waste is a precondition for high-quality recycling as contamination with other materials is limited.

Contamination
Contamination occurs in recycling when non-target materials are placed in recycling waste streams. These non-target materials include organic waste, other chemicals, or polymer mixtures. Contamination alters the physico-chemical properties of the secondary raw material.

Closed loop recycling
Closed loop recycling describes the recycling process in which the output (recyclate) is included in a product of the same sub-system (i.e. packaging) and which in turn can be recycled again.

Compostable (materials)
Materials, including compostable plastic and non-plastic materials, that are approved to meet local compostability standards (for example, industrial composting standard EN 13432 where industrial-equivalent composting is available).

Design for Recycling (D4R)
The process by which companies design their product and its packaging to be recyclable.

Downstream solutions
Solutions applied post-consumer. This includes collection, sorting, mechanical recycling, chemical recycling and disposal.

Disposal
The end-of-life deposition of the waste materials. Disposal routes are defined in this study as incineration with energy recovery, landfilling, and fuels fraction from chemical recycling.

Elimination
Practices that reduce unnecessary plastic packaging directly at source or through innovative product design and solutions.

End-of-life (EOL)
End-of-life is a generalised term to describe the part of the lifecycle proceeding the use-phase.

Europe / EU 27+1
This geographical focus of this study is Europe, which is represented by analysing the 27 countries currently being part of the European Union (EU27) plus the United Kingdom (+1).

Extended Producer Responsibility (EPR)
Schemes that enable producers to contribute to the end-of-life costs of products they place on the market.

Feedstock
Any bulk raw material – virgin or secondary – that is the principal input for an industrial production process[110] Plastic is currently to a large extent produced from petrochemical feedstock, i.e. from fossil fuels.

Formal waste sector
Individuals or enterprises who are involved in public or private sector recycling and waste management activities which are sponsored, financed, recognized, supported, organized or acknowledged by the formal solid waste authorities.

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

Leakage
Materials that do not follow an intended pathway and 'escape' or are otherwise lost to the system. Litter is an example of system leakage[110].

Lever
A specific solution modelled within a system intervention (e.g. within the Reduce intervention, three levers are pulled: eliminate, reuse: consumer, and reuse: new delivery model). → See also system change interventions and system change levers.

Like-to-like recycling
Like-to-like recycling describes the processes where recyclates are used for the same application again (e.g. bottles-to-bottles recycling).

Managed landfill
A place where collected waste has been deposited in a central location and where the waste is controlled through daily, intermediate and final cover, thus preventing the top layer from escaping into the natural environment through wind and surface water.

Mechanical recycling
Operations that recover after-use plastics via mechanical processes (grinding, washing, separating, drying, re-granulating, compounding), without significantly changing the chemical structure of the material.[110]

Mismanaged waste
Collected waste that has been released or deposited in a place from where it can move into the natural environment (intentionally or otherwise). This includes dumpsites and landfills that are not managed by applying daily cover to prevent waste interacting with the air and surface water. Uncollected waste is categorised as unmanaged.

Mixed waste streams
Waste streams are flows of specific waste, from its source through to recovery, recycling or disposal. In mixed waste streams, different materials are mixed which decreases the recyclability of this waste stream due to contamination and difficulties in separating those materials.

Municipal Solid Waste (MSW)
According to the EU Landfill Directive, municipal solid waste is defined as "waste from households, as well as other waste which, because of its nature or composition, is similar to waste from households". In the scope of this study, it includes all residential and commercial plastic that is collected by or on behalf of municipal authorities and thus excludes but excludes industrial packaging waste.

New delivery models
Services and businesses providing utility previously furnished by short-lived plastic in new ways, with reduced material demand.

Open-loop recycling
Process by which polymers are kept intact, but the recyclate leaves the sub-system to be converted into another type of product (e.g. park benches, fibres) and is unlikely to be recycled again due to the degraded quality and/or material properties.

Opex (Operating expenses)
Expenses incurred during the course of regular business, such as general and administrative costs, sales and marketing, or research and development.

Sub-system and plastic categories
Three plastic material categories which we have modelled as flowing separately through the system map: rigid monomaterial plastics, flexible monomaterial plastics, or multilayer/ multimaterial plastics.

- **Packaging (sub-system)**
    - **Beverage bottles:** A food-grade bottle used for water, beverages, and other drinks applications.
    - **Rigid monomaterial plastics:** An item made from a single plastic polymer that holds its shape such as a non-food bottle or tub.
    - **Flexible monomaterial plastics:** An item made from a single plastic polymer, that is thin such as plastic wraps and bags.
    - **Multilayer plastics:** An item, usually packaging, made of multiple plastic polymers that cannot be easily and mechanically separated.
    - **Multimaterials:** An item made of plastic and non-plastic materials (such as thin metal foils or cardboard layers), that cannot be easily and mechanically separated.

- **Household goods (sub-system)**
    - **Hygiene and sanitary products:** Plastic portion in hygiene and sanitary products such as diapers, wet-wipes, and toothbrushes.
    - **Multimaterial:** Household goods consisting of multimaterial plastic compositions such as toys and furniture.
    - **Rigid mono-material:** Household goods that consist of rigid mono-material (PP, ABS, PC).

- **Automotive (sub-system)**
    - **Bumpers and fuel tanks:** Large automotive parts such as bumpers and fuel tanks consisting of PP or PE polymers.
    - **Other Polyolefins:** Other PP/PE components such as cable insulation and interior trims.
    - **Other polymers:** Other plastic components based on other polymers than polyolefins (i.e. ABS, SAN, PUR and >30 others). Use cases include car body parts, headlight lenses, instrument panel, seats etc.

- **Construction (sub-system)**
  - **PVC:** Items made of polyvinyl chloride such as flooring, doors and window profiles.
  - **Polyolefins:** Items made from thermoplastics, i.e. a variety of products such as films and sheets that are based on polyolefins (e.g. PP or PE)
  - **Styrenics:** Rigid and foamed PS panels used almost exclusively for insulation in walls and roofs.
  - **Other plastics:** Other plastics such as PUR, PC, PMMA, PA and others used in smaller quantities and to a much lesser extent.

Plastic
A synthetic material made from a wide range of organic polymers

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

Plastic to fuel (P2F)
Process by which the output material of chemical conversion plants is refined into alternative fuels such as diesel.

Plastic to plastic (P2P)
Several chemical conversion technologies are being developed that can produce petrochemical feedstock that can be reintroduced into the petrochemical process to produce virgin-like plastic – a route which we define as 'Plastic to Plastic' (P2P).

Plastic utility
The valuable services (including protection, food preservation, etc.) that are provided by plastic under a business as usual scenario. In alternative scenarios, services of equivalent value could be provided in other ways with less plastic. In other words, all scenarios analyzed in this study have the same plastic utility (e.g., consumer demand for services), but the way which this utility is delivered can vary massively – in some scenarios it is done via virgin plastic, in others with recycled plastic, and in others with new delivery models.

Post-consumer waste
Post-consumer waste is according to ISO 14021 standard waste material generated by households or by commercial, industrial and institutional facilities in their role as end-users of the product (e.g. packaging) which can no longer be used for its intended purpose. It is to be distinguished from pre-consumer waste, which typically occurs in industrial production processes and is reintroduced as input material also known as scrap.

Product application
15 categories of plastic waste of similar functions and formats (e.g. 'water bottles', 'other food-grade bottles', etc.), which we sub-divided the waste stream into for certain calculations.

Recyclable
In order for something to be deemed recyclable, the system must be in place for it to be collected, sorted, reprocessed and manufactured back into a new product or packaging– at scale and economically[111]. Recyclable is used here as a short-hand for 'mechanically recyclable'[110].

Recycling rate
In this study, the (effective) recycling rate refers to the quotient of the volume of output stream from a recycling plant (i.e. recyclate) and the total mass of plastic waste generated.

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

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

Scenarios
For the purpose of our modelling, the study defines six scenarios:

- **Do Nothing Scenario**
  Based on plastic volumes identified in the academic and non-academic literature, the "Do Nothing" Scenario extrapolates values for 2020 to 2050 that does neither incorporate policy and industry commitments nor any circularity and GHG reduction levers.
- **Current Actions Scenario**
  This scenario incorporates quantifiable policy and industry commitments and serves as the reference baseline scenario for subsequent analyses.
- **Single Lever Scenarios** (Reduction & Substitution Scenario and Recycling Scenario) To assess the effects of applying system interventions singu-

larly, the Single Lever Scenarios only include the respective system intervention levers for reduction & substitution and recycling.

- **Circularity Scenario**
  The Circularity Scenario incorporates all circularity system interventions and levers to assess pathways of the modelled sub-systems towards increased circularity.
- **Retrofit System Change Scenario (RSCS)**
  The RSCS builds on the circularity scenario and incorporates GHG reduction levers to existing system infrastructure. It aims to retrofit the existing system infrastructure and operating model with low-emissions fuel and carbon capture.
- **Net Zero System Change Scenario (NZSCS)**
  The NZSCS adds to the RSCS approach by displacing some fossil feedstock with alternative sources of carbon and employs direct electrification in production to elaborate pathways to net zero.
- For detailed assumptions on each scenario, see the Technical Appendix.

Sorting
Physical processing techniques and processes to separate materials in waste streams. Sorting is typically performed in Material Recovery Facilities (MRFs) or specific Plastic Recovery Facilities (PRFs). Sorting can be performed automatically with sorting technologies or manually.

Substitution
Replacement of plastic by sustainable and circular materials. In this study, the substitution potential of paper and coated paper (plastic coating 5% of weight) as well as compostable materials capable of disintegrating into natural elements are considered and analysed.

System cost
Total system cost comprise cumulative capex and opex at each stage of the value chain for the respective scenarios and periods, including production and waste management of both plastics and substitute materials. System costs are funded through both capital investment and from P&L.

System interventions and system intervention levers
Five high-level system interventions and 16 associated system intervention levers have been defined and modelled in the overall analysis. The system interventions and levers are applied in different scenarios and drive the outcome of the model of the respective plastic sub-system.

1. **Reduction**
   - Reduce plastic through elimination
   - Reduce plastic through reuse or new delivery models (NDMs)
   - Reduce plastic through sharing models for vehicles

2. **Substitution**
   - Substitute plastic with suitable alternative materials; this needs to be done on a case-by-case basis and is application and geography dependant

3. **Mechanical recycling**
   - Design for mechanical recycling
   - Expand collection for recycling and sorting
   - Increase mechanical recycling capacity

4. **Chemical recycling**
   - Scale up chemical recycling – while the model differentiates between 4 types of chemical recycling, all types have been grouped together into a single lever.

5. **GHG reduction**
   - Apply carbon capture and storage to steam crackers
   - Use green hydrogen to fuel steam crackers and upgrade offgas
   - Apply GHG reduction levers to pyrolysis
   - Apply carbon capture and storage to incinerators
   - Use captured CO_2 and H2 as feedstock
   - Use sustainable biomass as a feedstock
   - Use electricity as a heat source for steam crackers
   - Apply carbon capture and usage to incinerators

Note: decarbonizing the electric grid in Europe does not appear as a lever because it is assumed that it happens in all scenarios (including Current Actions) given this transition is already happening and is expected to continue.

System map
A visual illustration of the main flows and stocks of the global Plastics system. System maps can be found in the technical appendix. For the purpose of this project, we have collected, calculated or estimated values for each of the arrows and boxes in each of the system maps on a European level per plastic category.

Upstream solutions
Solutions applied pre-consumer. This includes design for recycling (D4R); Reduce levers such as eliminate, reuse (consumer), reuse (new delivery model); and Substitute levers such as paper, coated paper and compostable plastic.

Virgin plastic
Virgin plastic is the polymer resin produced directly from the petrochemical feedstock.

Waste Hierarchy
Waste management hierarchy as defined by the EU in the Waste Framework Directive, outlining the preferred waste reduction options beginning with prevention, then preparing for reuse, recycling, recovery and finally disposal.

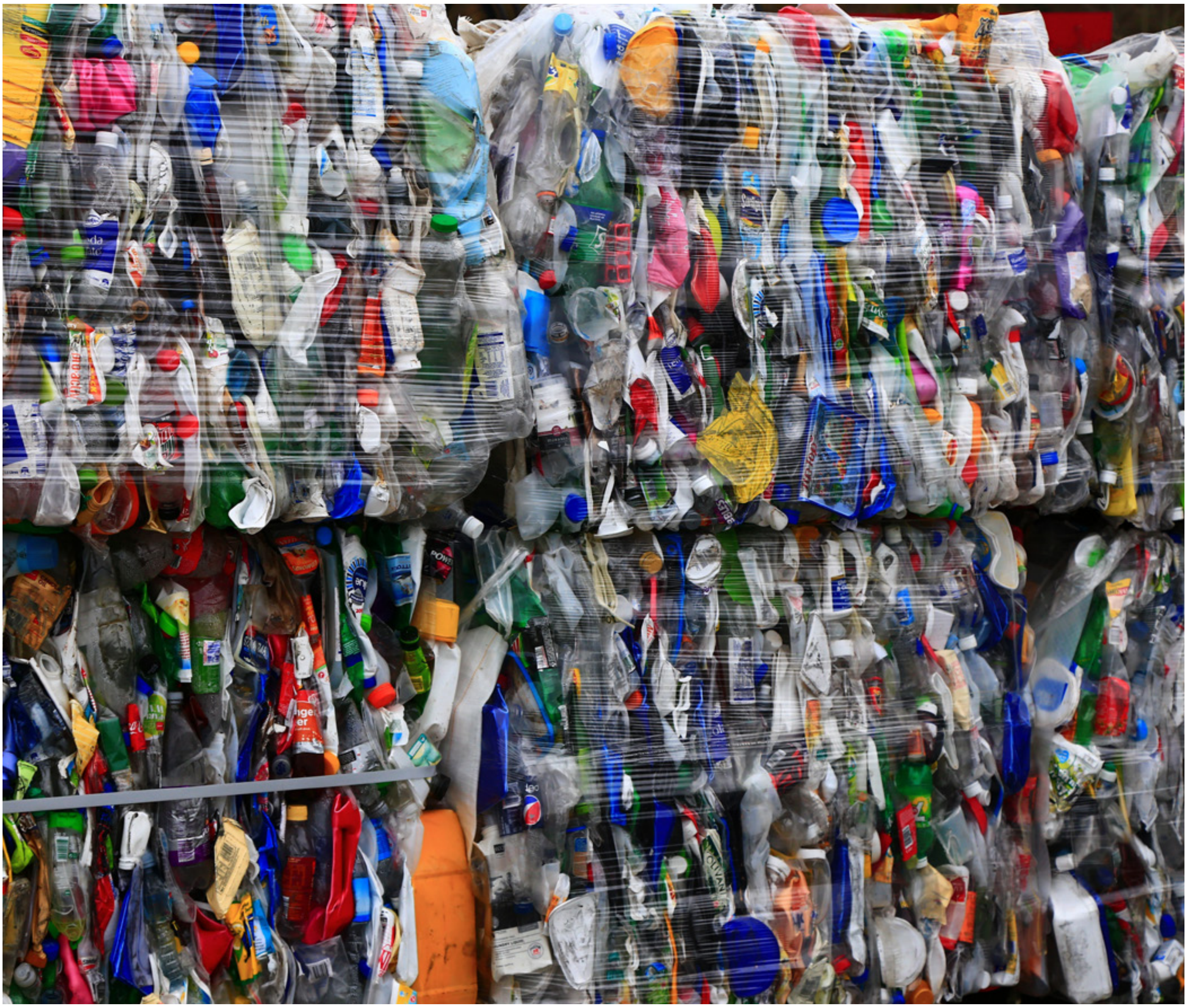


Photo by Nareeta Martin on Unsplash.

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“ReShaping Plastics: Pathways to a Circular, Climate Neutral Plastics System in Europe” presents an evidence-based roadmap for a paradigm shift in the European Plastics system. Following the approach developed in *Breaking the Plastic Wave*, it quantifies the economic, environmental, and social indicators for six possible scenarios to achieve plastic circularity while significantly reducing greenhouse gas emissions in Europe.

A Steering Committee comprising 13 senior leaders from public policy, civil society and industry provided strategic guidance for this work, while a panel of 10 experts ensured the scientific accuracy of the study.

The aim of this report is to help guide policymakers, industry executives, investors, and civil society leaders as they seek to understand the trade-offs and navigate through a highly contested and complex terrain towards a circular Europe plastics system.

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