Breaking the Plastic Wave

A COMPREHENSIVE ASSESSMENT OF PATHWAYS TOWARDS STOPPING OCEAN PLASTIC POLLUTION

THE PEW CHARITABLE TRUSTS

SYSTEMIQ

Thought Partners

UNIVERSITY OF OXFORD

UNIVERSITY OF LEEDS

ELLEN MACARTHUR FOUNDATION

Common Seas

FULL REPORT

About The Pew Charitable Trusts

The Pew Charitable Trusts is driven by the power of knowledge to solve today's most challenging problems. Pew applies a rigorous, analytical approach to improve public policy, inform the public, and invigorate civic life. As the United States and the world have evolved, we have remained dedicated to our founders' emphasis on innovation. Today, Pew is a global research and public policy organization, still operated as an independent, nonpartisan, nonprofit organization dedicated to serving the public.

Informed by the founders' interest in research, practical knowledge, and public service, our portfolio includes public opinion research; arts and culture; civic initiatives; and environmental, health, state, and consumer policy initiatives.

Our goal is to make a difference for the public. That means working on a few key issues, with an emphasis on projects that can produce consequential outcomes, foster new ideas, attract partners, avoid partisanship or wishful thinking, and achieve measurable results that serve the public interest.

Learn more at https://www.pewtrusts.org/en

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PreventingOceanPlastics@pewtrusts.org

About SYSTEMIQ

SYSTEMIQ Ltd. is a certified B Corp with offices in London, Munich, and Jakarta. The company was founded in 2016 to drive the achievements of the Paris Agreement and the United Nations Sustainable Development Goals by transforming markets and business models in three key economic systems: land use, materials, and energy. Since 2016, SYSTEMIQ has been involved in several system change initiatives related to plastics and packaging, including the New Plastics Economy initiative (Ellen MacArthur Foundation) and Project STOP (a city partnership programme focused on eliminating plastic pollution in Indonesia), among others. At the heart of our work is the core belief that only a smart combination of policy, technology, funding, and consumer engagement can address system-level challenges. The global plastics challenge is no different.

Learn more at https://www.systemiq.earth/

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Preface

In recent years, an increasing number of studies and reports have advanced the global understanding of the challenge posed by ocean plastic pollution. But most leaders across industry, government, and civil society have noted a critical gap: an evidence-based roadmap to describe the pathways available and to foster convergent action.

As a step towards building that roadmap, The Pew Charitable Trusts partnered with SYSTEMIQ to build on previous research and create this first-of-its-kind model of the global plastics system, with results suggesting that there is an evidence-based, comprehensive, integrated, and economically attractive pathway to greatly reduce plastic pollution entering our ocean. The findings of our analysis were published in the peer-reviewed journal, *Science* on 23 July 2020.

The speed at which ocean plastic pollution has climbed up the public agenda has been surprising. Yet, even as the world starts to comprehend the enormity of the challenge, major actors disagree on the solution. In preparing "Breaking the Plastic Wave: A Comprehensive Assessment of Pathways Towards Stopping Ocean Plastic Pollution," we consulted an extensive group of stakeholders from academia, industry, government, and nongovernmental organizations, who without exception shared the concern and demonstrated willingness to act—but often offered contradictory solutions.

We then developed perhaps the most comprehensive plastic system modelling tool to create a global analysis that evaluates various strategies to reduce ocean plastic flows and quantifies the associated economic, environmental, and social implications of each pathway. The ultimate aim of this work is to help guide policymakers, industry executives, investors, and civil society leaders through highly contested, often data-poor, and complex terrain. Our analysis includes several key findings that could help define changes to the global system that are necessary to stop plastic pollution from flowing into the ocean.

The research supporting this report involved 17 experts from across the spectrum of people looking at the plastic pollution problem and with broad geographical representation, and was undertaken by our two independent organizations in collaboration with four partner institutions—the University of Oxford, University of Leeds, Ellen MacArthur Foundation, and Common Seas.

In addition, the project team drew upon major publications, analyses, and reports, and consulted more than 100 independent experts, to develop and populate the model. These experts represented the plastic supply chain, academia, and civil society, and neither they nor their institutions necessarily endorse the report's findings.

"Breaking the Plastic Wave" 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 by reusing, redesigning, and recycling. This concept has garnered unprecedented support across the global plastics system.

By highlighting the systemic link between better plastic design, reuse, improved recycling economics, and increased collection incentives, these reports provided a central theme for the challenge addressed in "Breaking the Plastic Wave": how to apply the concept of a circular economy—along with increased reduction and substitution of plastics, and better waste management—in a way that urgently addresses this serious environmental challenge.

The model is already being applied at the national level in Indonesia under the public-private collaboration Global Plastic Action Partnership. Our hope is that the results of "Breaking the Plastic Wave" can serve as a map for policy leaders, decision-makers, and businesses in search of solutions to stem the flow of plastic into the ocean. This model can also be updated by stakeholders on an ongoing basis to inform solutions to the plastics pollution problem.

The problem of ocean plastic pollution was created in a lifetime, and we have reason to believe that it can be solved within a generation, or sooner. But such a solution requires political leaders, policymakers, business executives, and investors to shift from incremental to systemic change.

Among our findings, one is particularly stark: On the current trajectory, which we call Business-as-Usual, annual flows of plastic into the ocean could nearly triple by 2040. What's more, even if all current major industry and government commitments are met, the world would see a reduction in annual rates of plastic pollution flowing into the ocean of only 7 per cent from the Business-as-Usual scenario.

Yet we also show that if the world were to apply and robustly invest in all the technologies, management practices, and policy approaches currently available—including reduction, recycling, and plastic substitution—in 20 years there would be about an 80 per cent reduction from the current trajectory in the flow of plastic into the ocean. And the new solutions recommended in this report would provide consumers with the same services that plastic delivers today—at a lower cost to society.

We hope that the "Breaking the Plastic Wave" concepts, data, and analyses inform decision-makers who are responsible for setting industry and government action. The report's most important message is that, with the right level of action, tackling the problem of plastics pollution may be remembered as a success story on the human ability to rethink and rebuild systems that can sustainably support lives and livelihoods while the environment thrives.

Martin R. Stuchtey
Founder & Managing Partner
SYSTEMIQ

Tom Dillon
Vice President & Head of Environment
The Pew Charitable Trusts

Expert panel

This work was developed in partnership with an expert panel representing all relevant disciplines and geographies:

Richard Bailey
Professor of
Environmental Systems
University of Oxford

Julien Boucher
Co-founder
Quantis and Shaping
Environmental Action

Jill Boughton
Founder
Waste2Worth Innovations

Arturo Castillo
Research fellow
Imperial College London

Mao Da
Executive director
Shenzhen Zero Waste

Enzo Favoino
Researcher
Scuola Agraria del Parco
di Monza

Malati Gadgil
Independent consultant
Informal sector waste
management

Linda Godfrey
Principal researcher
Council for Scientific
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Jutta Gutberlet
Professor
University of Victoria

Edward Kosior
Managing director
Nextek

Crispian Lao
Founding president
Philippine Alliance for
Recycling and Material
Sustainability

Daniela Lerario
Triciclos Brazil

Ellie Moss
Senior adviser
Encourage Capital

Daniella Russo
Co-founder and CEO
Think Beyond Plastic

Ussif Rashid Sumaila
Professor
University of British
Columbia

Richard Thompson
Professor
University of Plymouth

Costas Velis
Lecturer
University of Leeds

Endorsements

Inger Andersen, U.N. under-secretary-general and executive director, United Nations Environment Programme (UNEP)

"Breaking the Plastic Wave: A Comprehensive Assessment of Pathways Towards Stopping Ocean Plastic Pollution" comes at a critical time to inform global discussions and help decision-makers evaluate options that will eliminate the long-term flow of plastic and microplastics into the ocean. By providing the evidence base for a way forward, the study convincingly shows the need for system-wide change and urgent action across the entire value chain. It inspires by demonstrating that projected plastic leakage can be reduced by 80% with existing solutions. The next two years will be critical in getting the world on a zero-plastic pollution path. We need to catalyse rapid transition; we need to act now!"

Marisa Drew, CEO, impact advisory and finance department, Credit Suisse

"Despite the awareness-raising and global efforts to reduce plastic production, consumption, and waste in our oceans, the current trajectory points to a dire outcome without a concerted effort to mobilise industry, civil society, and governments to address this critical environmental issue. This well-researched, peer-reviewed report from The Pew Charitable Trusts and SYSTEMIQ provides a roadmap for the investment and innovation required to tackle the challenge. The report also shows us that economically viable solutions exist today that are implementable if all relevant stakeholders across the value chain act with urgency.

Professor Juliet A. Gerrard, chief science advisor to the Prime Minister of New Zealand

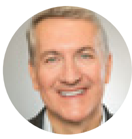
"This is a seminal piece of work on a topic of global importance. It will guide countries to align and unite as we move to conquer the plastic problem."

Von Hernandez, global coordinator, Break Free From Plastic

"Break Free From Plastic (BFFP) welcomes "Breaking the Plastic Wave" as a helpful addition to the global conversation about this rapidly growing threat to human and ecosystem health. "Breaking the Plastic Wave" demonstrates that no solution to the plastic crisis is possible without prioritizing urgent action to reduce the quantity of plastic used and produced. The report makes clear that existing private-sector commitments and public policies to limit plastic pollution are wholly inadequate and demonstrates that industry's expansion plans will produce even more staggering quantities of plastic pollution, greenhouse gas emissions, and irreversible damage to the ocean. While we agree with the report's general recommendation calling for a radical system change in how the world deals with plastic, we disagree that certain technologies analyzed in the report—including incineration, chemical recycling, and plastic-to-fuel—are part of that solution, as they will only perpetuate the problem as we see it. Above all, this report should serve as a wake-up call to governments: They must step in to halt the expansion of plastic production. Only then can we begin to see significant and sustained decline of plastic leakage into the oceans and to the environment."

Her Excellency Ms. Thilmeeza Hussain, ambassador of the Maldives to the United States and permanent representative of the Maldives to the United Nations

"This report is an important contribution to understanding the nature of the marine plastic pollution problem and provides many important ideas and proposals that diplomats and other actors will need to consider in deciding how the global community can effectively address this pressing problem."



Ramon Laguarta, chairman and CEO, PepsiCo

"Addressing the challenge of plastic waste is both urgent and complex and will require accelerated, collective action and a transformation of the way society thinks about single-use plastics. This report calls for immediate bold action in the global effort to stem the tide of ocean plastics. It makes clear that through increased collaboration, across industries, we can help create systems change, build a circular economy for packaging, and turn the corner on ocean plastics."

Dame Ellen MacArthur, founder and chair of trustees, Ellen MacArthur Foundation

"Breaking the Plastic Wave" brings an unprecedented level of detail into the global plastic system, confirming that without fundamental change, annual flows of plastic into the ocean could nearly triple by 2040. To turn the tide on plastic waste and pollution, we need to radically increase our efforts and speed up the transition to a circular economy. We must eliminate the plastics we don't need, and drastically reduce virgin plastic use. We need to innovate to create new materials and business models based on reuse and refill systems. And we need improved infrastructure to ensure that all plastics we use are circulated in the economy and never become waste or pollution. The question is not whether a circular economy for plastic is possible, but what we will do together to make it happen."

Grant Reid, CEO, Mars Inc.

"We applaud the depth and rigor of this report on what's necessary to stop ocean plastic pollution. Mars is committed to being a part of the transformational system change that this issue requires. We're taking action by removing packaging we don't need, exploring reuse models, redesigning what we do need for circularity, and investing to close the packaging waste loop with recycling systems that work for business and communities. We have much to do, so we must work together as a global community like never before."

Erin Simon, head, plastic and business, World Wildlife Fund

"If we're going to significantly reduce ocean plastic pollution, we need an innovative and rigorous approach to ensure that the strategies we design are set up to delivering results. This research does exactly that. By identifying a modelling approach that looks at plastic pollution holistically, we're able to better measure the environmental, economic, and social impact of the strategies being considered, and call for a greater level of ambition and immediate action from all stakeholders. This deeper understanding will help companies, governments, and other stakeholders to strengthen their efforts on plastic pollution. It will continue to be crucial to monitor and evaluate strategies on the ground to ensure that we as a society are delivering against our ambition."

Andrew Steer, president and CEO, World Resources Institute

"The ocean is being filled with plastic—hurting sea life and the billions of people who depend on the ocean for food, livelihoods and recreation. This is entirely unnecessary and unacceptable. This new important report, "Breaking the Plastic Wave" presents important solutions that can reduce plastic flows by 80% over the next 20 years. It is urgent that industry and government leaders follow these recommendations – starting today."

Laura Tuck, vice president for sustainable development, World Bank*

"The plastic problem took a lifetime to create and could be solved in a generation. That's the stark message of "Breaking the Plastic Wave," a welcome and comprehensive look at what we need to do—at every layer of society—to clean up the mess we are making. Its positive message is that we already have the solutions we need to address the challenge. But we will need to step up with multi-stakeholder coalitions that can tackle each element of the agenda as they are laid out here."

* Retired from the World Bank as of April 1, 2020

Melati Wijsen, founder, Bye Bye Plastic Bags

"Since starting to campaign against plastic pollution at 12 years old, I have seen numerous efforts come and go. Being born and raised in Bali, Indonesia, it was like watching the problem of plastic grow up with you. This is why we understood early on the importance of data and consistency. It is beyond exciting to hear that my home country has already applied the model featured in "Breaking the Plastic Wave." The only way forward is collaboration and persistence; let's turn the tide on plastic pollution once and forever."

Executive Summary

10 critical findings

Plastic waste lines the shore of a lake.
Sergey/Adobe Stock

The flow of plastic into the ocean is projected to nearly triple by 2040. Without considerable action to address plastic pollution, 50 kg of plastic will enter the ocean for every metre of shoreline. Our analysis shows that a future with approximately 80 per cent (82 ±13 per cent*) less annual plastic leakage into the ocean relative to business as usual is achievable by 2040 using existing technologies. This pathway provides benefits to communities, to governments, and even to industry. However, it depends on the immediate, ambitious, and concerted global implementation of solutions across the entire plastics value chain. This vision for system change represents an attractive and viable way forward.

Plastic pollution in the ocean is a major environmental challenge, yet a coherent global strategy to solve this growing crisis remains elusive. It is a by-product of fundamental flaws in an essentially linear plastic system in which 95 per cent of aggregate plastic packaging value—US$80 billion-US$120 billion a year—is lost to the economy following a short first-use cycle.[1]

Very different responses to the crisis have been proposed, from eliminating plastic entirely to turning it into fuels, and from developing biodegradable substitutes to recycling plastic back into usable products. Each solution comes with advantages and drawbacks. Understanding the effectiveness of different solutions, and the related economic, environmental, and social implications, is crucial to making progress towards stopping ocean plastic pollution.

Here we lay out our report's 10 critical findings, showing that a path forward to a low plastic pollution future already exists—now we have to make the choice to walk this path.

1

Without action, the annual flow of plastic into the ocean will nearly triple by 2040, to 29 million metric tons per year (range: 23 million-37 million metric tons per year), equivalent to 50 kg of plastic per metre of coastline worldwide.

Owing to four compounding trends—continued population growth; increases in plastic use per capita driven in part by increasing production of cheap virgin plastic; shifts to low-value/nonrecyclable materials; and the growing share of plastic consumption occurring in countries with low rates of collection—annual plastic flows to the ocean are expected to grow from 11 million metric tons (range: 9 million-14 million metric tons per year) in 2016 to 29 million metric tons in 2040 (range: 23 million-37 million metric tons per year), with consequences for communities, businesses, and ecosystems. Under our Business-as-Usual (BAU) Scenario, about 4 billion people are likely to be without organized waste collection services by 2040, contributing significantly to the expected mass of plastic leakage to the ocean. The cost of inaction is high to businesses, communities, and ecosystems; particularly stark is the US$100 billion annual financial risk that businesses face if governments require them to cover waste management costs at expected volumes and recyclability.

* All figures stated in parentheses are 95 per cent confidence intervals, unless otherwise specified. The range is given where distributions are not symmetrical.

2

Governments and industry leaders are stepping up with new policies and voluntary initiatives, but these are often narrow in focus or concentrated in low-leakage countries. By 2040, current government and industry commitments are likely to reduce annual plastic leakage to the ocean by only 7 per cent (±1 per cent) relative to the Business-as-Usual Scenario.

A review of the key government initiatives worldwide—such as the European Union's single-use plastics directive and the growing number of national plastic policies—often reveals a narrow focus on select items (e.g., straws, bags, cups, stirrers, cotton swabs, and bottles), which severely limits the reduction in total leaked plastic mass. Industry has also made high-profile commitments, but these are primarily focused on post-consumer downstream solutions and often in low-leakage countries. Our results indicate that a far greater scale of action at the system level will be needed to meaningfully address the challenge of plastic pollution. Government policies and leadership by consumer goods companies will be critical in driving upstream action on reduction, reuse, and redesign as well as downstream action to improve collection and recycling. Governments and investors also need to curtail the planned expansion in plastic production capacity to prevent locking us deeper into the status quo..

3

There is no single solution to end ocean plastic pollution. Upstream and downstream solutions should be deployed together.

To date, much of the debate has focused on either "upstream" (pre-consumer, such as material redesign, plastic reduction, and substitution) or "downstream" solutions (post-consumer, such as recycling and disposal). Our analysis shows that this is a false dichotomy. Upstream solutions that aim to reduce or substitute plastic use are critical and should be prioritized but will need to be scaled carefully to limit adverse social or environmental effects. Downstream solutions are also essential but limited by economic viability and the realistic speed of infrastructure development in the face of growing plastic waste production. Moreover, given the potential negative impacts on human health and the environment of some downstream disposal technologies, their use should be weighed against different trade-offs and carefully controlled. Modelled on their own, no "single-solution" strategies reduce annual leakage of plastic to the ocean even below 2016 levels by 2040. An ambitious recycling strategy, for example, with ambitious scale-up of collection, sorting, and recycling infrastructure coupled with design for recycling, reduces 2040 leakage by 38 per cent (±7 per cent) relative to BAU, which is 65 per cent (±15 per cent) above 2016 levels. Similarly, an ambitious reduction and substitution strategy, without massive expansion of downstream infrastructure, reduces 2040 leakage by 52 per cent (±9 per cent) relative to BAU, 28 per cent (±5 per cent) above 2016 levels. An integrated approach with new ways to deliver the benefits of today's plastic is needed to significantly reduce ocean plastic pollution.

4

Industry and governments have the solutions today to reduce rates of annual land-based plastic leakage into the ocean by about 80 per cent (82 ±13 per cent) below projected BAU levels by 2040, while delivering on other societal, economic, and environmental objectives.

It is not the lack of technical solutions that is preventing us from addressing the ocean plastic crisis, but rather inadequate regulatory frameworks, business models, and funding mechanisms. Although the technical solutions exist, the incentives are not always in place to scale up these changes fast enough. A reduction of plastic production—through elimination, the expansion of consumer reuse options, or new delivery models—is the most attractive solution from environmental, economic, and social perspectives. It offers the biggest reduction in plastic pollution, often represents a net savings, and provides the highest mitigation opportunity in GHG emissions.

As modelled in our integrated System Change Scenario, annual land-based plastic leakage into the ocean can be reduced by around 80 per cent (82 ±13 per cent) by 2040, compared with BAU, through the concurrent, ambitious, and global implementation of multiple synergistic system interventions:

Reduce growth in plastic production and consumption to avoid nearly **one-third** of projected plastic waste generation through elimination, reuse, and new delivery models.

Substitute plastic with paper and compostable materials, switching **one-sixth** of projected plastic waste generation.

Design products and packaging for recycling to expand the share of economically recyclable plastic from an estimated 21 per cent to 54 per cent.

Expand waste collection rates in the middle-/low-income countries to 90 per cent in all urban areas and 50 per cent in rural areas and support the informal collection sector.

Double mechanical recycling capacity globally to 86 million metric tons per year.

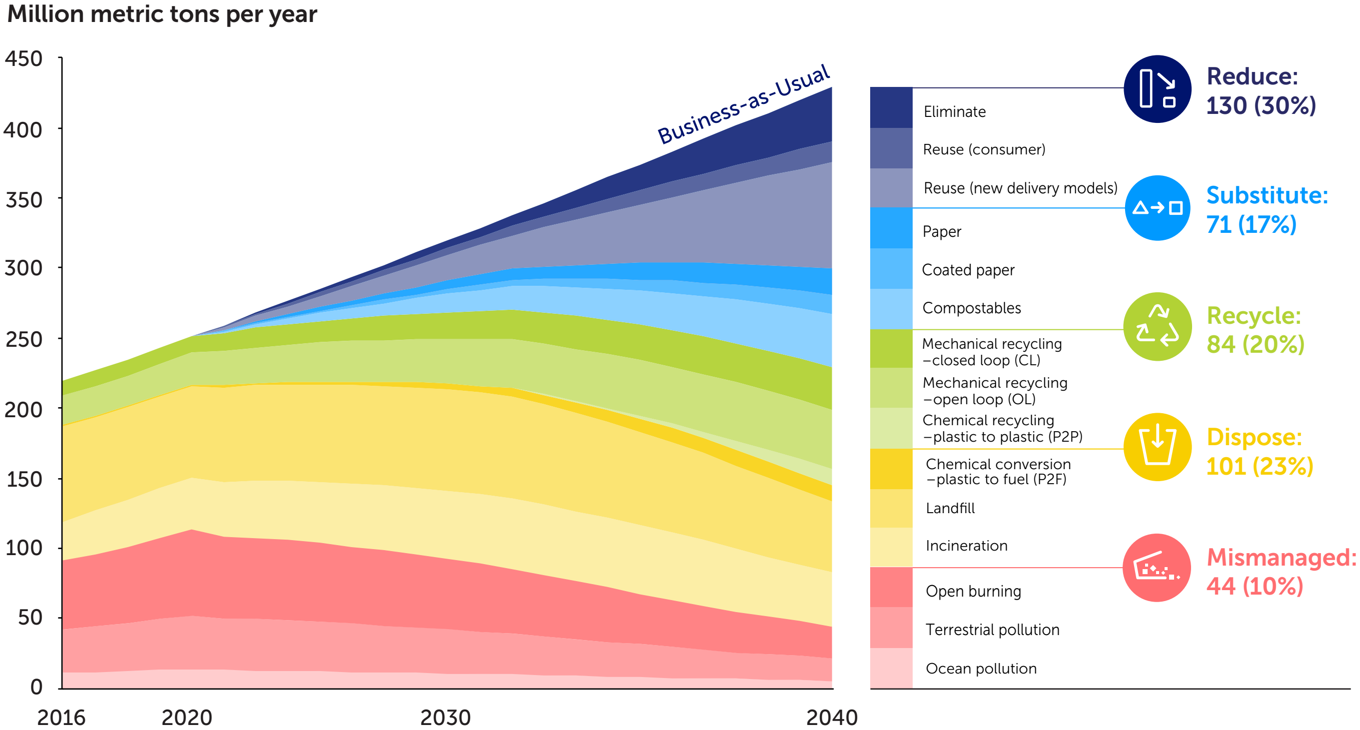
Develop plastic-to-plastic conversion, potentially to a global capacity of up to 13 million metric tons per year.

Build facilities to dispose of the 23 per cent of plastic that cannot be recycled economically, as a transitional measure.

Reduce plastic waste exports by 90 per cent to countries with low collection and high leakage rates.

Figure 1: Plastic fate in the System Change Scenario: a 'wedges' analysis

There is a credible path to significantly reduce plastic leakage to the ocean but only if all solutions are implemented concurrently, ambitiously, and starting immediately



This "wedges" figure shows the share of treatment options for the plastic that enters the system over time under the System Change Scenario. Any plastic that enters the system has a single fate, or a single "wedge." The numbers include macroplastic and microplastic.

Roll out known solutions for four microplastic (<5mm) sources—tyres, textiles, personal care products and production pellets—to reduce annual microplastic leakage to the ocean by 1.8 million metric tons per year (from 3 million metric tons to 1.2 million metric tons) by 2040.

Taken together, these system interventions describe a credible scenario for dealing with ocean plastic pollution. Under the System Change Scenario, 30 per cent (range: 27 per cent-32 per cent) of BAU plastic demand is reduced, 17 per cent (range: 15 per cent-18 per cent) is substituted, 20 per cent (range: 18 per cent-21 per cent) is recycled, 23 per cent (range: 22 per cent-26 per cent) is disposed of and 10 per cent (range: 9 per cent-12 per cent) remains mismanaged, as shown in Figure 1.

5

Going beyond the System Change Scenario to tackle the remaining 5 million metric tons per year (range: 4-7 million metric tons per year) of plastic leakage demands significant innovation across the entire value chain.

In 20 years, we can break the seemingly unstoppable wave of plastic pollution, but the System Change Scenario still does not go far enough. It leaves 5 million metric tons (range: 4 million-7 million metric tons) of plastic flowing into the ocean in 2040—which represents a 52 per cent (±8 per cent) reduction from 2016 rates. Achieving the vision of near-zero ocean plastic pollution will require technological advances, new business models, significant spending, and, most crucially, accelerating upstream innovation. This massive innovation scale-up requires a focused and well-funded R&D agenda exceeding US$100 billion per year by 2040, including moon-shot ambitions, to help middle-/low-income countries to leapfrog the unsustainable linear economy model of high-income countries. Most crucial will be solutions that focus upstream and can work in rural/remote areas (where collection economics are challenging), that replace multilayer and multimaterial plastics (e.g., new delivery models or new materials), and that lead to new tyre designs to reduce abrasion of microplastic particles while maintaining safety standards. Innovation will also be critically needed in financing and policy. The alternative is to greatly increase the ambition levels above the maximum foreseeable levels modelled under the System Change Scenario.

6

The System Change Scenario is economically viable for governments and consumers, but a major redirection of capital investment is required.

The present value of global investments in the plastic industry between 2021 and 2040 can be reduced from US$2.5 trillion (±US$800 billion) to US$1.2 trillion (±US$300 billion), but the System Change Scenario will require a substantial shift of investment away from the production and conversion of virgin plastic, which are mature technologies perceived as "safe" investments, to the production of new delivery models, plastic substitutes, recycling facilities, and collection infrastructure, some of which are less mature technologies and perceived as riskier. This shift will require government incentives and risk-taking by industry and investors. The total global cost to governments of managing plastic waste in this low-leakage System Change Scenario between 2021 and 2040 is estimated to be US$600 billion (range: US$410 billion-US$630 billion) in present value, compared with the US$670 billion (range: US$450 billion-US$740 billion) cost to manage a high-leakage system under BAU.

7

Reducing approximately 80 per cent (82 ±13 per cent) of plastic leakage into the ocean will bring to life a new circular plastics economy with major opportunities—and risks—for industry.

Plastic pollution presents a unique risk for producers and users of virgin plastics given regulatory changes and growing consumer outrage. But it is also a unique opportunity for providers of new and existing circular business models and materials. Embarking on the trajectory to get to about 80 per cent (82 ±13 per cent) leakage reduction will create significant opportunities for companies ahead of the curve, ready to embrace new business opportunities that unlock value from a circular economy that derives revenue from circulation of materials rather than one based on the extraction and conversion of fossil fuels. Large new value pools can be created around better design, better materials, better delivery models, improved sorting and recycling technologies, and smart collection and supply chain management systems. Our analysis shows that through integrated application of upstream and downstream interventions under the System Change Scenario, we could fulfil the growing global demand for "plastic utility" in 2040 with roughly the same amount of plastic in the system as today, and 11 per cent (±1 per cent) lower levels of virgin plastic production, essentially decoupling plastic growth from economic growth. However, in the meantime, hundreds of billions of dollars are being invested in virgin plastic production plants, locking us deeper into a BAU trajectory every day and making system change ever more urgent.

8

A system change would require different implementation priorities in different geographies and for different plastic categories.

Different regions of the world have fundamentally different contexts and jumping-off points: different sources of plastic leakage, waste composition, collection rates, policy regimes, labour and capital costs, infrastructure, population demographics, and consumer behaviour. Our model highlights the most urgently needed interventions and the unique set of outcomes projected for different geographies under the System Change Scenario. High-income countries should prioritize addressing microplastic leakage (which represents 62 per cent [range: 29 per cent-76 per cent] of leakage in high-income countries), technological and policy innovation to incentivize reduction and substitution, and further increasing recycling rates. Middle-/low-income countries should prioritize expanding formal collection, decreasing overall plastic consumption, investing in sorting and recycling infrastructure, and reducing post-collection leakage. However, universally, the top priority is reducing avoidable plastic—of which we estimate there will be 125 million metric tons (range: 110 million metric tons-142 million metric tons) globally by 2040 under BAU. Similarly, we should universally prioritize solutions for the highest-leakage plastic categories. Flexible packaging (bags, films, pouches, etc.), multilayer and multimaterial plastics (sachets, diapers, beverage cartons, etc.), and the microplastics that we modelled account for a disproportionate share of plastic pollution compared with their production, making up 47 per cent (range: 34 per cent-58 per cent), 25 per cent (range: 17 per cent-34 per cent) and 11 per cent (range: 6 per cent-17 per cent) of the leakage mass, respectively.

9

Addressing plastic leakage into the ocean under the System Change Scenario has many co-benefits for climate, health, jobs, working conditions, and the environment, thus contributing to many of the United Nations Sustainable Development Goals.

Our analysis suggests that addressing the ocean plastic pollution crisis helps reduce greenhouse gas (GHG) emissions relative to BAU. The integrated System Change Scenario results in 25 per cent (±11 per cent) lower plastic-related GHG emissions in 2040; however, it still represents an increase in emissions relative to today. As such, it will be vital to scale up measures offering the greatest GHG savings and further decarbonize energy sources. In the System Change Scenario, peak virgin plastic is reached by 2027. In addition, net direct employment in the value chain (including manufacturing, collection, recycling, and new delivery models) increases by 6 per cent (±1 per cent) relative to BAU by 2040. That's equivalent to 700,000 jobs (range: 541,000-795,000), redistributed among sectors and geographies, with almost all of the job growth occurring in middle-/low-income countries. The System Change Scenario also represents a positive social vision for the global community of 11 million waste pickers, who in 2016 were responsible for 60 per cent (range 56 per cent-65 per cent) of global plastic recycling. To date, their contribution to preventing ocean plastic pollution has largely gone unrecognized and typically underpaid. An increase in plastic material value through design for recycling can contribute to social justice by increasing the retained value for waste pickers and improving working conditions. Health hazards are also significantly reduced under this scenario, including the reduction relative to BAU of 109 million metric tons per year (range: 108-111 million metric tons per year) of open burning of plastic waste—a process that releases airborne particulates, carcinogens, and other toxins.

10

The time is now: If we want to significantly reduce plastic leakage, we have the solutions at our fingertips. An implementation delay of five years would result in an additional ~80 million metric tons of plastic going into the ocean by 2040.

All elements of the System Change Scenario exist today or are under development and near adoption. A system-wide implementation delay of five years would result in ~80 million metric tons more plastic stock in the ocean by 2040. That is equivalent to approximately half of today's stock. Delays in implementing the eight interventions would likely take the world off the path towards near-zero leakage. The next two years will be pivotal for breaking the trend and implementing a first horizon of change that will allow key milestones to be met by 2025, including stopping the production of avoidable plastic, incentivizing consumers around reuse, improving labelling, and testing innovations such as new delivery models. This work will lay the groundwork for the second and third horizons of change to take place by 2025 and 2030, and enable the implementation of further systemic solutions required in 2030-2040.

Achieving the outcomes modelled under the System Change Scenario would require substantial changes in the business models of firms producing and using plastics and their substitutes; overhauls to the recycling and waste disposal industries; transformation of the criteria used by investors; and modification of consumer behaviour.

Although these changes are feasible, they are unlikely to materialize unless governments create significant incentives for more sustainable business models and remove the cost advantage that virgin plastic feedstock has over recycled materials. Policies that create a clear and stable set of incentives and targets will make the conditions required under the System Change Scenario possible.

Industry, at the same time, should stop placing avoidable, single-use, and hard-to-recycle plastic on the market, invest in material and business model innovations, and join with governments to help finance waste collection and sorting. To achieve an approximately 80 per cent (82 ±13 per cent) reduction in annual plastics leakage into the ocean by 2040, public-private collaborations will be required to set higher standards on materials, formats, reuse, and recyclability. Fortunately, there are promising existing efforts to build on. The Ellen MacArthur Foundation's New Plastics Economy initiative, for example, has already united more than 400 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. There are also early discussions regarding strengthening an international agreement to prevent plastic pollution that may help provide the global policy framework for united government action.

Conclusion

Taken together, our findings on plastic pollution substantiate catastrophic outlooks for the ocean if we continue on the current trajectory. They also highlight the economic exposure to the plastic industry in the absence of resolute action. Yet our report gives us some cause for optimism: It shows that an approximately 80 per cent (82 ±13 per cent) reduction in projected plastic leakage is possible—without compromising social or economic benefits. Achieving the potential of such a rapid and holistic pathway towards the goal of near-zero ocean plastic leakage is within reach, but it will require enhanced ambitions.

A fisherman in Sri Lanka hauls in fish caught in his synthetic net. Nets like these are sometimes abandoned in the ocean, entangling marine life, leading to injury or death.
SmallWorldProduction/Adobe Stock

FAST FACTS

'Breaking the Plastic Wave' in numbers

Scale of the problem

11 million metric tons of plastic leaked into the ocean in 2016

29 million metric tons of plastic leakage into the ocean in 2040

40% of today's global plastic waste ends up in the environment

7% reduction of leakage if all current government and industry commitments were implemented by 2040

500,000 people need to be connected every day until 2040 to close the collection gap

11% of leakage is microplastic in 2016

By 2040:

2x plastic generation

3x plastic leakage into the ocean

4x plastic stock in the ocean

US$100B financial risk to industry under BAU in 2040

45% of today's leakage is from rural areas, where collection economics don't work

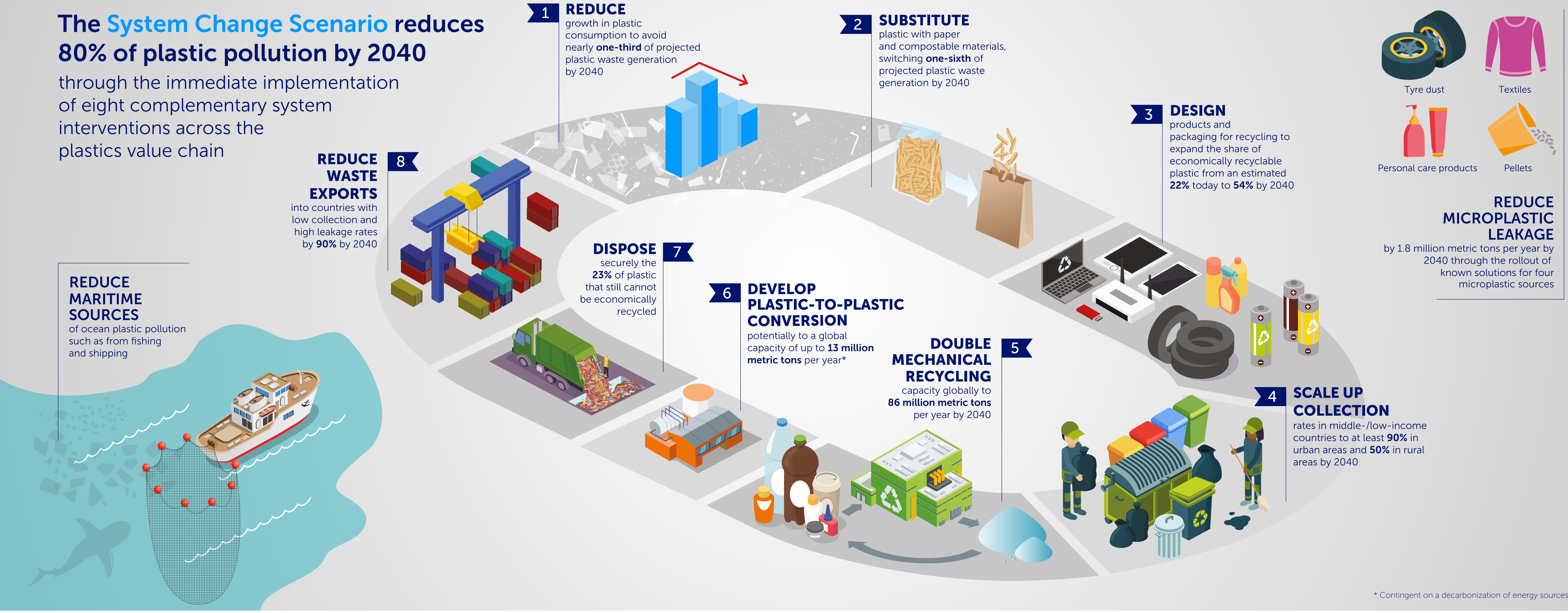
21% of plastics are economically recyclable (but only 15% are actually recycled) in 2016

19% share of carbon budget used by plastic industry by 2040 under BAU to stay under 1.5°C

80% share of leakage from flexible and multilayer plastics in 2016

The System Change Scenario reduces 80% of plastic pollution by 2040

through the immediate implementation of eight complementary system interventions across the plastics value chain



* Contingent on a decarbonization of energy sources

Integrated system change achieves social, environmental, and economic benefits

80% reduction in plastic leakage into the ocean by 2040 relative to BAU

US$70B saving for governments over 20 years relative to BAU

700,000 jobs created by 2040 relative to BAU

25% reduction in annual GHG emissions by 2040 relative to BAU

55% reduction in virgin plastic demand by 2040 relative to BAU

195 million metric tons reduction in other environmental leakage (land and atmosphere)

Introduction

Plastic, the ocean, and the global debate

A plastic bag floats underwater in France.
damedias/Adobe Stock

Ocean Plastic Pollution:
Challenges and opportunities in a complex system

Plastic was first invented in the 19th century, but it wasn't until the 20th century that plastic production soared, going from 2 million metric tons in 1950[2] to 348 million metric tons in 2017,[3] becoming a global industry valued at US$522.6 billion.[4] Plastic's low cost, light weight, convenience, durability, and ability to be produced in different colours and shapes for marketing have driven this proliferation. It is now used across thousands of applications and many sectors, ranging from packaging to automotive and construction. By 2040, production is expected to double yet again.[5]

As plastic production and use have surged, so too has plastic pollution, and with it the amount of plastic in the ocean,[6] which could already be as high as 150 million metric tons.[7] From coral reefs[8] to deep sea trenches[9] and from remote islands[10] to the poles,[11] plastic alters habitats, harms wildlife, and can damage ecosystem function and services.[12] More than 800 species are already known to be affected by marine plastic pollution, including all sea turtle species,[13] more than 40 per cent of cetacean species, and 44 per cent of marine bird species.[14]

Plastic has also been identified as having human health impacts throughout its life cycle, from the impacts of raw material extraction and production on neighbouring communities[15] to the chemicals in food packaging[16] and the health impacts of mismanaged waste.[17] Plastic waste can block rivers and drainage systems, causing flooding and trapping stagnant water that exacerbates the spread of diseases in impacted communities,[18] while open burning transfers the pollution burden to air and water, emitting toxic chemicals and greenhouse gases (GHGs). In 2016, open burning of plastic waste released an estimated 1 gigaton of equivalent carbon dioxide ($GtCO_2e$) of GHGs, a figure expected to grow to 2.1 $GtCO_2e$ under our Business-as-Usual Scenario.

Recent analyses based on beach clean-up data have identified the predominant items contributing to macroplastic pollution, namely single-use plastic items.[19] Single-use plastic is defined as products and packaging made wholly or partly from plastic that is not conceived, designed, or placed on the market to accomplish—within its life span—multiple trips or rotations by being returned to a producer for refill or reused for the same purpose for which it was originally conceived.[20] Abandoned, lost or discarded fishing gear, often known as "ghost gear," is also a significant source and poses an elevated risk of entanglement for many marine species.[21] Microplastic sources are varied and include both primary microplastic sources, such as tyre dust, plastic pellets, and microfibres from synthetic textiles, and secondary microplastics derived from the fragmentation of larger, macroplastic items already in the environment.[22]

Plastic pollution is not only an environmental tragedy, it is also economically imprudent— because billions of dollars of economic value are "thrown away" after a single, short use—as well as a social offence due to the health risks it creates.

What are the major challenges when analysing solutions to plastic pollution?

- **A fundamentally systemic problem requires a systemic answer.**
  Plastic pollution arises from structural flaws in an essentially linear plastic system— namely, that 95 per cent of the aggregate value of plastic packaging is lost to the economy after a single use cycle and that many plastic products are placed in markets that lack the capacity to collect and treat them economically after use.[23] The low and potentially decreasing cost of virgin plastic production relative to the cost of post-consumer collection poses a fundamental economic challenge to managing the material at end of life. Today, only 71 per cent of plastic produced is formally collected, and less than 15 per cent is actually recycled. To make a real difference, solutions should take a systemic approach and not only target the plastic leaking into the ocean, but also the much larger quantity of municipal solid waste (MSW) plastic produced every year. Effective systemic solutions require collaboration and accountability across the value chain (e.g., petrochemical producers, resin makers, converters, brand owners, retailers, consumers and waste management); across borders (to set global standards for materials, trade, and reporting); between the public and private sectors (to reduce investment risk and develop infrastructure); and among the value chains of different material types, to ensure a holistic approach to resource efficiency and environmental sustainability.
- **Formal collection is underfunded, and expanding informal collection entails economic limitations and undesired social consequences.**
  Collection of waste is chronically underfunded and, despite often being the single highest item in the budgets of municipalities,[24] formal collection coverage remains patchy. A significant share of plastic waste collection is carried out by the informal recycling sector, involving exposure to undignified labour conditions and significant health risks.
- **Design and packaging choices do not account for local infrastructure.**
  Many plastic products are designed for a global market, with marketing and sales rather than end-of-life sustainability as primary drivers of product design. There are thousands of plastic applications, requiring different solution sets, with little harmonization from region to region over what is placed on the market, what is considered recyclable, and what is actually collected for recycling. Globalized supply chains of consumer goods fail to account for the realities of the local waste management infrastructure available to deal with them, which can vary greatly from one municipality to another. Fast innovation cycles in product design outpace

slow innovation downstream (waste infrastructure), exacerbating the problem further.

- **A lack of incentives discourages the adoption of new solutions.**
  Today's markets are structured around the pervasive use of plastic, particularly in packaging. Reducing single-use plastics would require, in many cases, not just simple material substitutes but entirely new business models, providing an opportunity to providers of innovative solutions but also posing a risk to existing companies. There are currently few policy incentives to encourage the adoption of alternative materials, delivery models, or end-of-life technologies.

- **The debate is data-poor.**
  Consistent definitions and conventions for plastic waste data and metrics are lacking, and there is insufficient transparency regarding the plastic being placed on the global market (type, chemical additives, etc.), trade flows, waste production, consumption, and post-use patterns. In addition, there is a lack of field data measuring plastic stocks and flows throughout the value chain, and many parameters have high uncertainty. The result is a very data-poor debate, often led by opinions and preconceptions instead of facts. But there is sufficient data to better inform decision-makers and stakeholders about the outcomes of current policies and proposed solutions: That is the goal of this report.

About this project: A global stochastic model

This report presents a feasible and meaningful pathway towards collectively solving the ocean plastic pollution crisis. Prepared by The Pew Charitable Trusts and SYSTEMIQ, with a panel of 17 global experts, the University of Oxford, the University of Leeds, the Ellen MacArthur Foundation, and Common Seas, the report introduces a new model designed to quantify key plastic flows and stocks in the global plastic system, estimate the quantity of ocean plastic pollution expected under six scenarios between 2016 and 2040, and assess the economic, environmental, and social impacts of the principal known solutions and technologies. We estimate the capital expenditure (capex), operating expenditure (opex), direct employment, and GHG emissions associated with each future scenario at a greater granularity than previous studies. The analysis incorporates all major land-based sources of ocean plastic pollution, including both macroplastics (>5mm) and four sources of microplastics (<5mm), and highlights the factors contributing most strongly to plastic leakage to the ocean. Although our focus is on ocean plastic pollution, this problem is clearly connected to pollution of terrestrial environments, and mitigation strategies should seek to address both.

In undertaking this analysis, we aim to provide a new evidence base for decision-makers across government, business, civil society, and academia as they navigate their responses to this emerging global challenge, evaluate trade-offs, and implement solutions. Our goal is that the direction and conclusions of this analysis will inform the global discussion and planning around this urgent challenge. We found that through an ambitious, system-wide strategy, the international community can stem the growing sources of plastic pollution and stop it from reaching the ocean.

This study provides one of the most comprehensive global fact bases and analyses available to date to quantify and offer solutions to the ocean plastic pollution crisis. Specifically, this project is designed to address seven strategic questions that have not previously been answered:

- **Are we on track to solve the plastic pollution crisis?**
- **How bad will it get for the economy, for the environment, and for communities?**
- **Do we have the technology to solve the problem?**
- **What is the way out?**
- **What will it cost and who will bear the burden?**
- **Is the solution attractive for citizens, for businesses, for governments, and for ecosystems?**
- **Where do we start?**

"Breaking the Plastic Wave" builds on a global body of work by scientists, researchers, and institutions whose findings and determination have served to raise plastic pollution to the forefront of global debates, including the vision presented by the Ellen MacArthur Foundation's New Plastics Economy. And yet our project is unique in the following ways:

- **Quantitative analysis of solutions:** There are existing analyses of BAU projections of ocean plastic pollution,[25] but we provide one of the first in-depth quantitative analyses of the main available solutions and the economic, environmental, and social implications of each. Our study assesses both upstream and downstream solutions in great depth.
- **Criteria-based comparison of solutions:** We develop clear criteria designed to enable the comparison of very different solutions along environmental (pollution and GHG), economic, performance (health and safety), and consumer acceptance dimensions.
- **Scientific rigour and diverse input:** This analysis was conducted with scientific rigour, in conjunction with a panel of 17 experts representing diverse geographies and the full value chain, and involving more than 100 additional experts. All assumptions and methodologies have been extensively peer-reviewed and are available in a detailed technical appendix.
- **First-of-its-kind system-wide perspective:** Modelling provides us with a method by which to project future trajectories of ocean plastic pollution under different scenarios. The system map at the heart of this work (see Appendix B), and the stochastic model we developed together with Oxford University, allowed

us to better understand complex system dynamics and the relationships and synergies among different interventions in the system.

- **Broad scope:** The analysis covers all geographies, the entire value chain, and includes all municipal solid plastic waste and four key sources of microplastics: tyre abrasion, textile losses, personal care products, and pellet losses. Maritime sources of leakage are also considered, albeit qualitatively given constraints on data availability.
- **Highly granular:** The project is global in nature, but our analysis also distinguishes among eight different geographic archetypes to understand their vastly different characteristics and identify the most relevant solutions. The archetypes are divided into four groups depending on country income, according to World Bank definitions: high-income (HI) economies; upper middle-income (UMI) economies; lower middle-income (LMI) economies; and low-income (LI) economies; as well as according to United Nations urban-rural classifications. Because the problem of plastic pollution cannot be solved using a one-size-fits-all approach, the model differentiates among three plastic categories, due to their differing economics, applications and recyclability: rigid monomaterials (such as bottles, tubs, pots and trays), flexible monomaterials (such as bags or films), and multilayer/multimaterials (which combine different polymers and/or nonplastic materials, such as beverage cartons, sachets and diapers).

In undertaking this project, we followed three guiding principles:

- **Focus on prevention of leakage:** Our work is centred on preventing plastic from leaking into the ocean rather than cleaning up what is there already, although we estimate the volume of beach clean-ups for completeness and to understand their relative importance. Although new techniques to remove plastic waste from waterways are positive developments, strategies that rely predominantly on post-leakage collection will not bring about the systemic change needed. We focus on treating the problem at the source.
- **Balance environmental, economic, and social outcomes:** To understand the potential for unintended consequences, we model GHG emissions, costs, and jobs to quantify and balance key environmental, economic, and social outcomes of the interventions. Future analyses should build on this to also incorporate other outcomes, such as land use requirements, water use, chemical pollution, and human health to help ensure systemic and sustainable change.
- **Incorporate equity in health and safety standards:** When modelling solutions or infrastructure development, we assume that the same high level of environmental, safety, and health standards for technologies should apply globally, so we model costs for infrastructure that meet strict environmental, safety, and operational standards.

Taking a "wedges" approach

In undertaking this analysis, we aim to provide a new evidence base for decision-makers across government, business, civil society, and academia as they navigate their responses to this emerging global challenge, evaluate trade-offs, and implement solutions. Our goal is that the direction and conclusions of this analysis will inform the global discussion and planning around this urgent challenge. We found that through an ambitious, system-wide strategy, the international community can stem the growing sources of plastic pollution and stop it from reaching the ocean.

Box 1: Where can managed plastic waste end up? The four "wedges":

REDUCE

Reduction of plastic production and consumption without substituting to other short-lived materials. Sub-wedges include eliminating plastic (e.g., product redesigns, reduced overpackaging, and plastic bans), consumer reuse models (i.e., switching from single-use plastics to reusable items), and new product delivery models (e.g., refill services, shifting products to services, e-commerce, and dispensers).

SUBSTITUTE

Substitution with alternative materials that meet functional requirements for specific applications but are more easily recyclable or compostable after use. Sub-wedges include paper, coated paper, and industrially compostable or home-compostable materials.

RECYCLE

Recycling of products or materials. Sub-wedges include mechanical closed-loop recycling, mechanical open-loop recycling, and plastic-to-plastic chemical conversion systems that produce new packaging, products, or feedstock.

DISPOSE

Controlled disposal of plastic waste in ways that prevent leakage to the ocean. Sub-wedges include sanitary landfills (but not dumpsites), incineration, and plastic-to-fuel technologies.

Any plastic waste that is not included in these four wedges is considered mismanaged waste; this category includes waste that is open burned, or either dumped directly into or leaked to land or waterways.

Scenarios modelled

This analysis defines eight system interventions and models the main economic, environmental, and social implications of applying different combinations of these changes to the system, at different ambition levels, and in different geographic archetypes. Six possible scenarios for tackling ocean plastic pollution, each comprising a different combination—or lack—of system interventions are analysed in this report:

1. **Business-as-Usual**
   Assumes no intervention is made in relation to current plastic-related policy, economics, infrastructure, or materials, and that cultural norms and consumer behaviours do not change.
2. **Current Commitments**
   Assumes all major commitments already made by the public and private sectors between 2016 and 2019 are implemented and enforced. These include existing bans/levies on specific plastic products, and recycling and recyclability targets.
3. **Collect and Dispose**
   Assumes ambitious global expansion of collection services and increases in the global capacity of engineered and managed landfills and incineration facilities.
4. **Recycling**
   Assumes ambitious expansion and investment into collection, sorting, mechanical recycling, and plastic-to-plastic chemical conversion infrastructure.
5. **Reduce and Substitute**
   Assumes dramatic reduction of plastic use through elimination, ambitious introduction of reuse and new delivery models, and ambitious introduction and investment in plastic substitutes. This intervention would require strong policy interventions to ban specific single-use plastics and incentivize design for reuse and reduce.
6. **System Change Scenario**
   Assumes that all eight system interventions are applied concurrently and ambitiously for both macroplastics and microplastics. This scenario benefits from the synergies among upstream and downstream interventions, as it is the only one that includes both.

The specific macroplastic system interventions modelled in each scenario are shown in Figure 2. In addition, we have modelled microplastic interventions for the integrated System Change Scenario. Maritime sources of waste have been analysed qualitatively only.

Integral to our approach is that the interventions are constructed to deliver the same utility to consumers, in which utility refers to the total satisfaction received from consuming a good or service. Plastic utility is defined as the services (including protection, food preservation, etc.) that are provided by plastic under a Business-as-Usual Scenario. In alternative scenarios, the goods and services provided deliver the same utility to consumers in other ways with less plastic.

Figure 2: System interventions modelled under each scenario

Reduce · Substitute · Recycle · Dispose

	Baseline scenarios		Downstream scenarios		Upstream scenario	Intergrated scenario
System interventions	Business-as-Usual (BAU)	Current Commitments	Collect & Dispose	Recycling	Reduce & Substitute	System Change
I. Reduce consumption		✓	✓	✓	✔	✔
II. Substitute for alternatives		✓	✓	✓	✔	✔
III. Design for recycling		✓	✓	✔	✓	✔
IV. Expand waste collection			✔	✔		✔
V. Increase mechanical recycling		✓	✓	✔	✓	✔
VI. Scale up chemical conversion				✔		✔
VII. Build safe disposal facilities			✔			✔
VIII. Reduce waste exports		✓	✔	✓	✔	✔

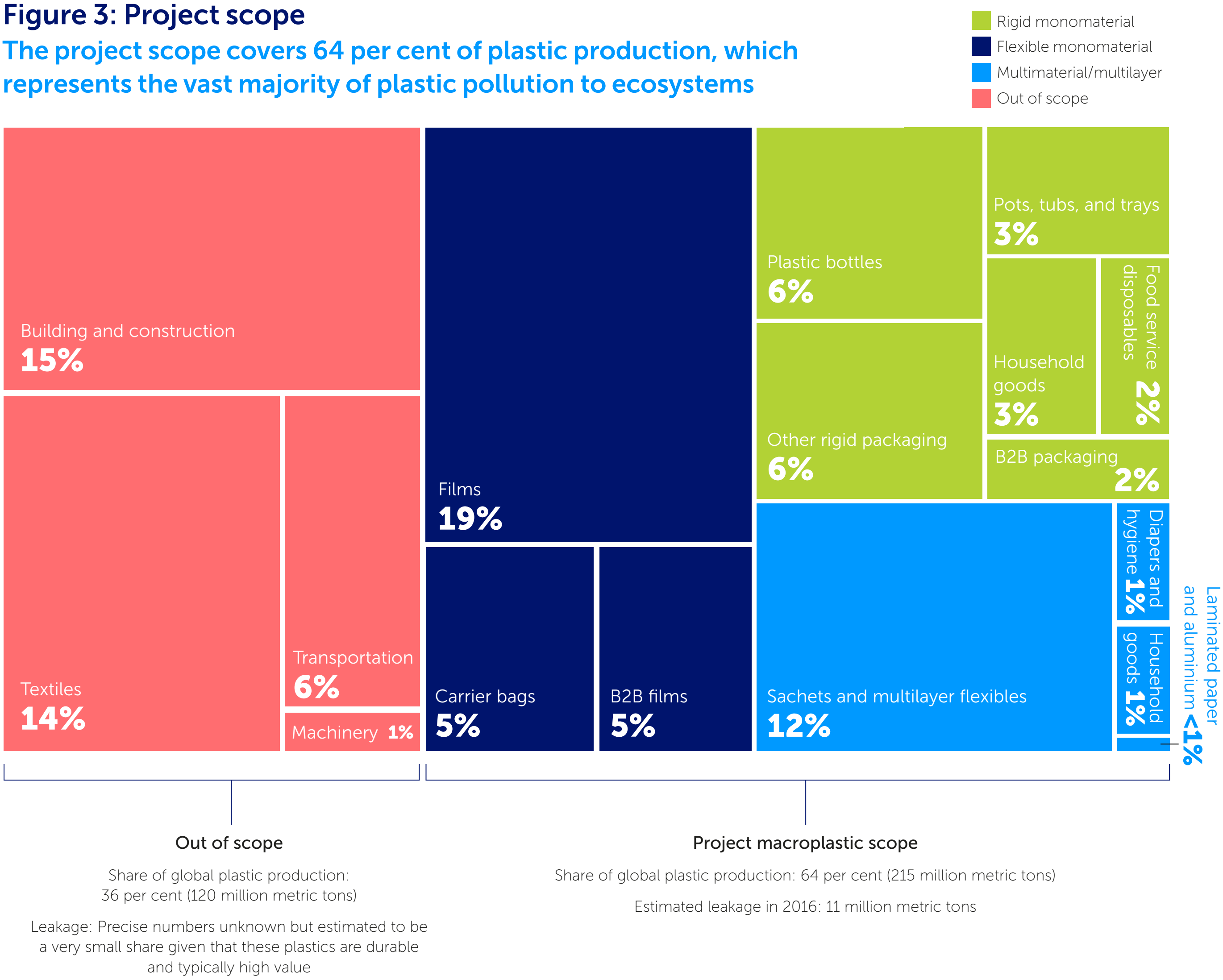
✓ Modelled at current commitment level ✔ Maximum foreseeable level

Project scope

Our analysis quantifies leakage rates and solutions for municipal solid waste plastic. This includes plastic packaging and single-use products, diapers and sanitary waste, cigarette butts, durable consumer products, household products, and business-to-business packaging (see Figure 3). Excluded from the project scope are medical waste; hazardous waste; electronics; textiles; furnishings; agricultural waste; and transportation, construction, and other industrial waste as these do not typically enter municipal solid waste. We also modelled four sources of microplastics (tyre abrasion, textile losses, pellet losses, and personal care products). Other sources of microplastics, for example, artificial turf, paint, microplastics generated by abrasion in food packaging,[26] and microplastic ingredients in other products such as fertilisers, were excluded due to limited data availability. Of the 335 million metric tons of plastic produced globally in 2016,[27] 215 million metric tons was within the scope of our analysis, covering the vast majority of land-based sources of plastic leakage to the ocean. Maritime sources of leakage were also considered, albeit qualitatively given constraints on data availability.

Figure 3: Project scope

The project scope covers 64 per cent of plastic production, which represents the vast majority of plastic pollution to ecosystems



The project scope shows the municipal solid waste macroplastic applications and their relative contribution to municipal solid waste globally. Total global plastic production in 2016 was 335 million metric tons, of which municipal solid waste represented 215 million metric tons, or 64 per cent.

System map

At the heart of our analysis is a conceptual model that highlights the main flows and stocks of the global plastic system for both macroplastics (Figure B.1) and microplastics (Figure B.2, Figure B.3, Figure B.4, Figure B.5). We collected data to set parameters for the size of each box and arrow in the system map for each geographic archetype, for each plastic category, and for each of the six scenarios. Where data were unavailable, expert opinion was collected; where expert opinion was unavailable, assumptions were transparently made—the rationale for which is outlined in the technical appendix.

To quantify the system map, we designed a stochastic stock and flow model of coupled ordinary differential equations. We used municipal solid waste data from the World Bank “What a Waste v2.0” data set to estimate the total land-based macroplastic input into the system with the potential to enter the ocean as plastic pollution. We projected the growth in demand for plastic as a function of population size coupled with per capita municipal solid waste generation derived from country-level municipal solid waste generation data. To set parameters for the potential scaling of the different interventions, we estimated maximum foreseeable growth and implementation rates based on historical trends. Economic costs calculated include operating and capital expenditures (opex and capex) where relevant, but do not include taxes, subsidies, or externalities; all government and private sector costs cited as outputs of scenarios are reported in 2016 US$.

Due to the differences in data availability, quality, and uncertainty of the data used in the analyses (e.g., plastic flows across the system map, among geographic archetypes, and plastic categories), we developed a data pedigree scoring framework to standardize uncertainty across all input variables. For each input variable, all data sources were scored across four attributes: sample size, uncertainty, accuracy and reliability, and date of publication (see the technical appendix). This uncertainty is propagated through to the model outputs using a Monte Carlo simulation. The Monte Carlo simulation allows us to estimate the variability in scenario outcomes, given the significant uncertainty associated with many flows in the system maps and the coupled nature of flow magnitudes. Using this approach, we ran 300 simulations of each scenario, for each archetype, over the years 2016-2040. In each simulation, input values throughout the model were sampled at random from a range of uncertainty defined by the data pedigree framework. This stochastic approach to estimating stocks and flows in the global plastic system produces a different model result for each model run, which collectively forms the range of potential outcomes for a given scenario. By comparing the range of outcomes among scenarios, robust trends emerge across scenarios, allowing us to draw conclusions about effective strategies and interventions for reducing ocean plastic pollution. Because there is no data set that is sufficiently detailed for validating the model, we conducted sensitivity analyses to assess the influence of key variables and assumptions on the results, as well as to identify the key drivers in the system. The analytical engine for the model is constructed in Matlab and the code can be run using freely available software. The Matlab source code and all data gathered for this project are publicly available. This project is less about providing one definitive answer than about a decision support tool for facilitating the debate on appropriate and effective strategies.

Taken together, our model and findings can help decision-makers understand some of the economic, environmental, and social implications of settling for BAU, and some of the potential benefits and risks of key system intervention strategies to reduce ocean plastic pollution. Moreover, our model would allow stakeholders to evaluate these trends, and benefits and risks, with their own data for their own situation.

Model limitations

The quantity and global distribution of plastic pollution depend on a complex set of human actions and system components that are constantly in flux and unlikely to be measured—let alone modelled—with a high level of certainty. Accordingly, we designed a series of scenarios to better understand the extent to which near-term decisions affect future plastic pollution and the conditions likely to minimize this pollution. The analyses we present in this report allow for the evaluation of major differences in the global plastic system through the assessment of alternative futures.

Although modelled scenarios were designed by an expert panel representing all relevant disciplines, and we used the best available information to inform mass flows and costs, the model does not capture all the components and complexity of the global plastic system. Because gaps exist in data on the generation, collection, recycling, disposal, and leakage of plastic waste, the model is unable to accurately measure all feedbacks in the system. Model design and construction required expert judgment to fill data gaps and estimate current and potential rates of change for the system components, which were then used to generate scenarios. As a result, the analyses include inherent assumptions and are unable to determine system sensitivities to important external drivers, such as the price of oil. In addition, a global model has, by definition, limited granularity, and our conclusions need to be applied carefully to local contexts.

Despite these limitations, the model results are informative as long as they are appropriately contextualized. Outputs from the Monte Carlo modelling approach should be treated as a range of potential values that could be observed, and individual numerical results should be treated as approximate and part of a range of possible outcomes. Despite some wide ranges, comparisons among scenarios can be robust, particularly when the rank-order of scenario results is consistent across Monte Carlo simulations. This means that, rather than providing specific directions for government and industry decision-makers to pursue at individual locations, outputs should be viewed as a system-level assessment of potential futures based on a broad suite of actions and stakeholder priorities. By conducting a sensitivity analysis to key assumptions, we found that the high-level findings outlined in the report's executive summary are robust. For example, it is evident that the plastic pollution crisis can only be solved with significant reduction and substitution of plastic in the system. Similarly, the economic limitations of recycling described in the report hold true even when different assumptions are made for some data inputs.

Uncertainty

All stochastic modelling results presented in the Executive Summary include 95 per cent confidence intervals. In the rest of the report, results are presented without confidence intervals. For the details on uncertainty calculations, please see section 5 in the technical appendix.

Additional information is available upon request. The complete codebase, all input files, and raw outputs for model runs are available at https://dx.doi.org/10.5281/zenodo.3929470.

A waste picker sifts through a mountain of garbage at the Jabon landfill site in Sidoarja, Indonesia.
Ulet Ifansasti

An Untenable Trajectory

The imperative to address the ocean pollution plastic crisis

Plastic waste in Pattaya, Thailand
Leonid Danilov/Pexels

The plastic crisis is getting worse—fast—and neither business-as-usual, nor the combined results of current commitments, nor any single solution, will solve the problem. This situation poses a growing risk to ecosystems, communities, businesses, and unaware investors alike.

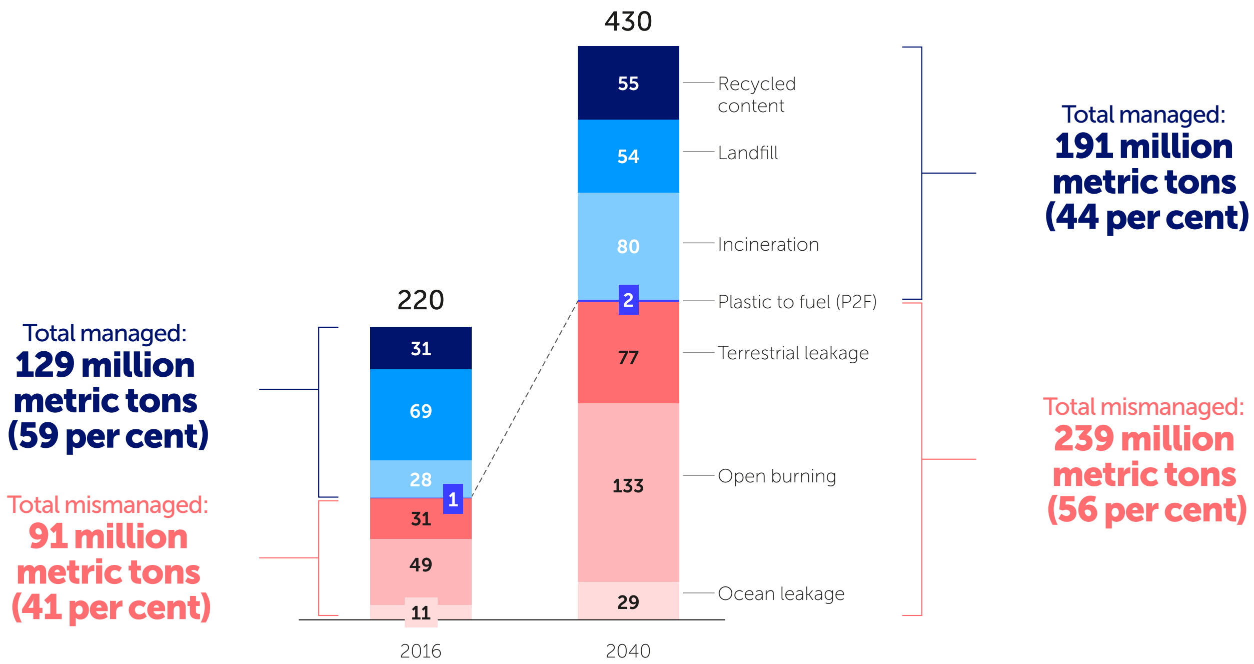
Super growth: Business-as-Usual will have nearly three times more plastic leaking into the ocean in 2040

We estimate that 11 million metric tons of plastic entered the ocean from land in 2016, adding to the estimated 150 million metric tons of plastic already in the ocean.[28] Plastic flows into the ocean are projected to nearly triple by 2040 to 29 million metric tons per year. Even worse, because plastic remains in the ocean for hundreds of years, or longer, and may never biodegrade, the cumulative amount of plastic stock in the ocean could grow by 450 million metric tons in the next 20 years—with severe impacts on biodiversity, and ocean and human health. The Business-as-Usual (BAU) Scenario presents significant health risk to communities—with a three-fold growth in open burning of plastics, increasing the release of persistent toxic chemicals, and a 2.4-fold growth in primary microplastic leakage to the ocean. BAU is also incompatible with the goals of the Paris Agreement: Without action, greenhouse gas (GHG) emissions associated with plastic production, use and disposal in 2040 would account for 19 per cent of the total emissions budget allowable if we are to limit global heating to 1.5°C. Businesses may also suffer financially under BAU, given that they may in the future be required to pay a virgin plastic tax or Extended Producer Responsibility fees to help cover the cost of collection and safe disposal—a total financial risk of US$100 billion per annum, equivalent to 25 per cent of turnover in a low-margin business.[29] Industry also risks losing the social license to operate, among multiple other risks.[30]

Figure 4: Fate of all plastic waste under Business-as-Usual

Mismanaged plastic waste will grow from 91 million metric tons in 2016 to 239 million metric tons by 2040

Million metric tons of plastic waste (macroplastic and microplastic)



More mismanaged plastic means more ocean plastic

Our model shows that the global mass of mismanaged plastic under BAU could grow from 91 million metric tons in 2016 to 239 million metric tons in 2040; plastic leakage to the ocean could therefore grow from 11 million metric tons in 2016 to 29 million metric tons in 2040, as shown in Figure 4. As a result, an estimated 1.7 trillion-6.6 trillion (10^{12}) pieces of macroplastic waste and 3 million trillion ($3x10^{18}$) pieces of microplastic waste could be entering the ocean annually by 2040.

Total plastic waste generation could increase by a factor of 2 by 2040; with waste infrastructure not being able to keep up with this exponential growth, plastic leakage to the ocean will, without massive intervention, nearly triple. Under such a scenario, the cumulative stock of plastic in the ocean is likely to grow by a factor of more than 4 by 2040 (see Figure 5).

What is leaking into the ocean and where is it coming from?

Figure 6 provides a detailed overview of the sources of plastic leakage into the ocean in 2016, based on our analysis, showing that:

- Rural areas contribute 4.7 million metric tons (43 per cent) of total annual plastic leakage to the ocean.
- Flexible monomaterials (such as films, wraps, and bags) make up 5 million metric tons (46 per cent) of leakage, and multilayer/multimaterial plastics (such as sachets, diapers, and beverage cartons) make up 2.8 million metric tons (26 per cent).
- Microplastics contribute 1.3 million metric tons (11 per cent) of total leakage.
- Upper middle-income (UMI) and lower middle-income (LMI) countries collectively contribute 9.5 million metric tons (88 per cent) of total leakage.

Our analysis modelled the four main routes through which land-based macroplastic waste enters the ocean, as presented in Figure 7: 1) uncollected waste directly dumped into water; 2) uncollected waste dumped on land that makes its way to water; 3) collected waste deposited in dumpsites that moves via land and air into water and; 4) collected waste dumped directly into the water by collection trucks. Based on our analysis, 61 per cent of total macroplastic leakage originates from uncollected waste, and this share could grow to 70 per cent by 2040 in the BAU Scenario as collection services fail to keep pace with macroplastic waste generation.

The perfect storm behind Business-as-Usual plastic leakage

Owing to four compounding trends—rapid population growth, rising per capita plastic use, shifts to low-value/hard-to-recycle materials, and disproportionate growth in markets with low collection—plastic flows to the ocean are expected to nearly triple by 2040.

Trend 1: A growing global population

The world's population is expected to grow by 23 per cent, from 7.5 billion in 2016 to 9.2 billion in 2040.[32] An estimated 84 per cent of the global population lives in middle-/low-income countries, where most countries don't have sufficiently high levels of waste collection.

Figure 5: Business-as-Usual projections for critical plastic indicators

The next 20 years will see plastic waste generation double, plastic leakage to the ocean nearly triple, and plastic stock in the ocean more than quadruple[31]

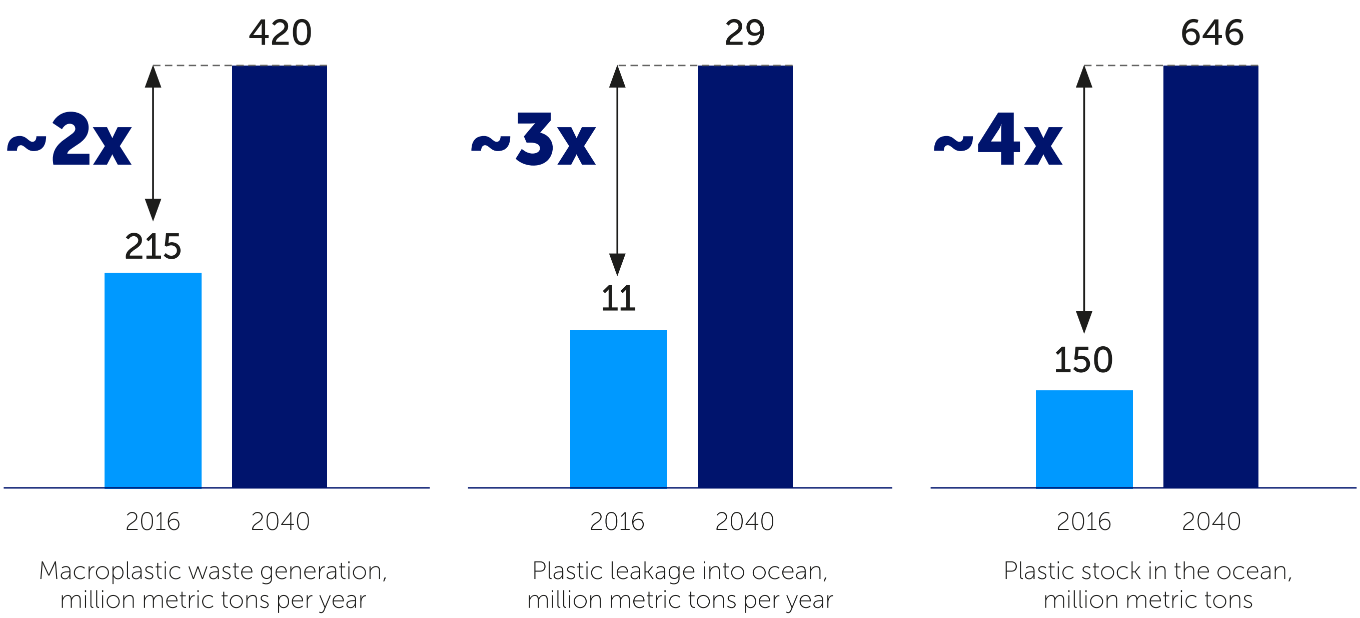
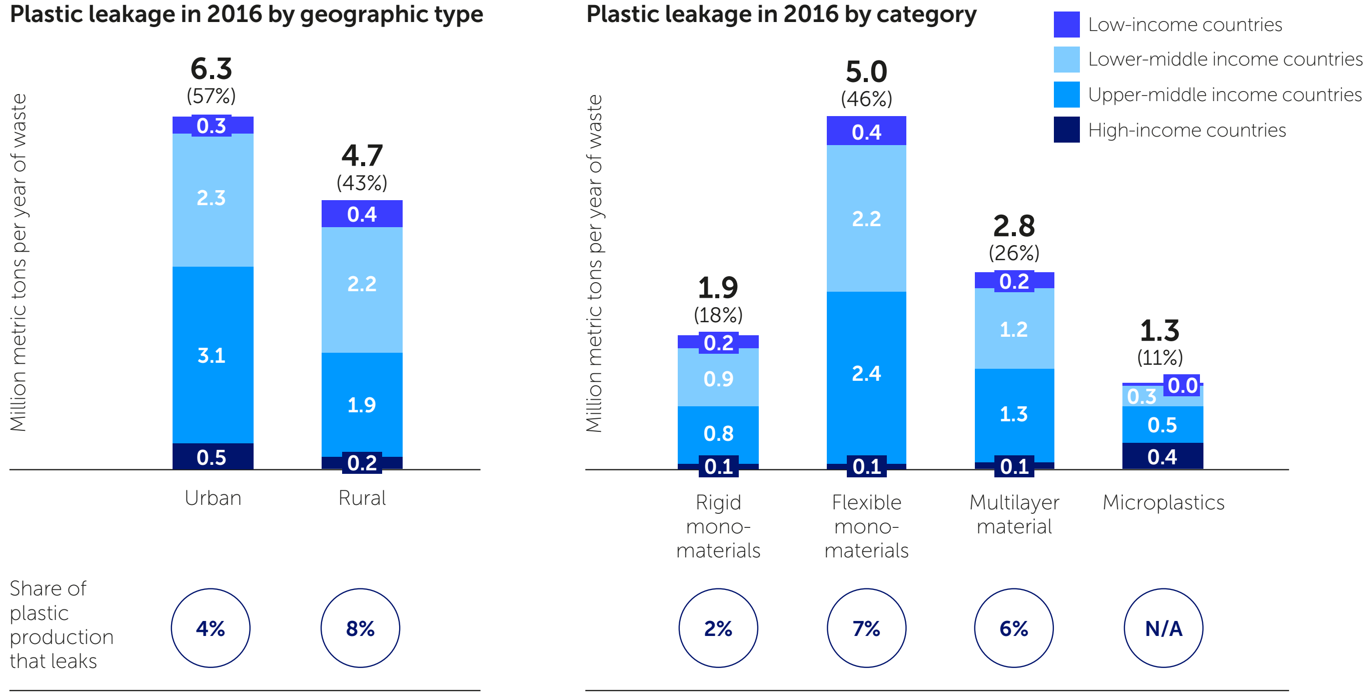


Figure 6: Main leakage points by geographic archetype and plastic category, 2016

Flexible monomaterials and multilayer materials have a disproportionate share of leakage



Trend 2: Rising per capita plastic consumption

Our analysis suggests that average global per capita plastic consumption will grow by 58 per cent under BAU, from 29 kg per year in 2016 to 46 kg per year by 2040. This global increase is largely driven by urbanization and rapid economic development in LI, LMI and UMI archetypes, where today's per capita consumption is much lower than the high-income (HI) average of 76 kg per year. It is also caused, at least in part, by the continued rise in the production and supply of cheap virgin plastic and the transition over the past generation to businesses using large amounts of single-use plastic in place of reusable alternatives or other materials or business models.

Taking trends 1 and 2 together, plastic waste generation nearly doubles over the next two decades, with the highest rates of growth occurring in LI, UMI and LMI archetypes at 260 per cent, 133 per cent and 127 per cent, respectively.

Trend 3: Shift to low-value, hard-to-recycle plastics

Rising waste generation could be exacerbated by an anticipated "race to the bottom," with a shift towards low-cost/low-value, hard-to-recycle plastic materials. Because low-value materials have significantly lower collection rates, this would likely increase ocean plastic pollution.

Trend 4: Disproportionate growth in markets with low collection

Our analysis indicates that the share of plastic waste generated in middle-/low-income countries is expected to grow from 58 per cent in 2016 to 71 per cent in 2040. This is because these countries will experience the greatest compounding effects from the first two trends. By 2040, under BAU, we estimate that the mass of uncollected macroplastic waste could triple, from 47 million metric tons per year in 2016 to 143 million metric tons per year.

Microplastics

Another set of trends will contribute to greater levels of microplastic pollution in the ocean. Four sources of microplastic leakage are included in this analysis: tyre abrasion from vehicle driving, plastic microfibres from synthetic textiles, personal care products containing microplastic ingredients, and pellet losses from plastic production and conversion facilities. Leakage from these sources is less well understood than macroplastic, but it is expected to increase by between 1.3 and 2.5 times by 2040 under BAU, driven by population growth, more vehicles per capita, increased consumption and production of plastic-based textiles, growing usage of personal care products containing microplastic ingredients, and rising plastic pellet production.

Our study quantifies primary microplastic leakage, i.e., waste that enters the environment as microplastic particles. However, the breakdown of macroplastic already in the environment into microplastic and nanoplastic particles is also an important risk to address, as it is expected to increase significantly as the stock of ocean plastic pollution grows..[33]

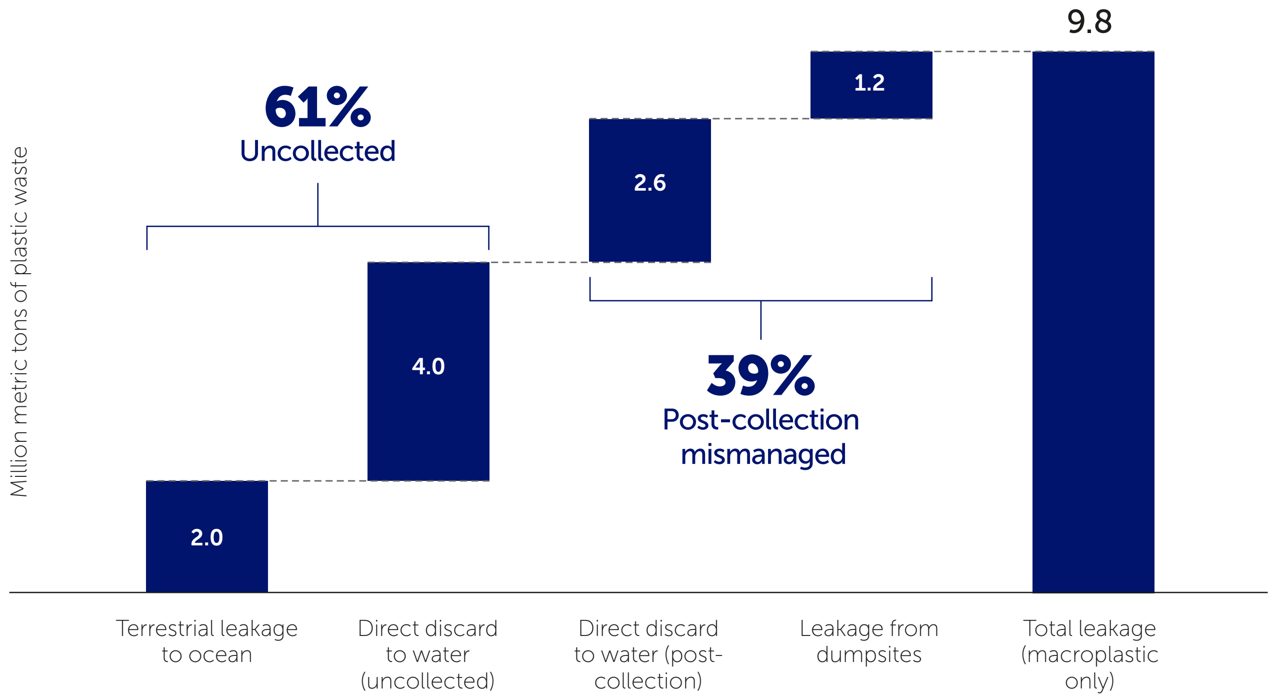
The multiple risks and costs of inaction

Environmental risks

Adding 450 million metric tons of plastic stock in the ocean would likely have severe impacts on biodiversity and ecosystem services. More than 800 species are already known to be affected by marine plastic pollution,

Figure 7: Macroplastic leakage into the ocean globally by leakage route, 2016

In 2016, uncollected waste contributed 61 per cent of total leakage, while the remaining 39 per cent was waste that was mismanaged after collection



This graphic reflects our estimate of how much macroplastic enters the ocean through different routes (and excludes microplastics). These numbers have high uncertainty and are highly sensitive to model inputs.

including all sea turtle species,[34] more than 40 per cent of cetacean species and 44 per cent of marine bird species.[35] Through ingestion or entanglement, macroplastics can cause mortality,[36] injury, and sublethal impacts such as malnutrition.[37] These impacts would be expected to occur at a greater frequency, affecting more individual animals and a greater number of species, as levels of plastic in the ocean rise. The uptake and trophic transfer of microplastics has also been observed in aquatic food webs, and laboratory studies have demonstrated dose-dependent impacts on growth, health, fecundity, survival, and feeding in a range of invertebrate and fish species.[38] Potential impacts on ocean carbon sequestration have also been postulated.[39] Although we still lack methods for measuring the harm caused by microplastics and nanoplastics in the natural environment, if microplastic emissions to the environment remain the same or increase, risk assessments indicate that the ecological impacts may be widespread within a century.[40]

Disturbances to the aquatic food web from plastic pollution can also negatively impact the scientific and cultural value of marine ecosystems and may degrade the function and productivity of marine environments.[41] Other studies show that invasive species and diseases are being transported on plastic debris to new locations where they can cause harm to local populations.[42]

New research suggests that the impacts from ocean plastic meet two of the three essential conditions for compounds to be considered a threat under the planetary boundary framework for chemical pollution. The framework defines boundaries for some manmade disturbances, set at levels to avoid thresholds or shifts in the Earth's functioning that would create increasing risks for the public. One review found that plastic pollution in the ocean is irreversible and globally pervasive, but that there is inconclusive evidence to determine whether it has disrupted Earth-system processes or regulating capacities.[43] Filling these knowledge gaps could allow a better understanding of the tipping points and environmental thresholds for plastic pollution.

Following the BAU trajectory would also further jeopardize our ability to mitigate climate change due to rising GHG emissions arising from increased plastic production. The goals of the Paris Agreement would be difficult to achieve, with life-cycle plastic-related emissions doubling from 1.0 $GtCO_2e$ in 2016 to 2.1 $GtCO_2e$ by 2040, accounting for 19 per cent (compared with 3 per cent today) of the total annual emissions budget allowable if we are to limit global heating to 1.5°C.[44]

Business risks

There are direct, physical risks from marine plastic pollution to businesses that rely on a clean ocean. This pollution is responsible for significant business costs to fisheries, tourism and infrastructure operators, among others, estimated at US$13 billion per year.[45] Risks include physical damage to ships and fishing assets, reduced fish catches from or declining fish stocks, and reduced demand and higher operating (i.e., clean-up) costs in the tourism industry. In addition, there are indirect risks to businesses stemming from the response to plastic pollution from regulators, investors, consumers, employees, and the general public.

In the event of a public backlash, businesses could face significant supply chain disruptions, reduced demand for plastic-intensive products, and reputational risk from brand association with plastic pollution.[46]

Our analysis suggests that the global cost of all MSW plastic waste collection and management in 2040 will be US$100 billion under BAU, out of which governments will fund US$60 billion, as shown in Figure 8. The remaining "funding gap" of US$40 billion presents a risk to the plastic industry in case it is required by government policy to fund that gap. Moreover, the industry also risks being required to pay for the US$60 billion funded by governments, through Extended Producer Responsibility (EPR) or other schemes. Together, this risk accounts for 25 per cent of the US$400 billion of the plastic industry's turnover.[47]

Socioeconomic risks

The use of virgin plastics is not as cheap as the market suggests. In fact, the current methods of (mis)handling end of life for these products have large costs that are not reflected in markets. Socioeconomic impacts include loss of land value due to proximity to plastic pollution and reduced quality of life for coastal communities. One estimate suggests a loss of US$1.5 trillion per year from the ocean due to the reduction in seafood, genetic resources, oxygen, clean water, cultural value, and the reduced ability to regulate climate.[48] Another study models the social and environmental impacts of marine plastic even higher, at US$2.2 trillion per year.[49] Although these specific estimates are contested, the socioeconomic risks of a polluted ocean are clearly significant.

Health risks

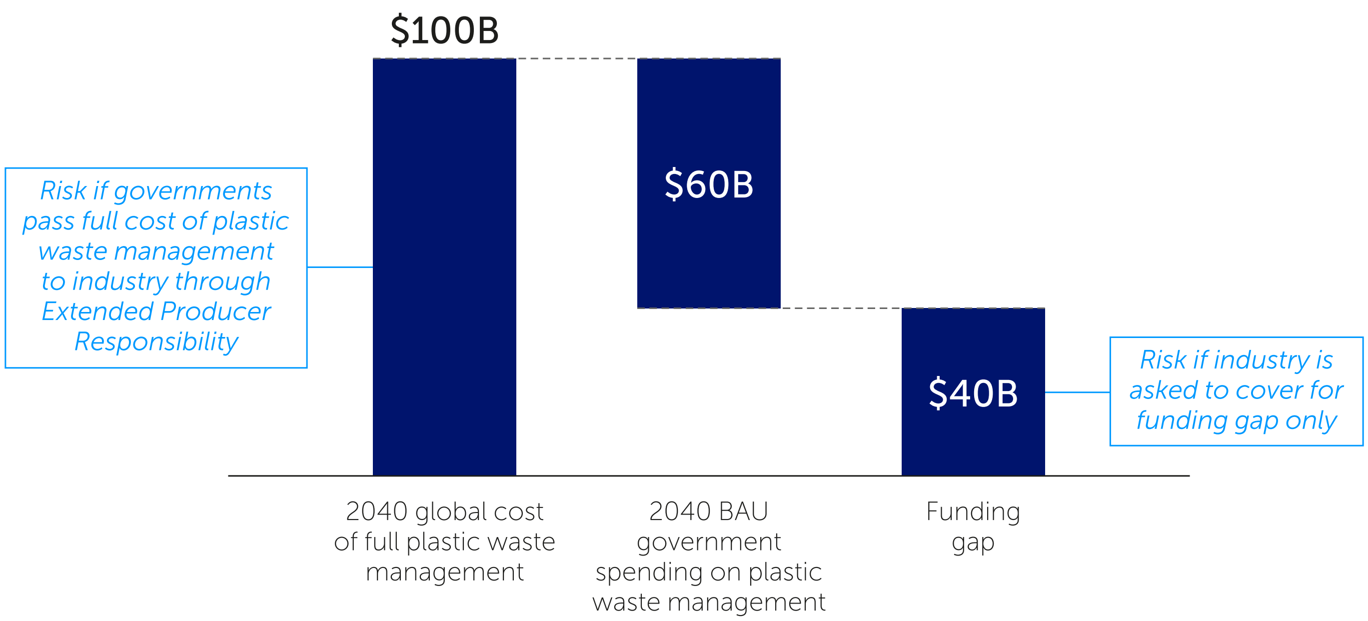
There are numerous human health implications across every stage of the plastics supply chain. Health risks associated with virgin plastic production are often caused by volatile organic compounds (VOCs, e.g., benzene, styrene and propylene) and persistent bio-accumulative and toxic pollutants (PBTs, e.g., lead, mercury and some polyaromatic hydrocarbons [PAHs]).[50] Long-term exposure in human populations is believed to increase the risk of cancer and reproductive health complications.[51] Plastic products themselves could also pose health risks due to the presence of PBTs and endocrine disrupting chemicals.[52, 53]

Mismanaged plastic waste can undermine the psychological benefits from coastal environments; it can block rivers and drainage systems, causing flooding and trapping stagnant water that exacerbates the spread of diseases in impacted communities.[54] Some of the most harmful health risks result from open burning, which based on our analysis is expected to nearly triple under BAU, from 49 million metric tons in 2016 to 133 million metric tons in 2040. In addition to GHG emissions, open burning releases a host of pollutants known to negatively affect human health.[55] These pollutants can increase the risk of heart disease, cancer, respiratory infections and asthma, reproductive health complications, and damage to the central nervous system.[56] The only real remedy is to avoid open burning altogether. For more details about the health implications of incinerating plastic waste, see Box 14.

Microplastic leakage from land-based sources, which is expected to increase by 2.4 times under BAU for the four sources modelled, also has potential health impacts. Studies have identified microplastics in foodstuffs, including in shellfish, in bottled water, and in the tissues of terrestrial and marine invertebrates, fish and humans.[57] However, this is a relatively new area of research, and microplastic exposure levels and their potential long-term consequences are not yet fully understood, as was concluded by the 2019 World Health Organization report on microplastics in drinking water, which calls for further assessment of the potential impacts on human health.[58]

Figure 8: Full plastic waste management cost versus government spending

Industry could face an annual US$100 billion financial risk by 2040—25 per cent of current turnover—if required to cover global plastic waste collection and management



Falling short: current commitments are inadequate for the scale of the challenge

Even if current government and industry commitments are fully implemented, plastic flows into the ocean in 2040 would likely be only 7 per cent lower than under BAU. In the meantime, hundreds of billions of dollars are being invested in new virgin plastic production plants, locking us deeper into the status quo every day.

Mounting public pressure on ocean plastic pollution has led many governments and businesses to make commitments. These range from banning certain plastics and setting more ambitious recycling targets to introducing product standards and Extended Producer Responsibility schemes, investing in recycling infrastructure, and imposing trade restrictions on plastic waste. The estimated impact of this Current Commitments Scenario adds up to 19 million metric tons per year reduction in plastic production and consumption due to policy regulations by 2040 and 5.4 million metric tons per year increase in recycled content by 2025 due to commitments expressed by more than 400 companies (see the technical appendix).

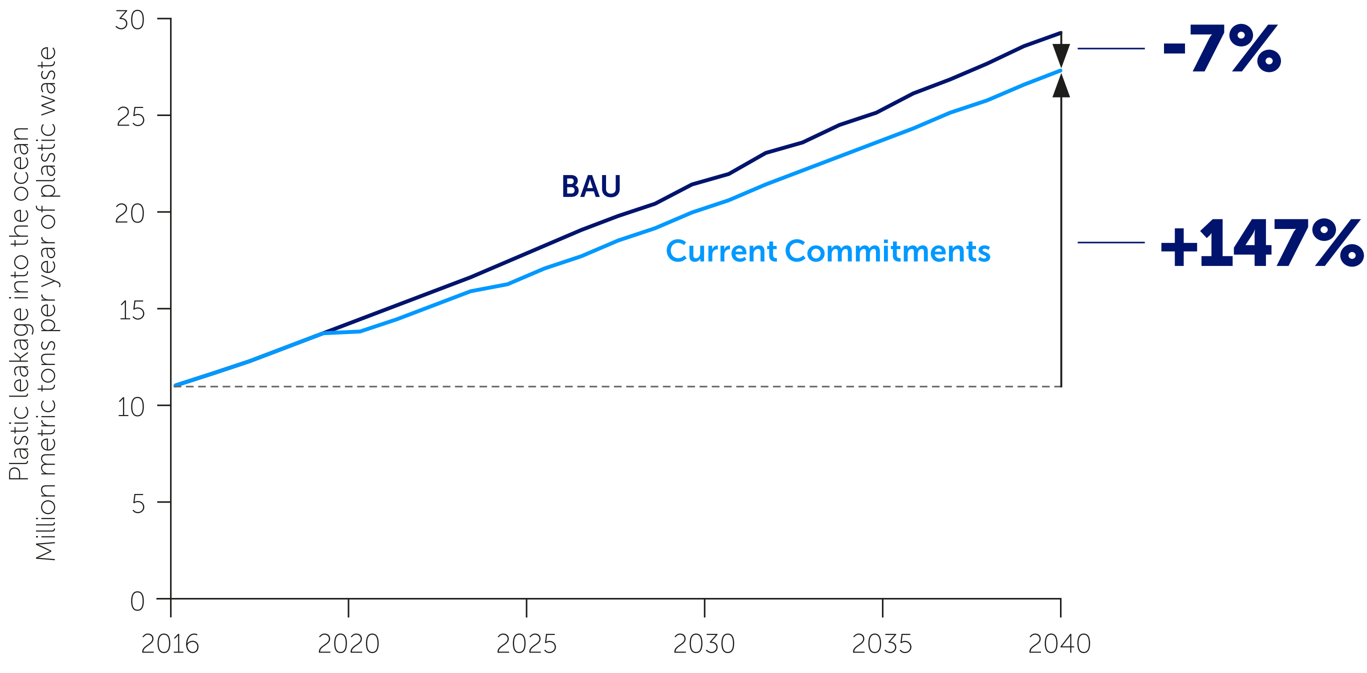
Good intentions

Although these current commitments represent very welcome and vital first steps, and the potential beginning of mutually reinforcing trends, our model indicates that even if all major existing industry pledges and government plans, targets and commitments—including the 2019 European Union single-use plastics directive (which bans certain plastic products and introduces consumption reduction measures and collection targets for others),[59] multiple national plastic bag and straw bans—are implemented and enforced, leakage to the ocean for the plastic categories modelled is still expected to reach 27 million metric tons per year by 2040, 7 per cent less than the BAU projection for 2040, as shown in Figure 9.

Government aspirations are broad and, if fully implemented, can have impact. However, most new regulations focus on specific items rather than enacting system-wide policies and setting system-wide standards, and do not address or significantly curb the projected growth in plastic production. This limited impact is further illustrated by the fact that, even if legislation akin to the European Union single-use plastics directive, one of the most ambitious regulatory initiatives to date, was emulated by all countries and implemented globally, it would still reduce plastic leakage to the ocean

Figure 9: Land-based plastic leakage under the Business-as-Usual and Current Commitments scenarios

Current commitments from industry and government policies achieve only a 7 per cent reduction in plastic leaking into the ocean relative to Business-as-Usual



by only 15 per cent compared with BAU by 2040. The collective impact of all current national and municipal legislation regarding items such as straws, bags, stirrers, cups, cotton swabs, and bottles simply does not add up to a significant reduction in the overall quantity of plastic waste generated and leaked globally. To compound this shortfall, there has been insufficient growth in waste collection infrastructure over the past two decades relative to plastic waste generation, which we estimate has been growing at a 4-7 per cent compound annual growth rate. Governments need to act now to curb the growth in plastic production; set system-wide standards, targets, and incentives to drive upstream reduction, reuse, appropriate substitution and design for recycling; and invest in downstream collection and recycling infrastructure.

Industry has made commitments through the New Plastics Economy Global Commitment, the Alliance to End Plastic Waste, and other vehicles. It is focusing most visibly on recyclability, recycling targets, and other downstream solutions, but significant efforts are also needed on upstream solutions. Business signatories to the Global Commitment have pledged to adopt 100 per cent reusable, recyclable, or compostable packaging by 2025 and to take action to eliminate problematic or unnecessary plastic packaging and move from single-use towards reuse models, but have not yet committed to specific targets on elimination or reuse.

Although these initiatives can have an impact, they also do not add up to a significant reduction in the quantity of plastic waste generated and leaked globally. To achieve a meaningful reduction in ocean plastic pollution, companies that have not made any commitments (the vast majority), should do so and ensure their implementation. Industry will need to fundamentally redesign business models, products, and materials at scale, and in ways that explicitly decouple economic growth from plastic growth, significantly scaling up its efforts on reduction, refill, and new delivery models.

In the meantime, the status quo is being reinforced every day, with global plastic production expected to increase by 40 per cent over the next decade.[60] Capacity growth is being driven by major petrochemical companies worldwide, which have announced large-scale investments in new refineries, steam crackers and production plants. The United States chemical industry alone is forecast to spend more than US$164 billion on 264 new plastic factories by 2023, with an additional US$140 billion being spent on 15 large projects in China, and more than US$100 billion earmarked for projects in Saudi Arabia.[61] Globally, the ethylene market—one of the main building blocks for plastic—is expected to grow at a compound annual rate of 8.7 per cent between 2019 and 2026.[62] In effect, plastic production is becoming the new engine of growth for a petrochemical industry potentially facing declining demand for oil in transportation and energy, raising concerns about the creation of a "plastic bubble" whereby new investments risk becoming stranded assets.

Our analysis shows that even if all current commitments are implemented, virgin plastic will likely continue to be a cheap commodity, plastic production will remain high and growing, and our dependence on the highest leakage plastic applications will persist. Avoiding the creation of a "plastic bubble" requires redesigning the system—instead of tinkering at the edges—and shifting ambitiously to circular solutions.

No panacea: single-solution strategies cannot stop plastic pollution

Many strategies have been proposed for reducing or even eliminating plastic leakage into the ocean, but there is no single solution that can do so effectively by 2040. Our modelling shows that, by 2040, none of the single-solution strategies can reduce leakage to the ocean below 2016 levels, let alone achieve near-zero leakage, without hitting significant technical, economic, social or environmental limits. Claims that we can combat ocean plastic pollution by focusing only on waste management or only on reduction and substitution may sound appealing but at best tell only half the story. To achieve the desired outcomes, we must combine solutions from all the different pathways.

Much of the current debate and strategizing on preventing plastic pollution focuses on either upstream or downstream solutions. Our analysis shows that this is a false dichotomy. Upstream solutions that aim to reduce or substitute plastic use are critical but need to be scaled carefully to limit unintended social or environmental consequences. Downstream solutions are also essential but are restricted by the limits of economic viability, their negative impacts on human health and the environment, and the realistic speed of infrastructure development—especially in the face of growing plastic waste production in middle-/low-income countries—and must be coupled with upstream efforts on reduction and reuse to maximize the efficient use of resources.

We modelled three single-solution scenarios that focused on ambitious implementation of either upstream or downstream measures—the Collect and Dispose Scenario, the Recycling Scenario and the Reduce and Substitute Scenario. Each of these scenarios was modelled using two approaches. In the first approach, we defined economic, environmental and social "red lines" for each scenario that are reflected in their maximum foreseeable growth and implementation limits.

To compare among solutions with very different environmental (pollution and GHG), economic, performance (health, safety, product protection), and consumer acceptance dimensions, each potential solution was evaluated against four criteria, and these informed the maximum foreseeable limits modelled for each potential solution:

- Technology Readiness Level: Is a solution available today?
- Performance: Does the intervention satisfy performance and health requirements?
- Convenience: Is the intervention acceptable for lifestyle and convenience?
- Affordability: Are the cost implications of the alternative acceptable?

In the second approach, we set the scenarios to achieve a level of plastic leakage to the ocean similar to the System Change Scenario, but without setting technical, environmental or social limits. The difference between these two approaches is described in Table 1.

Table 1: Description of the two scenario approaches

Approach 1: Scenarios constrained by limiting factors	Approach 2: Unconstrained scenarios, set to achieve System Change Scenario leakage levels
Collect & Dispose Scenario constrained by maximum foreseeable: • Collection rates by archetype, split by urban and rural regions *(Affordability & Performance limit)* • Scaling up of controlled waste management *(Affordability limit)* **Recycling Scenario constrained by maximum foreseeable:** • Collection rates by archetype, split by urban and rural regions *(Affordability & Performance limit)* • Separation at source *(Convenience limit)* • Food-grade requirements *(Performance limit)* • Technological improvements *(Technological limit)* • Incentives for recycling/recycled content *(Performance limit)* • Design for recycling *(Performance & Convenience limit)* • Scale up of chemical conversion technologies *(Technology, Environmental & Affordability limit)* **Reduce & Substitute Scenario constrained by maximum foreseeable:** • Technological availability of alternative materials and new delivery models *(Technology limit)* • Performance and environmental impact of alternative materials and reuse/new delivery models *(Performance limit)* • User adoption of substitute materials and reuse models *(Convenience limit)* • Industry adoption of alternative materials and new delivery models *(Affordability limit)*	For each of the scenarios, we set the model to achieve similar leakage levels as the System Change Scenario by not constraining collection and landfill levels to maximum foreseeable political, economical, environmental, or social realities. Instead, we modelled that collection and landfill are scaled to the extent necessary to bridge the gap between the remaining leakage in each scenario under Approach 1 and that of the System Change Scenario.

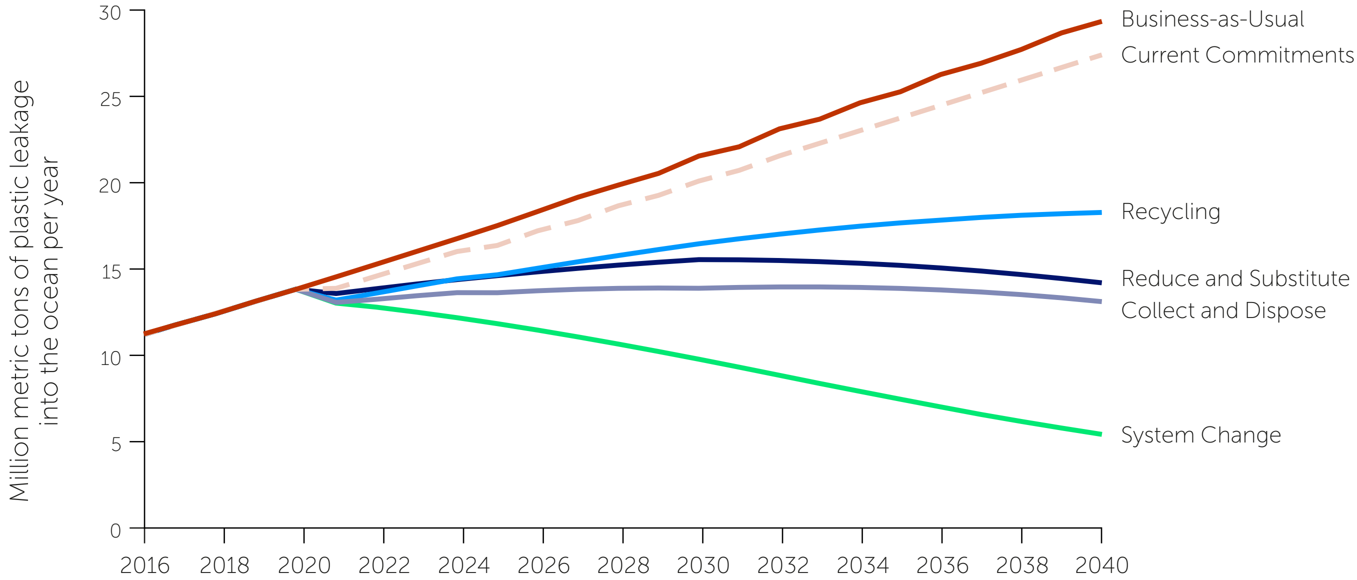
Results of Approach 1: Modelled scenarios with technical, social, and environmental limits

Although all three scenarios represent a significant reduction of plastic leakage to the ocean by 2040 relative to the BAU or Current Commitments scenarios, as Figure 10 shows, none of them offers a credible pathway to a near-zero leakage future by 2040. For full assumptions and results by scenario, see the technical appendix.

It is important to acknowledge that attempting to solve the ocean plastic challenge through waste management alone would require closing a huge collection gap. Today, 2 billion people globally do not have waste collection services.[63] By 2040, the global population is expected to grow by 1.7 billion (out of which 95 per cent are in middle-/low-income countries), making the total number of people who require being connected to collection services approximately 4 billion by 2040. Closing this collection gap would require connecting about 500,000 people to collection services per day, every day, until 2040. Most people without waste collection live in middle-/low-income countries, where funding is less available, and/or in rural areas, where collection is more logistically challenging and expensive. Considering the growth of plastic production and consumption projected under BAU, collecting all plastic, including in all rural locations, would come at the very high cost of US$510 billion from 2021 to 2040. To make matters more difficult, collection is a "bundled system"—in other words, plastics cannot be collected in isolation; other waste streams also need to be collected. As a result, the actual government cost for waste management amounts to US$3.1 trillion in present value for all municipal solid waste to be collected in this period (see Box 7). Any solution based only on waste management is therefore highly unlikely to succeed in curbing plastic pollution unless accompanied by a meaningful reduction of waste in the system.

Figure 10: Land-based plastic leakage under different scenarios

The System Change Scenario would achieve about an 80 per cent reduction in annual plastic leakage to the ocean relative to Business-as-Usual, exceeding all other modelled scenarios



The graphic shows expected levels of plastic leakage into the ocean over time across different scenarios. It shows that although upstream-focused pathways (Reduce and Substitute Scenario) and downstream-focused pathways (Collect and Dispose Scenario and Recycling Scenario) reduce annual leakage rates relative to BAU, they do not reduce leakage below 2016 levels. Only the integrated upstream-and-downstream scenario (System Change Scenario) can significantly reduce leakage levels.

Implications of the Collect & Dispose pathway

A strategy focused solely on collection and disposal would likely still leave 13 million metric tons of plastic leakage to the ocean per year by 2040, 18 per cent above 2016 levels, and would cost governments US$130 billion more than BAU in present value between 2021 and 2040.

One option, in theory, for dealing with all mismanaged plastic waste is to scale up collection systems globally and develop sanitary landfills and/or incinerators to dispose of the waste. Landfills have been presented as a potential panacea for their (perceived) affordability, ease of implementation and generation of tax revenue through landfill fees. Incineration with energy recovery has been proposed as a scalable solution because it does not require redesigning products or sorting waste; it makes plastic waste "disappear," generating electricity in the process. Some countries, including China, are scaling up incineration rapidly to reduce the need for landfills. Our analysis reveals insurmountable limitations to this approach.

Economic implications: Attempting to address plastic pollution through this scenario would cost governments US$800 billion in present value between 2021 and 2040 for waste management (i.e., collection, sorting, and safe disposal), relative to US$670 billion under BAU. The vast majority of these costs would fall on middle-/low-income countries. This pathway is very uneconomical (and very unlikely) because landfilling is a net-cost solution that generates no revenue (except for tipping fees, which are a tax, not a revenue driven by economic value creation) and is therefore not scalable through market forces. Like landfills, incineration with energy recovery is also a net-cost solution once collection costs are factored in, although—based on local market prices for electricity—it is more economical than landfilling. Investing in incinerators would also lock us even further into carbon-intensive energy generation, relying on a long-term, stable flow of plastic feedstock to recuperate the hundreds of millions of dollars in capital costs required to build each plant. Moreover, the value of heat or energy recovery is persistently below collection costs. If we accounted for the cost of carbon, even at low carbon prices (e.g., US$50 per ton of CO_2e), incinerators would no longer have a business case.

Health and environmental implications: This scenario would result in annual GHG emissions of 1.8 GtCO_2e by 2040, making up 17 per cent of the total allowable annual carbon budget if we are to limit global heating to 1.5°C. Incineration emits 5.4 tons of carbon dioxide equivalent (tCO_2e) per metric ton of plastic, making it the solution with the highest level of GHG emissions among all solutions analysed (see Figure 12), as well as generating significant health risks, as outlined in Box 14.

Implications of the Recycling pathway

A strategy focused solely on recycling—including ambitious design for recycling coupled with an ambitious scale-up of collection, sorting, mechanical recycling and plastic-to-plastic chemical conversion infrastructure—would still result in 18 million metric tons of plastic flowing into the ocean each year by 2040, 65 per cent above 2016 levels, and would cost governments US$140 billion more than BAU in present value between 2021 and 2040.

Many envision a system with a high-quality, economically viable mechanical recycling component (powered by the improved design of materials, products, and recycling technologies; high demand for recycled content; and new automated waste sorting and separation technologies) coupled with emerging chemical conversion technologies that convert low-value plastic waste into chemical feedstocks for petrochemical products.

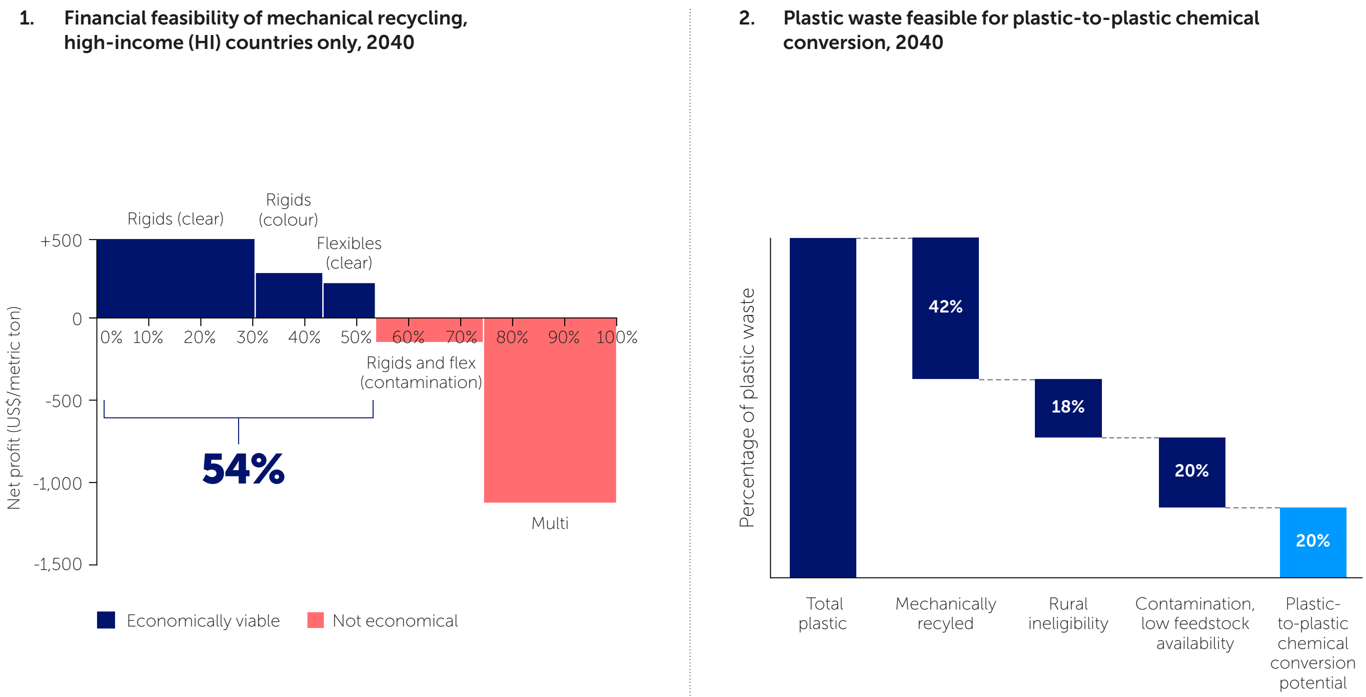
Although scaling up recycling is critically needed, our study finds that stopping plastic pollution by capturing all plastic materials in the recycling process is neither technically nor financially feasible. The utility of mechanically recycled plastic is limited by the quality requirements of food-grade plastic and the fact that most plastic is limited to two or three recycling loops before quality deteriorates. Although this is not a technological limiting factor in chemical conversion, an emerging recycling technology that returns plastics to their more basic molecular building blocks, we estimate that 20 per cent of plastic could be eligible for chemical conversion, as shown in Figure 11, because of contamination or limited feedstock due to collection limitations.

Even though this scenario includes ambitious design for recycling and investment in infrastructure, unless recycling economics can pay for collection, it will recycle plastic that would have been collected anyway. In other words, recycling feedstock would be made up of landfill-bound plastic, not ocean-bound plastic. Although diverting more plastic from landfill to recycling is beneficial in terms of resource efficiency, GHG emissions, and health implications, significant plastic pollution will still flow to the ocean under the Recycling Scenario because not enough is done to reduce the amount of unmanaged plastic waste.

Economic implications: The total present value of the 2021-2040 costs amount to US$810 billion for governments globally (21 per cent above the US$670 billion under BAU). As the left side of Figure 11 shows, we estimate that even in HI countries, about half (54 per cent) of plastic could be economically recycled using mechanical recycling by 2040

Figure 11: Limitations of mechanical recycling and plastic-to-plastic chemical conversion

By 2040, mechanical recycling could deal with 54 per cent of the plastic waste stream economically while plastic-to-plastic chemical conversion could deal with 20 per cent



Left: By 2040, 54 per cent of plastic will be economically recyclable in HI, when accounting for design for recycling. Net profit is US$ per metric ton of collected plastic, which is calculated as sales price minus the cost of recycling for different material types. No taxes are included, and the costs of collection and sorting have been excluded. Contamination is defined as the share of plastic that is not collected separately for recycling. This analysis represents HI, where the share of uncontaminated waste is higher than in middle-/low-income countries. Commodity prices are assumed to remain stable.

Right: The scope of chemical conversion is limited to 20 per cent of total plastic waste. Mechanical recycling takes precedence over chemical conversion. The scale requirements further reduce the chemical conversion potential by eliminating rural areas based on low feedstock availability. Of the remaining plastic waste, 50 per cent is assumed to be either contaminated or incompatible with a pyrolysis plant.

(compared with 21 per cent today). This assumes that the recycler does not cover the costs of collection and sorting, which in HI countries are often absorbed by governments or can be paid by industry through Extended Producer Responsibility schemes.

Health and environmental implications: This scenario would result in GHG emissions of 1.8 $GtCO_2e$ per year by 2040, making up 17 per cent of the total allowable annual carbon budget if we are to limit global heating to 1.5°C, largely driven by the fact that chemical conversion uses high levels of energy, as described in Figure 20. Chemical conversion with pyrolysis also releases several harmful pollutants that increase risks for cancer, respiratory infections, kidney damage and neurotoxicity.[64] More information can be found in Box 11.

Although scaling up recycling is critically important, stopping plastic pollution by capturing all plastic materials in the recycling process is neither technically nor financially feasible.

Implications of the Reduce & Substitute pathway

A strategy focused solely on reduction and substitution would result in 14 million metric tons of plastic leaking into the ocean per year by 2040, 28 per cent higher than 2016 levels.

Some organizations, government bodies and citizens have proposed a dramatic reduction of plastic use through bans, reuse and refill models, coupled with substitution of plastics for other materials. Yet, while reduction and substitution of plastic is critically needed, if carried out in isolation, these strategies are unlikely to succeed in eliminating plastic leakage by 2040 because there are many plastic applications that are difficult to reduce or substitute within social, political, environmental, and economic limitations and within this time scale. Considering these limitations (see System Intervention 1 and technical appendix for the scoring framework used to determine limiting factors), our analysis estimates that 47 per cent of BAU plastic utility demand can be met by plastic reduction and substitution measures by 2040. This is equivalent to capping global plastic production and consumption at 2017 levels, while continuing to provide the projected total utility demands and lifestyle expectations of a growing population through new delivery models and/or alternative materials.

Reuse models can certainly reduce costs, and some reuse solutions have already reached scale, such as soft drinks and milk distributed in reused plastic or glass bottles, and reusable crates and pallets used in business-to-business packaging. However, expanding reuse to 100 per cent of plastic may face significant barriers to consumer adoption in certain applications, and many refill projects are small scale and too new to have proved their long-term viability.[65]

Substitute materials also have their own environmental impacts—on land and water use, GHG emissions, pollution, etc.—and require investment in end-of-life collection and processing infrastructure. Their use should therefore always be considered with a holistic set of environmental indicators in mind. Our scenario includes substituting nonrecyclable plastics with recyclable paper and coated paper, or with certified compostable materials in situations where suitable home- or industrial-scale composting infrastructure is rolled out. Our global analysis does not include substituting to single-use glass, metal or drinks cartons due to our assessment of social, economic, and environmental trade-offs, although in specific cases and geographies, these may be suitable (see section on System Intervention 2 for further details).

Given existing market conditions and available solutions, it is therefore not likely to be feasible to reduce or substitute 100 per cent of plastic in use by 2040. A Reduce and Substitute Scenario in isolation would reduce ocean leakage by 58 per cent compared with BAU in 2040. However, without a comprehensive set of downstream solutions being rolled out at the same time, significant ocean leakage will still occur because much of the plastic produced will fail to be collected and managed, particularly in middle-/low-income countries.

Economic implications: The total present value of the 2021-2040 costs amount to US$540 billion for governments globally (20 per cent less than the US$670 billion under BAU), driven by 90 million metric tons less waste needing collection and processing. However, the cost to businesses and consumers increases significantly, driven by the higher production cost of paper and compostable packaging compared with plastic. These extra costs of substitute materials are to a large extent offset by the savings created by reducing unnecessary plastics and moving towards reuse and new delivery models. It is possible to increase the extent of substitution further than in this scenario by using other substitutes, such as glass or metal, but this could have further negative impacts on product prices due to higher production, recycling and/or shipping costs. Aluminium cans and glass bottles are 33 per cent and 167 per cent more expensive than PET (polyethylene terephthalate) bottles, respectively.[66]

Health and environmental implications: This scenario would result in GHG emissions of 1.7 $GtCO_2e$ per year by 2040, making up 16 per cent of the total allowable annual carbon budget if we are to limit global heating to 1.5°C. Caution is required in sustainably sourcing the paper and compostable materials, and ensuring that they are recycled or composted at end of life. If levels of substitution were significantly higher than those modelled here, it would likely exceed the availability of materials that could be sourced and processed sustainably. The environmental footprint of alternative materials depends on several factors, including the length of supply chains, the rate of reuse and recycling, and the availability of recycled content. For example, glass has very high reuse rates in Latin America, and a lower GHG footprint as a result,[67] but it has a higher GHG footprint in single-use applications in regions where there is a low glass recycling rate. If supply chains could be shortened, materials reused, or transport decarbonized, a variety of substitute materials may perform well, but all options should be assessed on multiple criteria, including the likelihood of leaking into the environment, water and land use, pollution, and health risks from the use of unregulated chemicals or recycled content. For detailed GHG emissions of specific material alternatives, refer to Figure 20.

Results of Approach 2: Releasing feasibility constraints

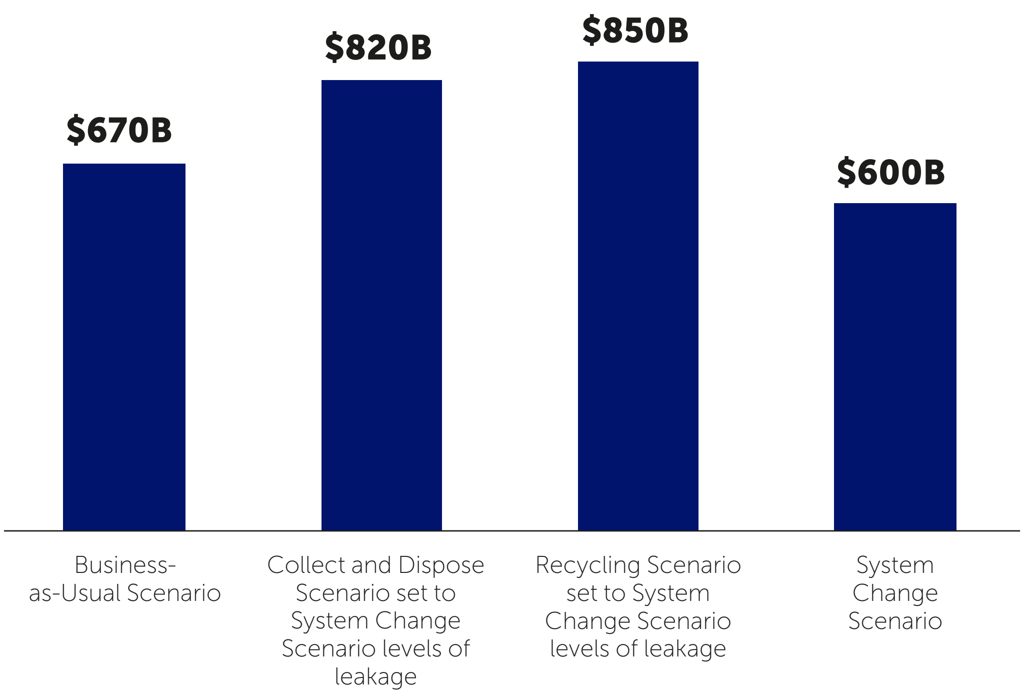
The scenarios modelled above are all limited by technical, economic, environmental, and political constraints to what is feasible. We also modelled the implications of overriding these constraints to quantify what the cost of the Collect and Dispose and the Recycling scenarios would be if we "forced" them to achieve similar levels of plastic leakage to the ocean by 2040 as under the System Change Scenario (5 million metric tons per year). The present value cost to governments of forcing the Collect and Dispose Scenario and the Recycling Scenario is estimated at US$820 billion and US$850 billion, respectively, compared with a cost of US$600 billion under the integrated System Change Scenario. Figure 12 compares the different scenarios on key economic and environmental indicators. It shows that an integrated System Change Scenario, as outlined in Chapter 2, outperforms all other scenarios across all dimensions.

In either approach—with or without enforcing technical limits—the System Change Scenario produces superior results across economic, environmental, and social dimensions. The conclusion of this analysis is that a system-wide problem demands system-wide change. Any of the single-solution strategy approaches hit technical, economic, environmental, and/or social limits. To solve the open plastic pollution problem, we need a portfolio of both upstream and downstream solutions—or system interventions. The next chapter describes what such an integrated pathway could look like—one that matches available solutions to different plastic categories and different geographies, and estimates the relative share of the ocean plastic problem that each solution contributes towards reducing when they work in synergy. These estimates aim to provide an indication of the relative effort, investment and policy support to be allocated to each system intervention to achieve the overall result of the System Change Scenario.

Figure 12: Comparison of different scenarios on cost, plastic leakage, and GHG emissions

The System Change Scenario is the most affordable for governments

Cost to governments, in US$ billions, 2021-2040 (net present value)



2040 plastic leakage, million metric tons	29	5	5	5
2040 GHG, $GtCO_2e$	2.1	1.8	1.7	1.6

Changing the System

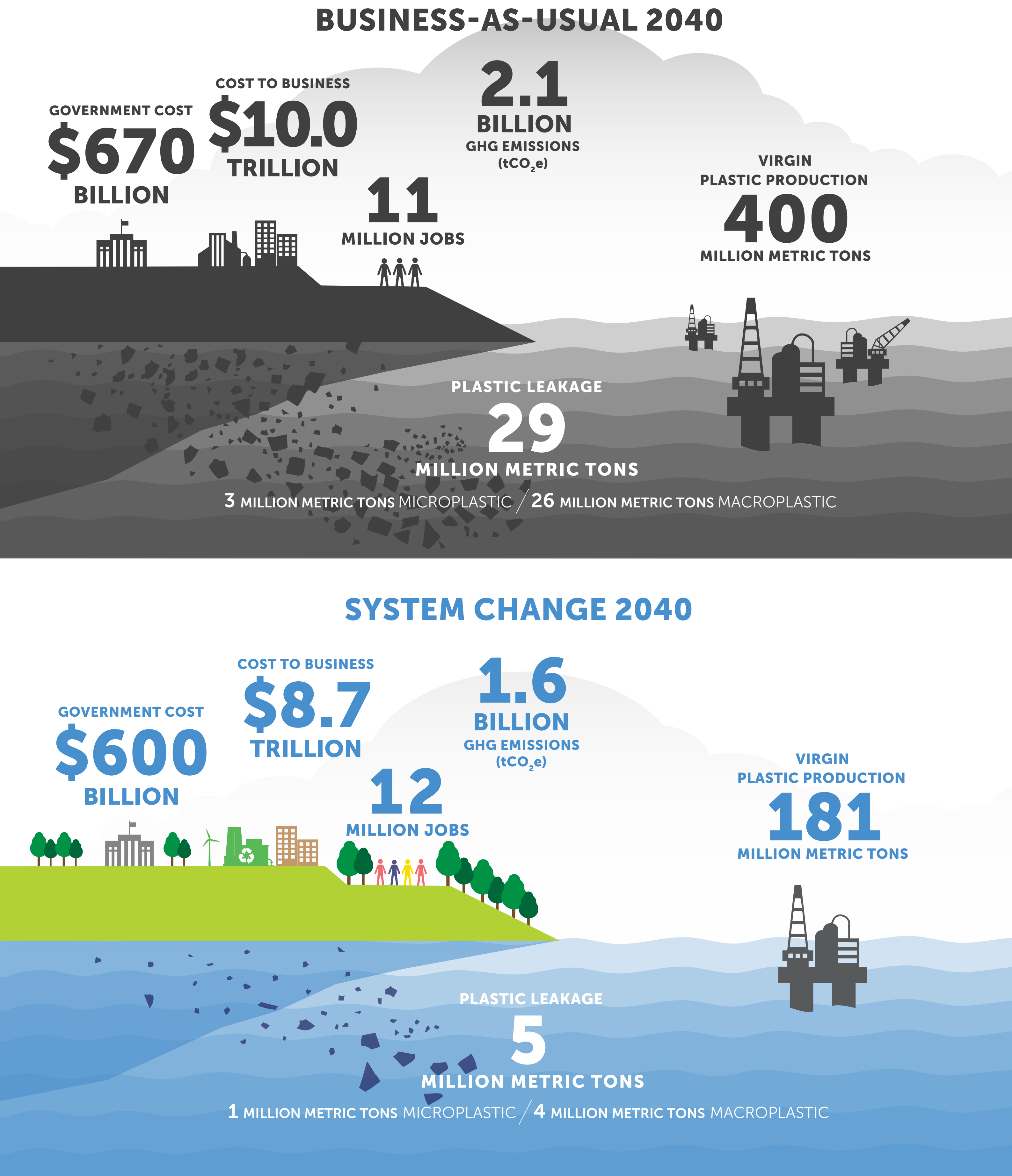
A strategy to reduce ocean plastic pollution rates by 80 per cent

Waves roll ashore in Cape Town, South Africa.
Dan Grinwis/Unsplash

Figure 13

Changing the plastics system: better for the economy, the environment, and communities

Continuing on our current Business-as-Usual trajectory will nearly triple the annual flow of plastic into the ocean by 2040, with severe environmental, economic, and social impacts. A cleaner, more sustainable future is possible with concerted action starting in 2020 across the entire global plastics system, with lower costs to governments and lower greenhouse gas (GHG) emissions.



A viable pathway: an integrated circular strategy can offer better economic, environmental, and social outcomes

Dramatically reducing the mismanaged waste generated by the plastic ecosystem is a complex system-level challenge that requires system-level interventions. Our System Change Scenario sets out a feasible pathway towards ending ocean plastic pollution while creating co-benefits for climate, health, jobs, and the environment. To realize this transformation, the scenario applies eight system interventions concurrently, ambitiously, and starting immediately.

Figure 14 summarizes the upstream and downstream system interventions that define the System Change Scenario, according to the plastic categories and geographies for which they are most relevant. To be successful, these system interventions must be applied together and to both macroplastics and microplastics where possible.

Some interventions rely on others to be effective; for example, collection precedes recycling, landfilling and incineration; and design for recycling helps improve the economic viability and scalability of mechanical recycling. The synergistic impact of scaling all interventions concurrently is shown in Figure 15.

Figure 14: System interventions relevance by geographic archetype and plastic category

System interventions need to be applied to the regions and plastic categories for which they are most relevant

Highly applicable | Somewhat applicable | Not applicable

	System intervention	Most relevant income groups				Urban/ rural		Most relevant plastic categories				Main responsible stakeholder
1	Reduce growth in plastic consumption	HI	UMI	LMI	LI	U	R	Rigid	Flex	Multi	Microplastics	Consumer goods brands; retailers
2	Substitute plastics with suitable alternative materials	HI	UMI	LMI	LI	U	R	Rigid	Flex	Multi	Microplastics	Consumer goods brands; retailers
3	Design products and packaging for recycling	HI	UMI	LMI	LI	U	R	Rigid	Flex	Multi	Microplastics	Consumer goods brands
4	Expand waste collection rates in the Global South	HI	UMI	LMI	LI	U	R	Rigid	Flex	Multi	Microplastics	Local governments
5	Increase mechanical recycling capacity globally	HI	UMI	LMI	LI	U	R	Rigid	Flex	Multi	Microplastics	Waste management companies
6	Scale up global capacity of chemical conversion	HI	UMI	LMI	LI	U	R	Rigid	Flex	Multi	Microplastics	Waste management companies; petrochemical industry
7	Build safe waste disposal facilities	HI	UMI	LMI	LI	U	R	Rigid	Flex	Multi	Microplastics	National governments
8	Reduce plastic waste exports	HI	UMI	LMI	LI	U	R	Rigid	Flex	Multi	Microplastics	National governments

Behind the BAU vs. System Change Scenario numbers

All costs reflect the present value of global costs incurred between 2021 and 2040 (capex and opex) using a 3.5 per cent discount rate.

Cost to government: Net opex and capex to governments for formal collection, formal sorting (material recovery facilities), incineration plants, and landfill facilities for plastic and substitute materials (excluding the cost of nonplastic waste), excluding taxes and subsidies such as landfill fees.

Private costs: Net opex and capex of the plastics value chain (and substitutes) to the economy, including material production, conversion, informal collection, sorting, recycling, landfilling, and incineration. Costs are net of any revenues generated, such as from recycling.

Plastic leakage to ocean: Total mass of 2040 plastic leakage to the ocean (microplastic and macroplastic).

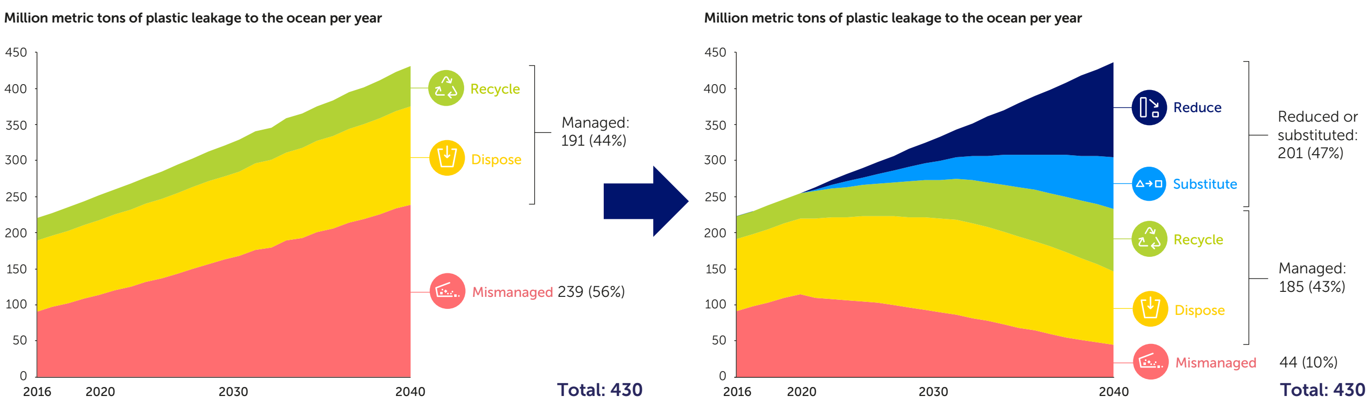
GHG emissions: Total 2040 life-cycle assessment emissions of all plastics (and substitutes), including production, conversion, collection, sorting, mechanical recycling, chemical conversion, incineration, landfill, and open burn.

Job creation: Number of livelihoods in 2040 directly connected to the plastics value chain or making a living by selling waste (waste pickers); includes formal and informal employment; System Change Scenario likely an underestimate as new delivery models were assumed to generate the same jobs as the plastic it replaces.

Virgin plastic production: Total amount of virgin plastic production in 2040.

Figure 15: Plastic fate in Business-as-Usual versus System Change Scenario: a "wedges" analysis

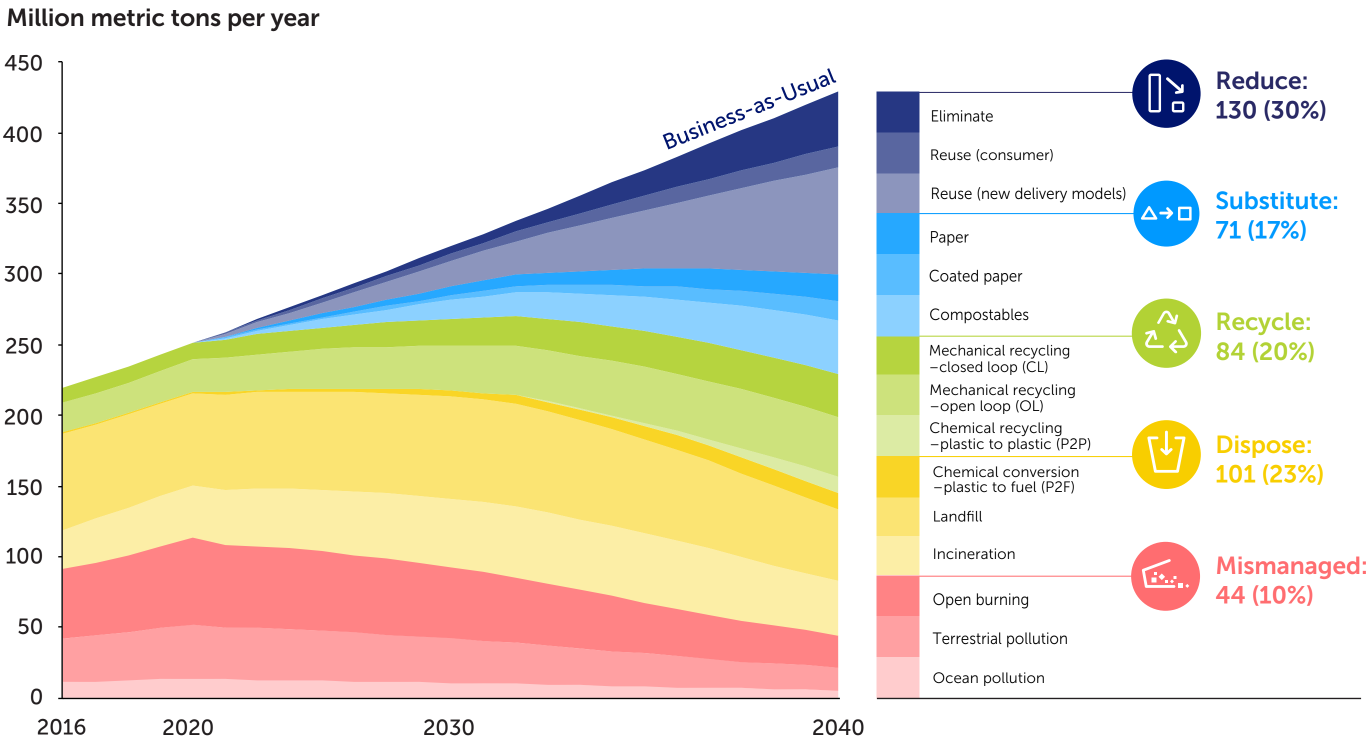
Mismanaged waste could be reduced from 56 per cent under Business-as-Usual to 10 per cent under the System Change Scenario



This figure compares the mass of plastic in each "wedge" under BAU, left, with the amount of plastic in each "wedge" under System Change Scenario, right, over time. Reduced "wedge" refers to plastic utility that can be fulfilled without generating any plastic waste (details in System Intervention 1). Substituted "wedge" refers to plastic utility that can be fulfilled with alternative materials (details in System Intervention 2). This figure shows that mismanaged waste can be reduced from 239 million metric tons under BAU to 44 million metric tons under the System Change Scenario, a reduction of about 80 per cent (82 ±13 per cent). This is the same level of reduction to annual plastic leakage mass by 2040 if the System Change Scenario is implemented.

Figure 16: Plastic fate in the System Change Scenario: a "wedges" analysis

There is a credible path to significantly reduce plastic leakage to the ocean, and it requires all solutions to be implemented concurrently, ambitiously, and starting immediately



This "wedges" figure shows the share of treatment options for the plastic that enters the system over time under the System Change Scenario. Any plastic that enters the system has a single fate, or a single "wedge." The Reduce wedge represents plastic utility that has been fulfilled without using physical plastic. The Substitute wedge reflects plastic utility that has been fulfilled by alternative materials such as paper or compostable materials. The Recycle wedge accounts for the plastic that is recycled in the system, either mechanically or chemically. The Dispose wedge includes plastic that cannot be reduced, substituted, or recycled but is managed in a way that ensures that it does not leak into the environment. All other plastic is considered Mismanaged. The numbers include macroplastic and microplastic.

Figure 16 shows that there is a credible and appealing pathway to deal with ocean plastic pollution. This strategy involves scaling up Reduce levers to 130 million metric tons (30 per cent of Business-as-Usual plastic waste) to replace avoidable plastic, growing Substitute levers to 71 million metric tons (17 per cent), expanding Recycle levers to 84 million metric tons (20 per cent) and Disposing 101 million metric tons (23 per cent) of the remaining plastic waste in controlled facilities.

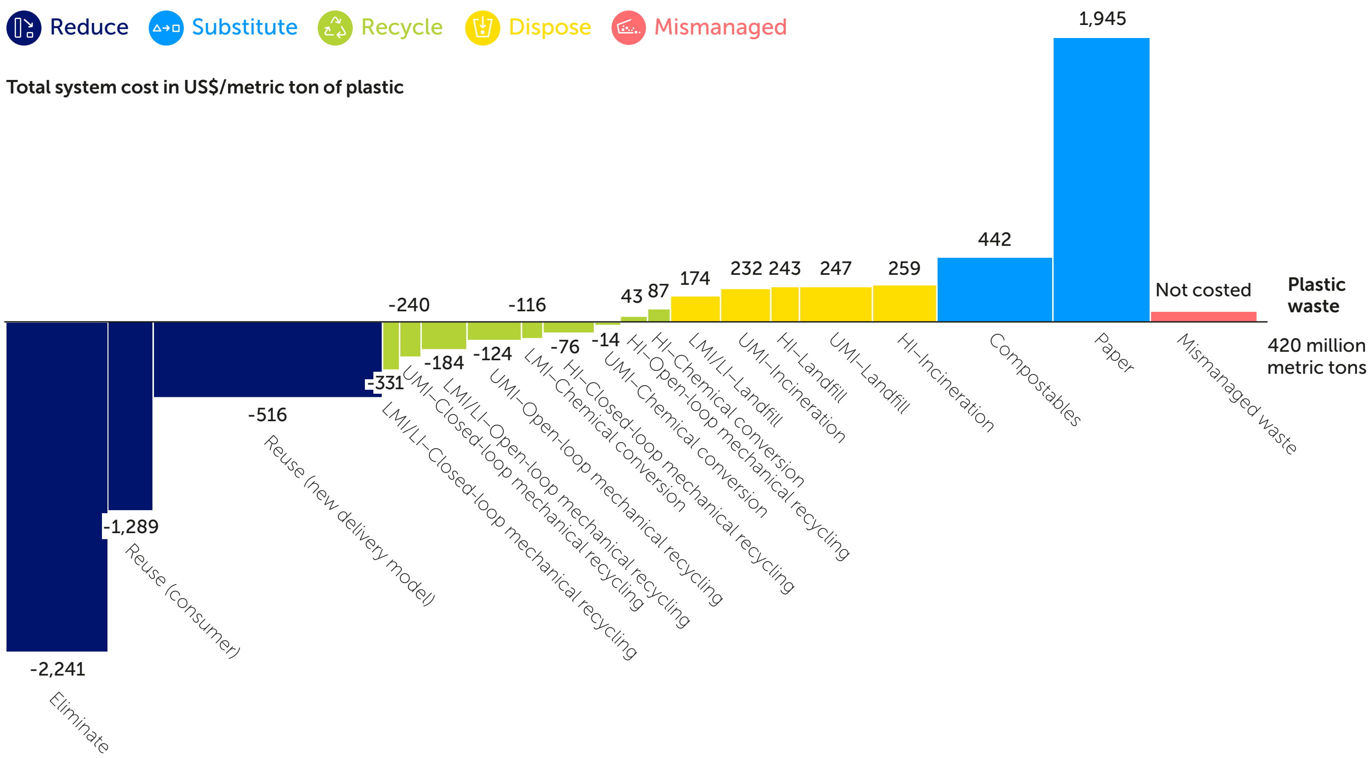
As Figure 17 shows, Reduce levers are the most attractive from an economic perspective, often representing a net-saving solution. Plastic elimination, such as through bans and product redesign, is assumed to have zero cost; therefore, each metric ton of eliminated plastic would save the full cost of 1 metric ton of plastic in the Business-as-Usual (BAU) plastics value chain, i.e., US$2,241. Mechanical recycling offers a saving in low-income (LI), lower middle-income (LMI) and upper middle-income (UMI) archetypes, but a cost in high-income (HI) countries due to higher labour costs. Although recycling solutions represent a net cost today, they could become much more economical in the future with scale, technological improvements, and policy support, and could even represent a net-saving solution for certain plastic categories in certain geographies (especially if oil prices do not fall, driving down the value of recyclates).

Chemical conversion is estimated to offer a savings only in LMI countries due to the relatively lower cost of collection. Dispose options (landfill and incineration) cost between US$92 and US$259 per metric ton (including collection), depending on the technology and geographic archetype, and always incur net costs to the system. Finally, substitution is the most expensive option, not least because more than a metric ton of paper is required to substitute a metric ton of plastic. However, relative to the cost of the products themselves, substitutes may be affordable for certain products and in certain geographies, and, within GHG emission budgets, they have a role to play in addressing the global plastic pollution challenge. Mismanaged plastic has not been costed, but we have assumed it to be the least desirable outcome.

The systemic shifts in the global plastics value chain brought about by the System Change Scenario interventions would make a major contribution to the 2030 Agenda for Sustainable Development adopted by United Nations Member States in 2015.[68] Reducing plastic production and controlling unmanaged waste streams will help towards achieving the Sustainable Development Goals (SDGs), with the impact felt well beyond the specific target to prevent and significantly reduce marine pollution, to include SDGs related to poverty, health, employment, innovation, climate change, and more, as shown in Figure 18.

Figure 17: Costs and masses per treatment type in the System Change Scenario, 2040

Reduce levers are often the most economical to implement while plastic substitutes are typically more expensive



The X axis of this chart shows the mass (million metric tons) of plastic waste per treatment type under the System Change Scenario in 2040. The Y axis represents the net economic cost (US$) of that treatment, including opex and capex, for the entire value chain needed for that treatment type (for example, mechanical recycling costs include the cost of collection and sorting). Negative costs (on the left) represent a savings to the system relative to BAU, while positive costs reflect a net cost to the system for this treatment type. Costs near 0 mean that their implementation is near "cost neutral" to the system. Subsidies, taxes or other "artificial" costs have been excluded; this graphic reflects the techno-economic cost of each activity. The costs shown do not necessarily reflect today's costs, but costs that could be achieved after the system interventions are implemented, including design for recycling and other efficiency measures. Where costs in different archetypes were similar, we combined the figure stacks for simplification and took a weighted average of the cost per archetype. The cost of mismanaged waste, such as plastic in the environment, has not been factored in because we did not price the externalities that mismanaged waste causes.

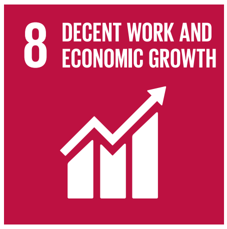
Figure 18: United Nations Sustainable Development Goals impacts by 2040 under the System Change Scenario

The System Change Scenario is better than BAU for communities, for the economy, and for the environment

Better for the economy

Creation of 700,000 net new jobs in middle-/low-income countries by 2040

Reduced exposure to chemicals and toxins from 82% lower levels of open burn by 2040



Larger share of collection and recycling served by the formal sector

Better for society

Development of better plastic alternatives and recycling technology

Reduction of 11% in government spending on waste between 2021 and 2040

Decoupling of economic growth from plastic growth

Better for the environment

Reduced GHG emissions by 25% by 2040

Reduced leakage of plastic into the ocean by 80% by 2040

Reduced leakage of plastic to land by more than 80% by 2040

Better for the economy

Savings for governments

The total global cost to governments of managing plastic waste in this low-leakage system between 2021 and 2040 is estimated to be US$600 billion in present value, compared with the US$670 billion cost to manage a high-leakage system under BAU. In other words, governments can save US$70 billion globally, while also reducing plastic pollution (although the cost in middle-/low-income countries will be US$36 billion higher under the System Change Scenario, spread over 20 years). Costs are higher under the Collect and Dispose and Recycling scenarios than under BAU, given that those scenarios do not include a reduction in plastic mass.

Overall system cost and social welfare

The total system cost (for both the public and private sectors) is comparable under the System Change Scenario relative to BAU, making the new system economically feasible and affordable for society. These similar costs, for equal plastic utility, suggest that overall social welfare is comparable between the System Change Scenario and BAU. However, this assessment excludes externalities such as health, climate, and the biodiversity impacts of plastics, which we have not quantified. These externalities would likely make the System Change Scenario substantially more economically and socially attractive to communities than BAU. The shift towards reusable, sustainable products will also save consumers money if reuse systems are well-designed and reach scale, and if brands pass these cost savings on. On the other hand, as shown in Figure 17, substitutes are more expensive currently than plastic and these costs could be passed on to the consumers for certain products. However, similarly, the costs of using plastic could increase, such as through Extended Producer Responsibility schemes.

Although the total system costs under the System Change Scenario (which include opex and capex and account for annualized depreciation) are similar to BAU, the present value of global investments in the plastic industry between 2021 and 2040 (which includes capex only and indicates the cash flow required to acquire or upgrade fixed assets such as technology or buildings) can be reduced from US$2.5 trillion to US$1.2 trillion under the System Change Scenario, with a substantial shift of investment away from the production and conversion of virgin plastic to the production of new delivery models, plastic substitutes, recycling facilities, and collection infrastructure.

Benefits and opportunities for industry

Plastic pollution presents a unique risk for producers and users of virgin plastics given ongoing regulatory changes and rising consumer outrage. But it also presents a unique opening for providers of new and existing circular business models and materials. Embarking on a trajectory to achieve about an 80 per cent reduction in plastic pollution rates will create opportunities for companies ahead of the curve: Consumer goods companies and retailers can connect with their consumers in new ways, and other suppliers in the value chain can provide alternative materials, business models, technologies, and solutions to help accelerate the change to a circular plastics economy. System change will generate new business opportunities to unlock value from a circular economy that derives revenue from the circulation of materials rather than one based primarily on the extraction of fossil fuels; large new value pools can be created around better design, better delivery models, improved recycling technologies, higher recycling demand, and smart collection systems. Our analysis shows that through the integrated application of upstream and downstream interventions, we could fulfil the growing global demand for plastic utility in 2040 with roughly the same amount of plastic in the system as today, and 11 per cent lower levels of virgin plastic production, essentially decoupling plastic growth from economic growth.

Better for society

Under the System Change Scenario, 700,000 net new formal jobs will be created by 2040 in middle-/low-income countries to fulfil demand for plastic services, including new delivery models and the production of compostables. Crucially, the System Change Scenario represents a positive social vision for the global community of 11 million waste pickers who are currently responsible for 60 per cent of global plastic recycling. To date, the huge contribution of the informal sector towards preventing ocean plastic pollution has gone largely unrecognized and is often underpaid. An increase in the material value of plastic through design for recycling, as well as the implementation of new technologies and proactive efforts to improve working conditions and integrate informal workers into waste management systems in sensitive and mutually beneficial ways, can significantly improve the lives of waste pickers.

Health hazards would also be significantly lessened under the System Change Scenario. Among the key health benefits would be a large reduction in the open burning of plastic waste, which releases carcinogens and other toxins, from 133 million metric tons per year in 2040 under BAU to 23 million metric tons per year.

Better for the environment

Plastic pollution

Under the System Change Scenario, about an 80 per cent reduction in annual leakage rates can be achieved by 2040 relative to BAU. This reduction will significantly lessen the impacts on ecosystems, habitats, and biodiversity. However, 5 million metric tons of plastic waste will still flow into the ocean in 2040 and a cumulative 248 million metric tons of plastic will have entered the ocean between 2016 and 2040. It is important that stakeholders strive to accelerate upstream innovation and go beyond the maximum foreseeable levels modelled under the System Change Scenario.

Climate change

The eight integrated System Change Scenario interventions result in 14 per cent lower cumulative plastic-related greenhouse gas (GHG) emissions relative to BAU over 2021-2040 (and 25 per cent lower annual emissions in 2040), driven by a reduction in both the production and conversion of virgin plastic (together, currently responsible for 80 per cent of life-cycle plastic emissions) as well as from decreases in open burning. Different solutions have very different GHG profiles

Figure 19: Total government cost by income groups

The System Change Scenario can save governments US$70 billion in present value between 2021 and 2040

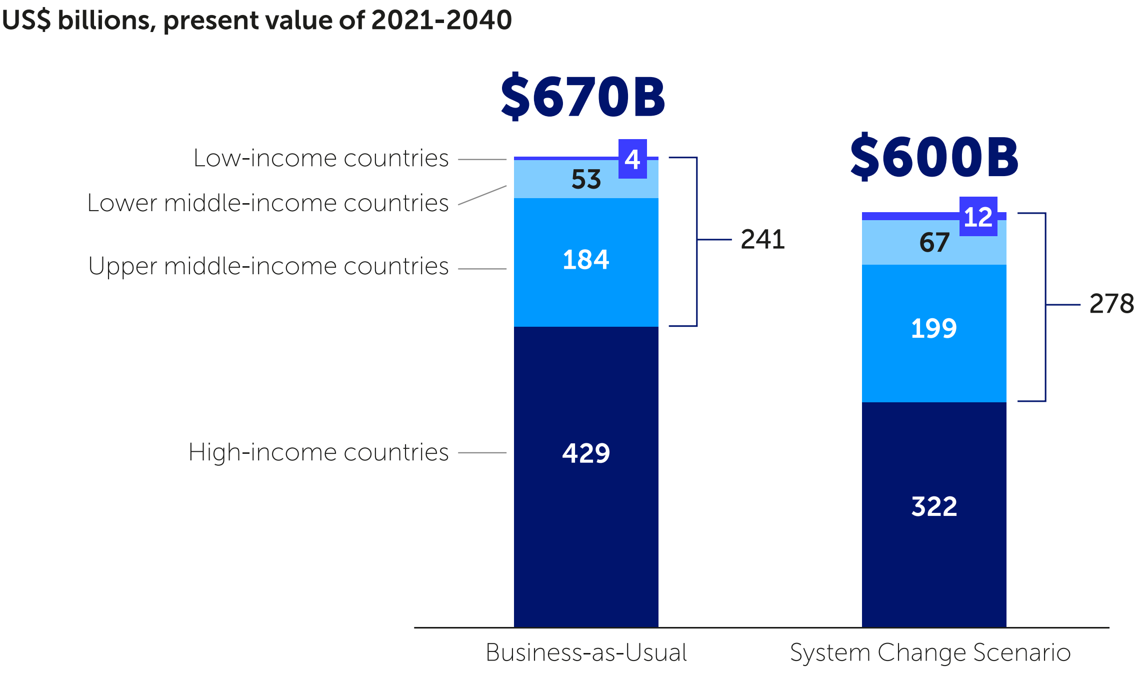
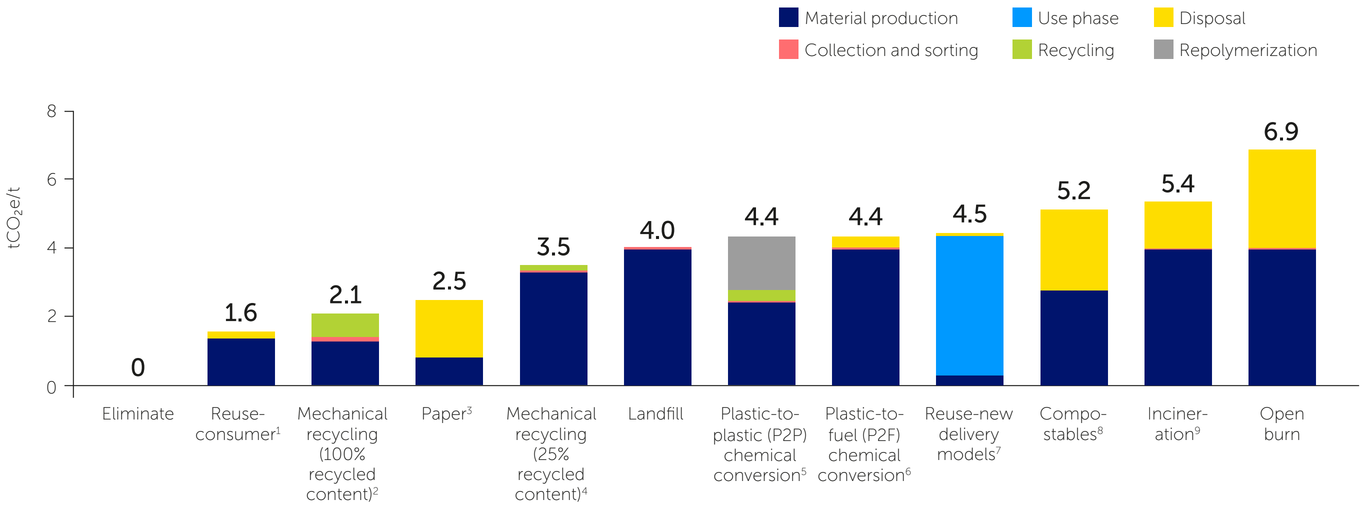


Figure 20: Greenhouse gas emissions of 1 metric ton of plastic utility

Different treatment options have vastly different greenhouse impacts



1. Production and disposal emissions were based on how much less waste would be produced (65% less). "Disposal" in this lever includes all end-of-life emissions, including collection, sorting, and recycling.
2. Valid for both closed-loop and open-loop recycling. This assumes 100 per cent recycled content, which entails the collection and sorting of a larger proportion of waste to account for losses.
3. The average life-cycle emissions of paper or coated paper packaging per metric ton, multiplied by an average material weight increase from plastic to paper of 1.5. Emissions differ depending on how the paper is sourced. Disposing includes all end-of-life emissions including recycling, which we don't distinguish for this lever.
4. Valid for both closed-loop and open-loop recycling. This assumes 25% recycled content, which entails the collection and sorting of a larger proportion of waste to account for losses. The remaining 75% is fulfilled by virgin plastic production.
5. Emissions include the repolymerization of naphtha as well as the pyrolysis process itself. It should be noted that data for GHG emissions for this technology are limited.
6. Does not include the emissions from burning the fuel, as we assume that it replaces regular fuel with a similar GHG footprint. It should be noted that data for GHG emissions for this technology are limited.
7. NDM=New delivery models. Production and disposal emissions were based on how much less waste would be produced (88% less). "Disposal" in this lever includes all end-of-life emissions, including collection, sorting, and recycling; use-phase emissions were assumed to be the same as traditional plastics, although in practice they could be much lower once NDMs reach scale.
8. Life-cycle emissions from polylactic acid (PLA) per metric ton.
9. The emissions for incineration are adjusted to reflect the emissions replaced from generating an equivalent amount of energy with average emissions.

The GHG emissions associated with each pathway are calculated from the point at which plastic waste is generated to the production of 1 metric ton of plastic utility. One metric ton of plastic utility is defined as the material/services required to provide the equivalent value to consumers as 1 metric ton of plastic.

(see Figure 20). Eliminating low-utility avoidable plastic through bans and incentives is assumed to emit zero emissions; reuse creates only 1.6 tons of CO_2e per metric ton of plastic utility; and compostables, incineration and open burn emit the highest quantities at 5.2, 5.4 and 6.9 tons of CO_2e per metric ton of plastic utility, respectively, although emissions from compostables could decrease significantly over time with the correct sourcing and composting infrastructure.

Although the System Change Scenario represents a significant improvement over BAU, it still uses 15 per cent of the 2040 carbon budget, compared with the plastics value chain contributing 3 per cent of global emissions today. This five-fold increase in the share of the carbon budget is driven by a combination of a 54 per cent growth in annual plastic life-cycle GHG emissions under the System Change Scenario in 2040 compared with today, and a reduction in the annual carbon budget allowable by 2040 under the Paris Agreement. These increases are projected despite our assumption that the energy used throughout the plastic life cycle (notably, in mechanical recycling and chemical conversion) would be provided by a rapidly decarbonizing energy sector. For this calculation, we followed the International Energy Agency projections for a 2° C global heating scenario based on a radical transformation of the global energy sector.[69]

Given that the GHG emissions in 2040 under the System Change Scenario are higher relative to today, it will be critically important to look beyond the interventions modelled in the scenario and identify ways to scale reduction and reuse beyond the levels modelled to reap the potential CO_2 savings; advance technologies that decarbonize the production of plastics and substitutes beyond the assumptions in our model; limit the expansion of carbon-intensive end-of-life technologies, such as incineration and chemical conversion; and focus on broader systemic change, including reduced consumption, sourcing locally, and decarbonizing transport. Analysing these potential GHG emissions reduction solutions are outside the scope of this report. We caution that when choosing the appropriate portfolio of interventions, all decision-makers must carefully consider the trade-off between GHG emissions and preventing plastic from entering the ocean.

Use of natural resources

Our analysis shows that, by 2040, it is possible to fulfil a doubling of demand for the services that plastic provides with 11 per cent less virgin plastic than in 2016, through reduction, substitution and switching to recycled plastic. The composition of feedstock under the System Change Scenario would be transformed from the 95 per cent virgin plastic we have today to only 43 per cent of plastic utility fulfilled by virgin plastic in 2040; with 44 per cent of plastic utility replaced by reduction and substitution and 8 per cent by recycled feedstock. Under the System Change Scenario, peak virgin plastic production would be reached by 2027.

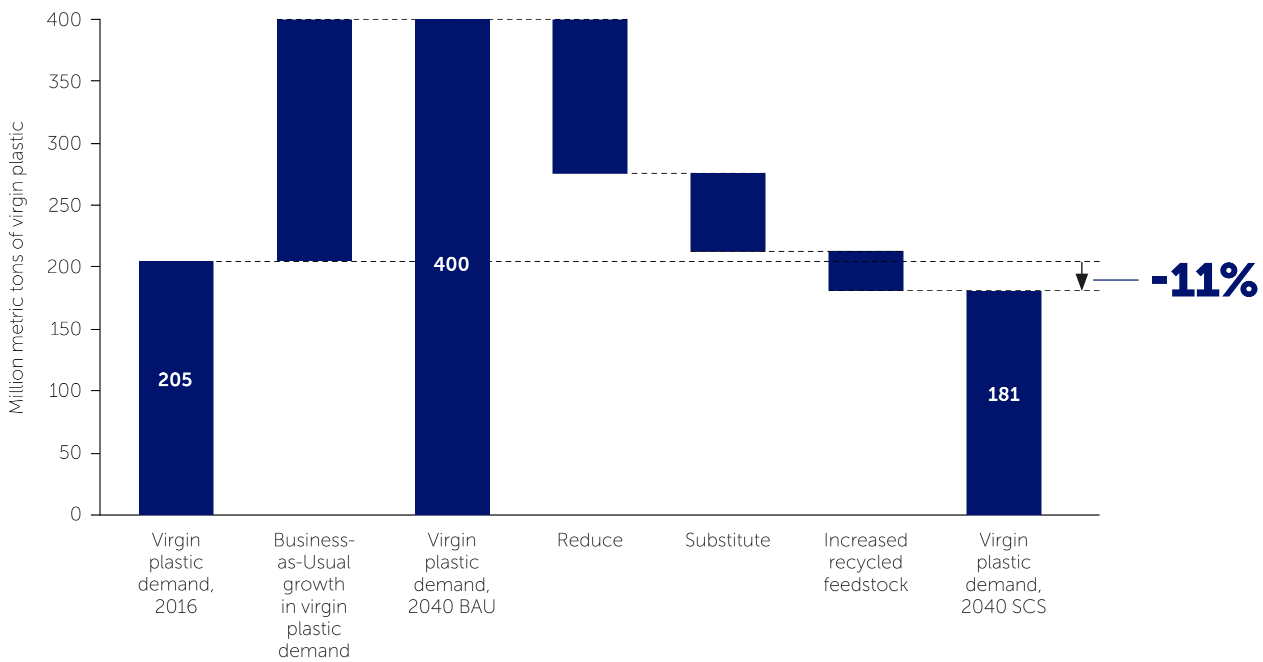
Prioritizing solutions discussed in this report

Under the System Change Scenario, the overall reduction in plastic leakage into the ocean depends on the condition that all system interventions are applied ambitiously and concurrently; deviation from the levels set for any modelled intervention could yield a different outcome. In practice, where government funding and investment dollars are limited, guidance on prioritization can be helpful. How the different solutions and system interventions could be prioritized depends on the desired outcome, such as cost reduction, plastic pollution reduction, GHG emission reductions, implementation speed, technology readiness or feasibility, and the acceptable trade-offs. Although the plastic system is complex, our model design, coupled with a criteria- and evidence-based approach, allowed us to evaluate which solution applies to different materials and geographies. And, in turn, we were able to derive some general guidance on prioritization:

- A reduction in plastic production—through elimination, the expansion of consumer reuse options or new delivery models—is the most attractive solution from an environmental, economic, and social perspective. It offers the biggest reduction in plastic pollution, often represents a net savings, and provides the highest mitigation opportunity in GHG emissions.
- Mechanical recycling is more attractive than chemical conversion or substitute materials from an economic, climate, technology readiness and regulatory point of view. To be viable, plastic should and can be designed for recycling and, importantly, be mechanically recycled wherever that is possible (see details in System Interventions 3 and 5). Each metric ton of mechanically recycled feedstock offsets 48 per cent in GHG emissions relative to virgin plastic production, reduces the need for the extraction of virgin materials, and helps achieve a circular economy.
- Substitution of plastic with alternative materials should be evaluated on a case-by-case basis depending on the desired application and geography. Substitutes are typically more expensive than plastics and their carbon impact could be better or worse depending on the specific material/geography in question. Designing products for reuse is preferable to simple substitution with another single-use material. Yet, where this is not possible, certain materials may be very effective for certain applications (see details in System Intervention 2).
- Plastic-to-plastic chemical conversion allows feedstock to be reintroduced into the petrochemical process to produce virgin-like plastic, reducing the need for extraction of virgin materials, which helps achieve a circular economy. Furthermore, it could create an economic sink for low-value plastic where other solutions do not work. However, for the time being, chemical conversion has not been proved at scale. Compared with mechanical recycling, it has higher costs, energy requirements and GHG emissions. Although its viability at scale should be developed and evaluated, its expansion should be contingent on the decarbonization of energy sources, and natural lead times and limitations of emerging technologies must be recognized.
- Controlled disposal (e.g., landfill, incineration and plastic-to-fuel) should be a last resort given that it is not a circular solution and hence has a high resource and long-term environmental footprint. Its economic costs are also high if full system costs, e.g., collection, and externalities, e.g., land-use change and emissions, are properly accounted for.

Figure 21: Virgin plastic demand under Business as Usual and the System Change Scenario

By 2040, virgin plastic demand could fall by 11 per cent relative to 2016 under the System Change Scenario



Today, 95 per cent of plastic demand is fulfilled by virgin plastic. By 2040, we expect the demand for virgin plastic to reduce by 11 per cent relative to today due to the significant reduction by Reduce and Substitute as well as an increase in recycled feedstock. This calculation includes only plastic in Municipal Solid Waste (MSW).

System change and the future of plastic products

Changing the plastic system would secure a world in which many of the single-use plastic products we know and use today would be eliminated or replaced by reusable items and new delivery models. Nonrecyclable and hard-to-recycle plastics could be substituted to paper or compostable materials, with the remaining plastic waste being recycled at much higher rates, resulting in much less plastic polluting the environment.

Five product types/applications contribute to **85%** of all plastic leaking into the ocean today. Taking action across the global plastics system would lead to many of these plastic product types/applications being removed, substituted or recycled by 2040.

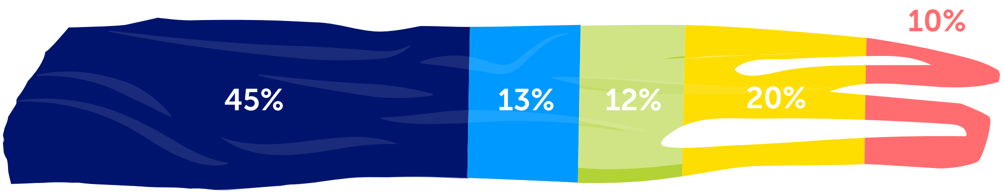
% of Business-as-Usual demand of the following products:

Reduced | Substituted | Recycled | Disposed | Mismanaged

Monomaterial films (e.g., cling film, flow wrap, pallet wraps)

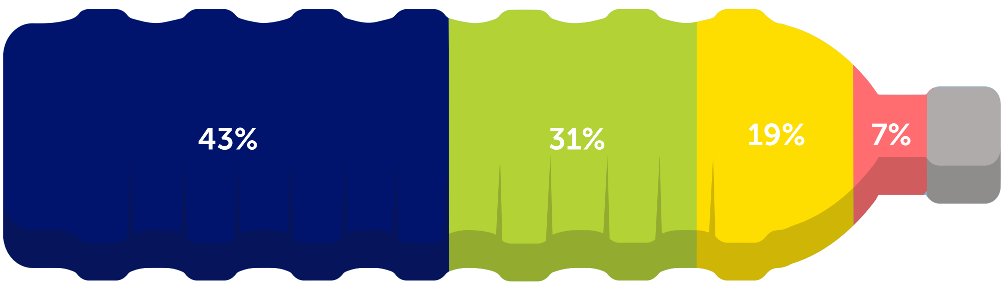
58% of monomaterial films can be avoided through reduction measures and substitution to paper and compostable alternatives.

Carrier bags (e.g., grocery bags, shopping bags)



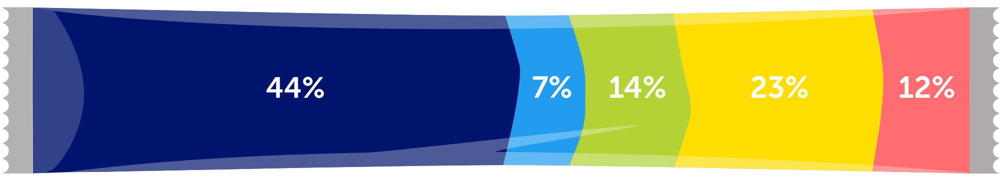
45% of bags can be avoided through bans, incentives, and reuse models.

Bottles (e.g., water bottles, drinks, cleaning products)



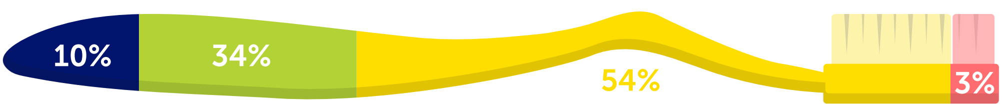
The recycling rate of rigid monomaterial plastic would **double** compared with today.

Sachets and multilayer films (e.g., condiment and shampoo single-portion sachets; coffee, chips, and sweets packets)



In 2016, **48%** of these plastic products were mismanaged. Under the System Change Scenario, the mismanaged rate for these products could drop to **12%.**

Household goods (monomaterial and multimaterial plastic objects, e.g., pens, toys, combs, toothbrushes, durable goods, buckets)



The recycling rate of household goods **nearly quadruples** compared with today.

A woman cuts the labels off of plastic bottles that are collected by Project STOP in Muncar, Indonesia.
SYSTEMIQ

A workable agenda: Eight synergistic system interventions can break the cycle of ocean plastic pollution

All the solutions presented under the System Change Scenario already exist, and their implementation is technically feasible, economically viable, and socially acceptable. It is not a lack of technical solutions that is preventing us from addressing the ocean plastic crisis, but rather inadequate regulatory frameworks, business models, incentives, and funding mechanisms. If we overcome these challenges, we can realize the full potential of the integrated pathway demonstrated by the System Change Scenario and achieve about an 80 per cent reduction of annual leakage by 2040.

The System Change Scenario integrates the main available system interventions for land-based sources of plastic leakage across both macroplastics and microplastics. For several of the system interventions, the analysis is divided between various “levers,” specific methods with different assumptions related to feasibility, costs, emissions, and jobs. We also present a qualitative framework for addressing maritime sources of plastic pollution, as this can be a significant source of ocean plastic pollution, but the current lack of data precluded a quantitative analysis. Qualitative insights on how to reduce maritime sources of plastic are presented.

Upstream and downstream solutions have very different basic requirements. The former will require more responsible use of plastic and is about valuing plastic as a resource, using plastic strategically, and putting less and higher-value plastic waste into the system; the latter will require more responsible management of plastic waste and is about linking up the entire plastic life cycle from design to disposal and increasing the capacity of waste management systems.

Macroplastic system interventions

SYSTEM INTERVENTION 1
Reduce growth in plastic production and consumption to avoid one-third of projected plastic waste generation by 2040

INTERVENTION SUMMARY

- It is socially, technically, and economically feasible to reduce BAU plastic consumption by 30 per cent by 2040—reducing 125 million metric tons per year of avoidable macroplastic waste—before considering switching to single-use substitute materials.
- This proposal decouples economic growth from plastic growth, so that global plastic consumption per person remains approximately flat, rather than the 60 per cent increase expected under BAU. Global demand for plastic still increases overall nevertheless, driven by a 23 per cent increase in population.
- Reductions include eliminating unnecessary items and over-packaging (an 8 per cent reduction in plastic); expanding reuse options that can replace the utility currently provided by plastic, including products intended for consumers to reuse (4 per cent reduction); and new delivery models such as refill systems (18 per cent reduction). See definitions in Table 2.
- Focusing on six key applications—multilayer/multimaterial flexibles, business-to-business packaging, films, bottles, carrier bags, and food service disposables—can achieve 86 per cent of the avoidable growth in plastic waste. Other products, such as multimaterial household goods, have fewer feasible solutions.
- Low- and middle-income countries have an opportunity to leapfrog to low-waste solutions that appeal to consumers, reduce costs, and avoid exacerbating their already overburdened waste infrastructure.

Highly applicable   Somewhat applicable   Not applicable

Most relevant geographic archetypes

HI Urban	UMI Urban	LMI Urban	LI Urban
HI Rural	UMI Rural	LMI Rural	LI Rural

HI: High-income
UMI: Upper middle-income
LMI: Lower middle-income
LI: Low-income

Most relevant plastic categories

Rigid	Flex	Multi

Main responsible stakeholders

- **Consumer goods brands**
- **Retailers**

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The first system intervention is dedicated to reducing the amount of plastic waste generated (substituting plastic with alternative materials is covered in System Intervention 2). The focus is on the transition away from plastics that have only a short period of use, such as packaging and disposable items, which are low-value applications and a key driver of ocean plastic pollution. Our analysis is constrained by design to deliver the same or equivalent utility as BAU, meaning that any solutions must adequately replace the services currently provided by plastic, such as food preservation and protection. This intervention does not demand a reduction in general consumption, but rather an elimination of avoidable plastic and a shift towards products and services based on reuse. After an initial transition period, this intervention offers significant cost savings across the board, both by cutting spending on single-use packaging and by decreasing the burden on waste management systems.

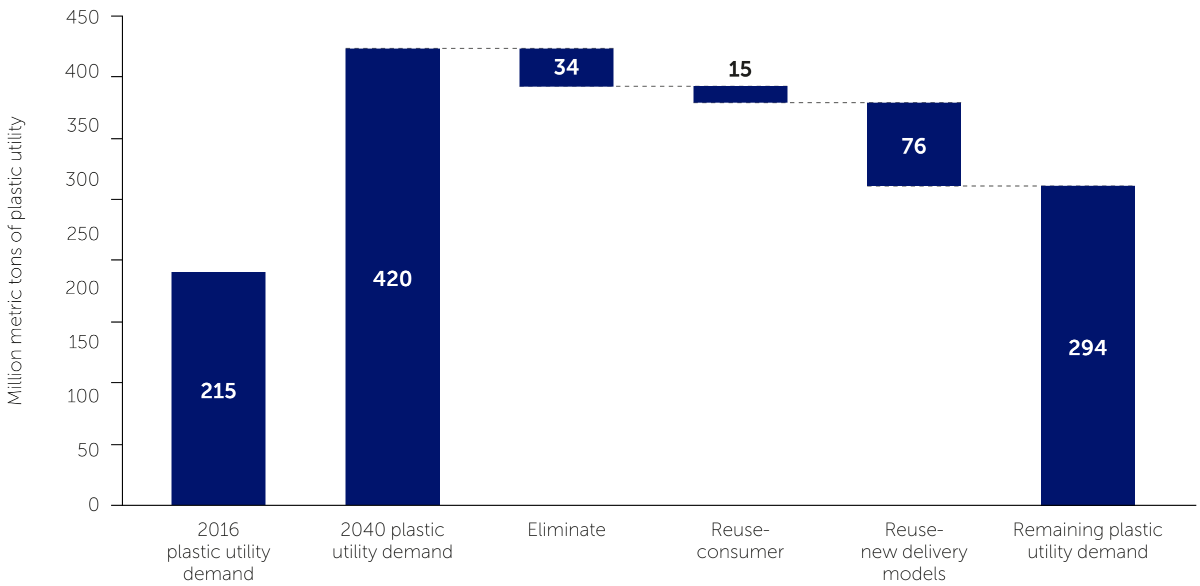
To calculate the maximum potential reduction achievable by 2040, we analysed three Reduce levers, i.e., solution options: (a) eliminate; (b) reuse-consumer; and (c) reuse-new delivery models, as laid out in Table 2.

Table 2: Definition and examples of the three modelled Reduce levers

	Definition	Examples
Eliminate	Policy interventions, innovations, consumer behaviour shifts and incentives that lead to reduced material demand or product redesign for low-utility avoidable plastic, and that **do not require a replacement.**	Redesign overpackaging such as double-wrapping plastic film and excess "headspace," develop packaging-free products, decrease consumption and production of avoidable bags and films, increase utility per package, extend life of household goods. (Note: Does not include light-weighting or shifting from rigids to flexibles as this commonly reduces the end-of-life value and can increase the likelihood of plastic leakage in middle- and low-income countries).
Reuse (consumer)	Replacement of single-use products and packages with **reusable items owned and managed by the user.**	Reusables owned by consumers (e.g., water bottles, bags for life), or owned by institutions (e.g., cutlery, crockery, plastic pallets).
Reuse (new delivery models)	**Services and businesses providing utility** previously furnished by single-use plastics in new ways, with reduced material demand.	Refill from dispensers (e.g., bottles, multilayer/multimaterial flexibles and sachets), subscription services, concentrated product capsules, take-back services with reverse logistics and washing, package-as-a-service models (e.g., shared ownership of takeaway containers).

Figure 22: Utility demand in 2016 and 2040, and how it is met by the three Reduce levers in the System Change Scenario

Avoidable plastic accounts for 30 per cent of total plastic waste generation in 2040 under Business-as-Usual



This figure shows plastic utility demand (in other words, plastic waste generated under BAU) in 2016, 2040, and in 2040 after the Reduce levers are applied. The respective per cent of plastic waste in 2040 that is reduced by each lever is 8 per cent, 4 per cent and 18 per cent, for a total reduction of 125 million metric tons or 30 per cent of projected 2040 utility demand.

Figure 23: A four-criteria framework was used to determine the maximum feasible uptake of each Reduce solution

A Technology	B Performance	C Convenience	D Affordability			
Is a solution **available today**?	Does the intervention satisfy **performance and health** requirements?	Is the intervention acceptable for **lifestyle and convenience**?	Are the **cost implications** of the alternative acceptable?	**Overall score**	**2030** market penetration	**2040** market penetration
Yes: Technology Readiness Level (TRL) 9, available in multiple locations	**Yes**	**Yes**	**Yes** (net savings or acceptable cost)	4	50%	80%
Only at pilot: TRL 5-8	**Mostly** (but not for all applications)	**Mostly** (some challenges)	**Mostly** (but not for all applications)	3	20%	50%
Only in labs: TRL 1-4	**Partially** (limited applications only)	**Partially** (niche consumers)	**Partially** (niche consumers)	2	1%	10%
No alternative available	No	No	No	1	0%	0%

This framework was used to determine the maximum foreseeable uptake of Reduce solutions. In this context, a solution is one of the three Reduce levers, applied to one of 15 product subcategories. Each solution was scored against four criteria labelled A-D, with its lowest score determining its "limiting factor" of 1-4. Each limiting factor was assigned a corresponding market penetration potential at 2030 and 2040, based on an analysis of the speed of historical socio-technical shifts (see the technical appendix). For example, combinations with a limiting factor score of 3 out of 4 were assumed to reach 20 per cent market penetration by 2030 and 50 per cent by 2040. The same scoring framework and limiting factor market penetration assumptions are also applied to the Substitute intervention described in a later section.

To estimate the potential to reduce plastic waste, we divided the waste stream into 15 plastic application subcategories and assessed the applicability of each reduction lever to each subcategory based on existing businesses, policies, available technologies, environmental trade-offs, and consumer trends. Each combination of plastic application subcategory and Reduce lever was scored against four criteria laid out in Figure 23—technology readiness level, performance, convenience, and cost—with the lowest score determining this combination's "limiting factor" and maximum foreseeable uptake rate over time.

We applied the three Reduce levers in order of priority in terms of costs and environmental impact, with each lever resulting in reductions as laid out in Figure 22. First, for each plastic application subcategory, we assessed how much avoidable plastic could be eliminated, through redesign, policy, and consumer incentives. The eliminate lever avoids the need for producing materials in the first place and is assumed to offer 100 per cent cost savings on eliminated plastic without unacceptably reducing utility.

Second, we analysed how much of the remaining plastic could be reused by consumers, such as with reusable bags (which accounted for 53 per cent of the waste reduction under this lever), water bottles, and crockery for sit-in restaurants. This lever delivers system cost savings of 40 per cent compared with disposables, as multiuse products are initially more expensive but generally deliver cost savings over time. Key barriers to this lever are consumer and business convenience, which are not quantified but could be significant if reuse systems are poorly designed or have insufficient policy and financial incentives.

Finally, we applied the reuse-new delivery model lever, which is the most effort-intensive of the three levers, as it requires new services and infrastructure to be rolled out and sometimes water resources for washing, but offers the largest reduction potential. This lever is responsible for more than half of all avoided waste under the Reduce intervention. It delivers 23 per cent cost savings compared with single-use plastic when new delivery models reach scale, including the cost of purchasing reusable packaging and operating reverse logistics and washing.

Scoring was conducted separately for the HI archetype and the other archetypes to reflect differing constraints, such as access to clean water in LI, LMI, and UMI countries. We recognize that differences in transportation systems, food systems, cultural practices, and more will affect the portfolio of solutions that are most suitable for rural areas. However, there are many cases in which Reduce levers work very effectively in rural settings. For example, there are glass bottle refill schemes that have operated economically even in the most remote locations, and many essential products are already refilled or sold without packaging in local village markets.

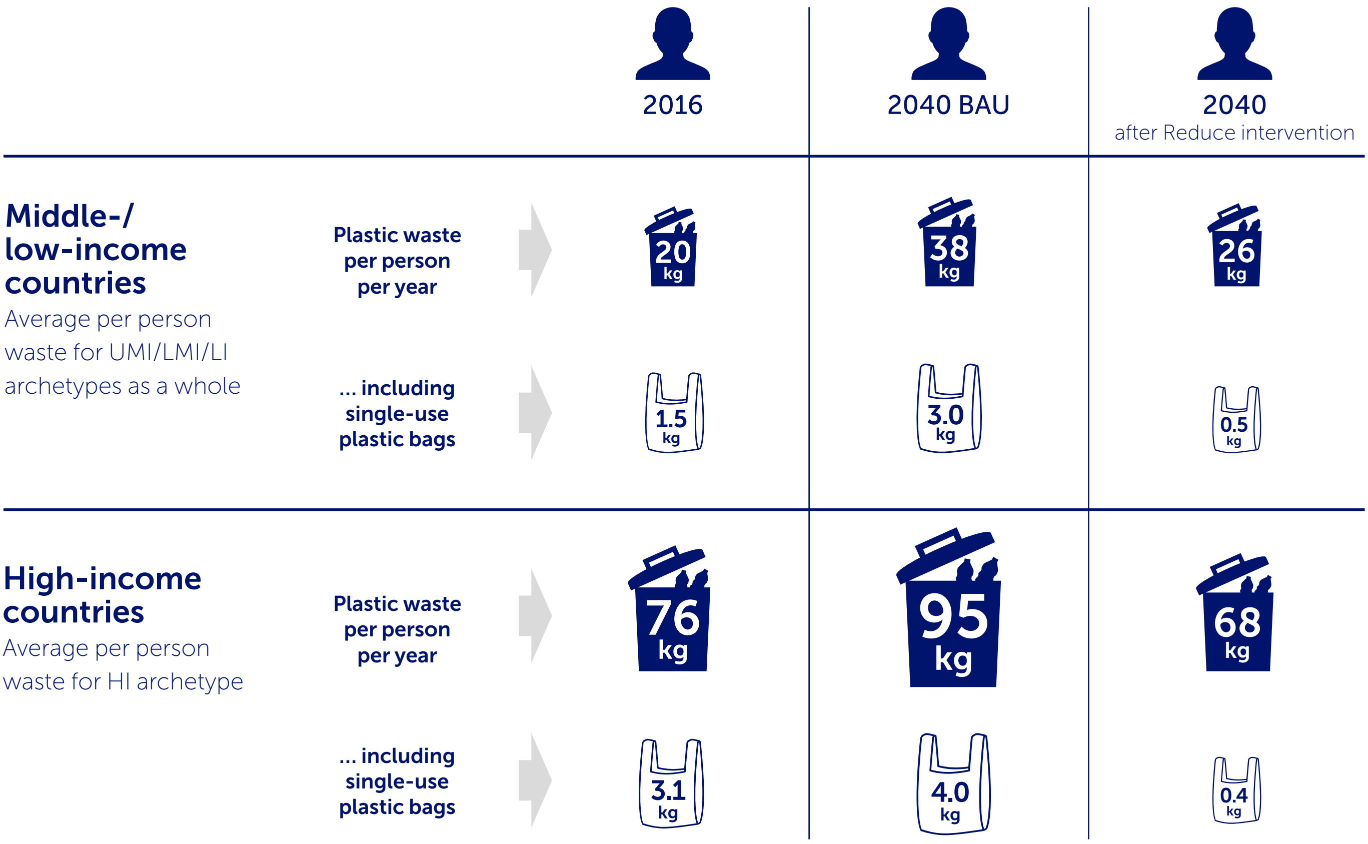
In HI countries, because per capita plastic consumption is already high and the expected further growth in demand for plastic utility is slower than in the rest of the world, our analysis suggests that plastic waste per capita could be decreased through the Reduce intervention alone, bringing plastic waste generation per person down from 76 kg in 2016 to 68 kg in 2040. In contrast, average per capita plastic across the LI, LMI, and UMI archetypes grows from 20 kg to 26 kg per year despite ambitious reductions in key items (see Figure 24).

An increased focus is needed on reduction strategies for avoidable sachets and multilayer flexibles, business-to-business packaging, monomaterial films, and bottles

Many plastic reductions implemented to date have focused on the Eliminate lever, largely by light-weighting packaging, and regulating bags, straws, and other small-mass items. Our analysis suggests that greater reductions could be achieved by focusing on the six plastic applications projected to account for 86 per cent of the total reduction achievable in 2040 (see Figure 25). In terms of the absolute mass of plastic avoided, sachets and multilayer/multimaterial flexibles (such as for shampoo and condiment portions, chips, and sweets packets) have the highest reduction potential at 26 million metric tons per year plastic waste avoided, followed by business-to-business packaging such as crates and pallet wrap, monomaterial films, bottles, carrier bags, and food service items. Currently, national and subnational product bans and regulations overwhelmingly focus on carrier bags and food service items,[70] two applications that

Figure 24: Change in total plastic waste generation and plastic bag consumption per capita in the Business-as-Usual Scenario and after Reduce interventions are applied

Most plastic reductions in the System Change Scenario are in high-income countries



Per capita waste generated decreases from 2016 to 2040 in HI countries after the Reduce levers are applied, as this archetype starts with high waste per capita. In contrast, in LI, LMI, and UMI countries, plastic waste increases slightly even after the Reduce intervention, as these archetypes start from a much lower level per person. The chart also highlights specific results for single-use carrier bags in each scenario as an example of a product application for which the Reduce interventions cause rapidly decreased consumption across all archetypes. Single-use plastic bag mass excludes the weight of reusable bags (not shown). Note: Per capita waste for LI, LMI, and UMI is a weighted average across the archetypes; the actual 2016 per capita waste for each is 28 kg for UMI, 15 kg for LMI, and 12 kg for LI.

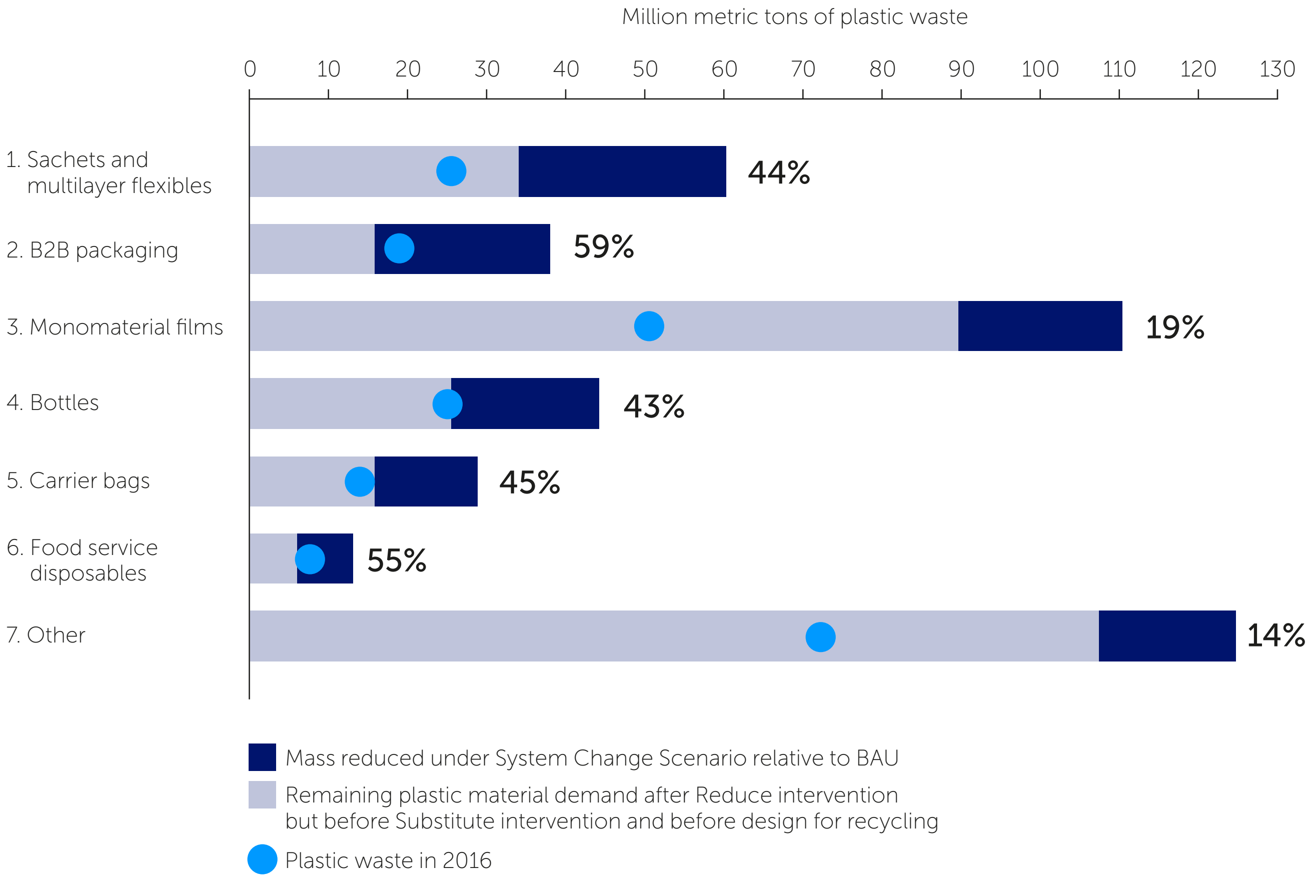
together make up just 10 per cent of the entire plastic waste stream and 16 per cent of potential reductions from this intervention. The other four applications represent a huge, untapped opportunity.

Sachet packaging is an iconic single-use, multilayer/multimaterial waste item in LI, LMI, and UMI countries; it makes up approximately 10 per cent of plastic waste in the Philippines, for example.[71] After consumption, these low-value plastic materials are often not collected and are a major source of ocean pollution. In some countries, such as India, our market observations suggest that full-size bottles are currently more expensive per use for consumers than buying sachets, but regulations such as Extended Producer Responsibility with full end-of-life cost recovery could make recyclable rigid plastic packaging less expensive than sachets in the future. Our analysis suggests that new delivery models could also offer a better alternative for delivering products to consumers in these countries; new delivery models on the market today offer 30 per cent savings to consumers compared with bottles,[72] bringing them in line with sachet costs—with radically less waste and plastic flow to the ocean per use (see Figure 26).

A reduction of plastic production—through elimination, the expansion of consumer reuse options, or new delivery models—is the most attractive solution from environmental, economic, and social perspectives. It offers the biggest reduction in plastic pollution, often represents a net savings, and provides the highest mitigation opportunity in GHG emissions.

Figure 25: Annual mass of plastic reduced compared with Business-as-Usual, and remaining material demand after Reduce intervention applied, for top six applications ranked by absolute mass reduced, 2040

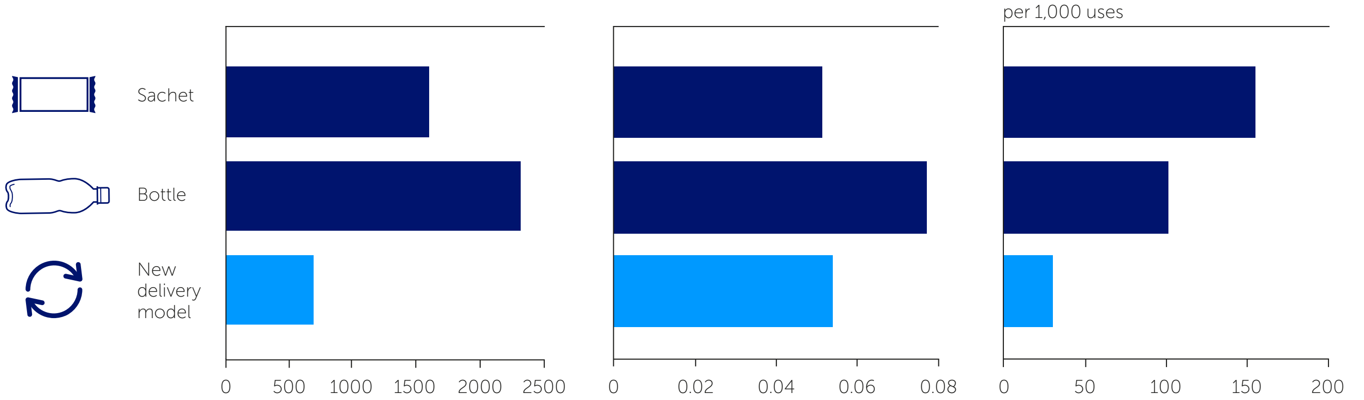
Six product applications represent the vast majority of avoidable plastic



Numbers by the bars reflect per cent of BAU plastic in 2040 of each product category that is reduced under the System Change Scenario. The remaining material demand, in light blue, is before the Substitute intervention is applied (see System Intervention 2) and before design for recycling is applied (see System Intervention 4). Business-to-business packaging includes both flexible and rigid packaging; bottles include water, food, and nonfood bottles; other includes pots, tubs, and trays; household goods; other rigid monomaterial packaging; laminated cartons and aluminium; and diapers and hygiene products.

Figure 26: Implications of different packaging options to consumers and the environment

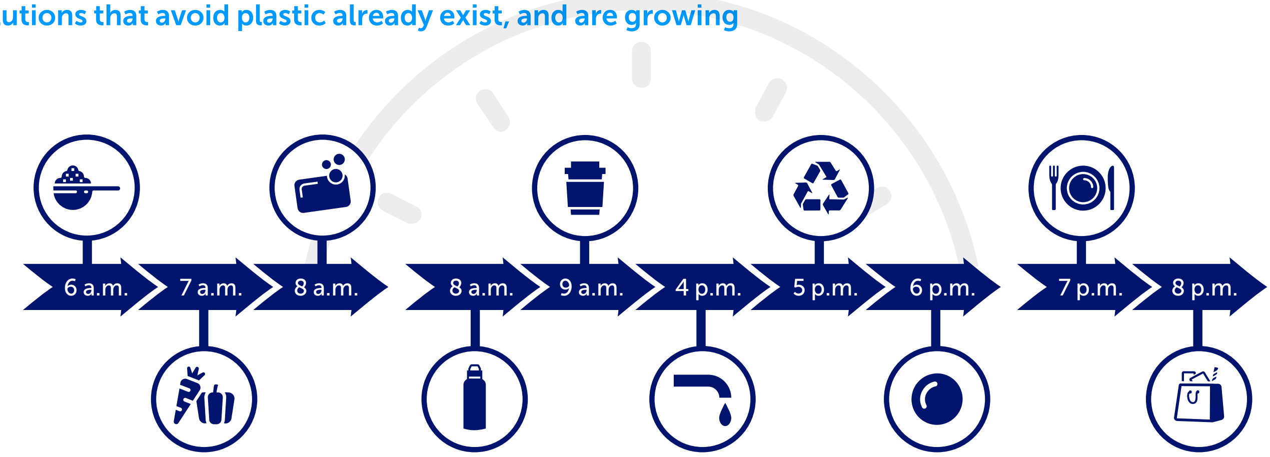
New delivery models can generate less plastic waste, cost consumers less, and bring less leakage to the ocean



The data suggest that shampoo delivered via new delivery models (light blue bars) could reduce waste and plastic pollution without increasing consumer cost per use compared with sachets or bottles. Due to small sample sizes, this analysis should be considered illustrative only. Primary data on the consumer cost and mass of bottled shampoo and sachet-packaged shampoo, per 8 gram serving, was provided by direct measurements in India[73] and Indonesia.[74] New delivery model costs and mass were based on an existing business case study.[75] Leakage was calculated using average leakage probability in BAU 2016 for middle-/low-income countries, for the rigid plastic category (for bottles and new delivery model bottles), and for the multilayer/multimaterial plastic category (for sachets).

Figure 27: Illustrative examples of attractive Reuse solutions and New Delivery Models that are available today in high-income countries, maintaining lifestyles with much less plastic waste

Solutions that avoid plastic already exist, and are growing



Morning routine

6 a.m. Use concentrated capsules to top up household cleaners,[a] soaps[b] and soda fountain[c]

7 a.m. Fresh food delivery, in returnable box and containers. Leave refillable packaging on the doorstep for collection,[d] and diapers for centralised washing[e]

8 a.m. Tooth brushing using concentrated toothpaste tabs[f] and hair washing with a shampoo bar[g]

On-the-go

8 a.m. Pack reusable water bottle and bag

9 a.m. Coffee in a returnable coffee cup[h]

4 p.m. Refill at soda fountain dispenser[i]

5 p.m. Return reusable to collection point

6 p.m. At the gym, top up on sports drink in an edible seaweed "bubble"[j]

Packaging-free meals

7 p.m. Fast food served on real crockery for a quick sit-down meal[k]

8 p.m. Top up the pantry with some basics bought from bulk dispensers[l] and fresh produce from the plastic-free aisle, all placed in a reused bag

Each of the examples are of solutions already emerging today, as per the following example businesses: a) RePlenish, b) Splosh, c) SodaStream, d) GoodClub, e) Tidee Didee, f) Signal, g) Lush, h) CupClub, i) Pepsi, j) NotPla, k) Rethink Disposables, l) MIWA.

Box 2: Waste and emission reductions from reuse levers

Data on existing consumer reuse and new delivery models was leveraged to calculate the significant waste savings that both models can offer: 65 per cent mass reduction for reuse-consumer and 88 per cent for reuse-new delivery models. The reusable packaging can be made from glass, metals, new materials, or plastics, depending on the best trade-offs of GHG emissions and performance. For the reuse-consumer lever, it was assumed that GHG emissions savings would be proportional to the mass reduction achieved, as only a minority of the reuse would require significant additional emissions, such as from washing. For the new delivery model lever, as most models involve GHG emissions from transportation and reverse logistics, we conservatively assume that new delivery models emit the same amount of CO_2e by mass as using single-use plastic, although this could change in the future with low-carbon transportation and renewable energy powering reverse logistics.

Box 3: Is plastic really necessary to protect our fruits and vegetables?

Plastic can play an important role in increasing the shelf life of perishable food. Approximately 40 per cent of plastic packaging is used for perishable food and drinks.[76] With one-third of all food produced currently ending up as waste, contributing 7 per cent of global GHG emissions,[77] it is important that action taken to reduce plastic packaging does not inadvertently increase food waste. We take that into account in our analysis, and 29 per cent of the total reductions we modelled relate to packaging for perishable foods. This intervention assumes that packaging for perishable food and drinks can be reduced by 27 per cent compared with packaging mass in 2040 under BAU, which is a moderate increase in mass compared with today's levels.

Avoidable plastic: Our model suggests that much of the projected growth in plastic food packaging can be avoided by eliminating the packaging that is not playing an essential food preservation role. For example, packaging used for branding purposes or to incentivize purchasing multipacks or large quantities can encourage people to buy more than they need, driving up food waste. Spoilage can also be prevented in other ways, such as improved cold chains, digital trackers, shorter supply chains, reusable business-to-business packaging, and misting.

Health impacts: Although many consumers believe that packaged products are safer, the link between plastic packaging and health is complex. In most cases, fresh produce either has a peel or skin providing a natural barrier to contamination or that can be washed by consumers before eating. Plus, reducing plastic usage for food and beverages in general could reduce human exposure to chemicals and additives in plastic.[78] However, new legal and regulatory safeguards will be required to ensure that reuse and refill systems satisfy food safety standards and reassure consumers.

Design and scaling innovations can enable substantial reductions in material demand, and catalyse a leapfrogging to attractive low-waste alternatives

Beyond plastic product bans, it is possible to achieve large waste reduction outcomes by scaling up attractive alternatives that produce radically less waste, particularly through the new delivery models lever. In middle-/low-income countries, in particular, there is an opportunity to leapfrog directly to a low-plastic-waste system, reducing both environmental pollution and the massive burden on waste management systems without constraining lifestyle aspirations. Products would increasingly be delivered through services rather than increasing amounts of single-use packaging, either leveraging traditional delivery routes such as local markets, street vendors, and glass or plastic bottle refill schemes, which already have large market reach, or using new digitally enabled technology and services (see Figure 27). As HI countries are starting from higher plastic consumption levels, they can make even greater reductions per capita using the types of models emerging today, as shown in Figure 27.

Enabling conditions

Policy, economic, and innovation drivers required to accelerate this intervention include:

- Adoption of standards or regulatory requirements for plastic packaging that focus on elimination of avoidable packaging and product redesign, alongside regulation on uses of plastic with a high likelihood of leakage.
- Global uptake by multinationals of innovative models and commitments to long-term quantitative goals to eliminate and reuse packaging; companies leveraging their global reach and R&D budgets to facilitate change across geographic archetypes.
- Regulatory and/or voluntary standards, consumer education, and reusable packaging targets to facilitate reuse and address hygiene concerns regarding food contact materials.
- Policies that shift the burden of waste generation onto producers and so "level the playing field" for new business models and zero-packaging solutions, for example, Extended Producer Responsibility schemes, a tax on single-use plastics, and landfill or incineration fees.
- Innovation in system design, such as seasonal food, shortening supply chains, e-commerce, digital trackers, and choice editing (reducing the need for packaging to differentiate products).

Macroplastic system interventions

SYSTEM INTERVENTION 2

Substitute plastic with paper and compostable materials, switching one-sixth of projected plastic waste generation by 2040

INTERVENTION SUMMARY

- In the System Change Scenario, paper, coated paper, and compostable materials can substitute 17 per cent of plastic waste generated by 2040, equivalent to 71 million metric tons of plastic, without fundamentally decreasing the performance, affordability, or social and environmental acceptability of packaging and single-use items.
- Ninety-five per cent of this potential substitution comes from six key product applications for which known material alternatives already exist at some level of scale: monomaterial films; other rigid monomaterial packaging; sachets and multilayer films; carrier bags; pots, tubs, and trays; and food service disposables.
- All substitutions need careful management at end of life and have varied environmental impacts. They create opportunities, risks, and trade-offs that must be carefully managed and assessed on a case-by-case basis.
- The Substitute system intervention has 1.7-2 times higher production costs than virgin plastic per metric ton of plastic utility, so substitutes were selected only when they replace plastic that cannot be reduced or mechanically recycled. The intervention plays an important role in minimizing ocean plastic pollution and could help reduce overall GHG emissions.

Highly applicable | Somewhat applicable | Not applicable

Most relevant geographic archetypes

HI Urban	UMI Urban	LMI Urban	LI Urban
HI Rural	UMI Rural	LMI Rural	LI Rural

HI: High-income
UMI: Upper middle-income
LMI: Lower middle-income
LI: Low-income

Most relevant plastic categories

Rigid	Flex	Multi

Main responsible stakeholders

- Consumer goods brands
- Retailers

kyrychukvitaliy/Adobe Stock

After implementing both the Reduce and Substitute system interventions, our analysis indicates that plastic waste generation could be capped at approximately today's global levels by 2040 without unacceptable compromises on cost, utility, or performance (see Figure 22), despite increasing populations and economic development. This equates to an absolute decrease in plastic waste in HI countries (-27 per cent) and an absolute increase in plastic waste from middle-/low-income countries compared with today (average +26 per cent), driven by population growth as per capita plastic production and consumption remain at today's levels. We estimate that 17 per cent of plastic waste can be substituted in 2040, relative to BAU: 4.5 per cent to paper, 3.5 per cent to coated paper and 9 per cent to compostable materials (see Figure 28). That is equivalent to 71 million metric tons of plastic waste avoided annually.

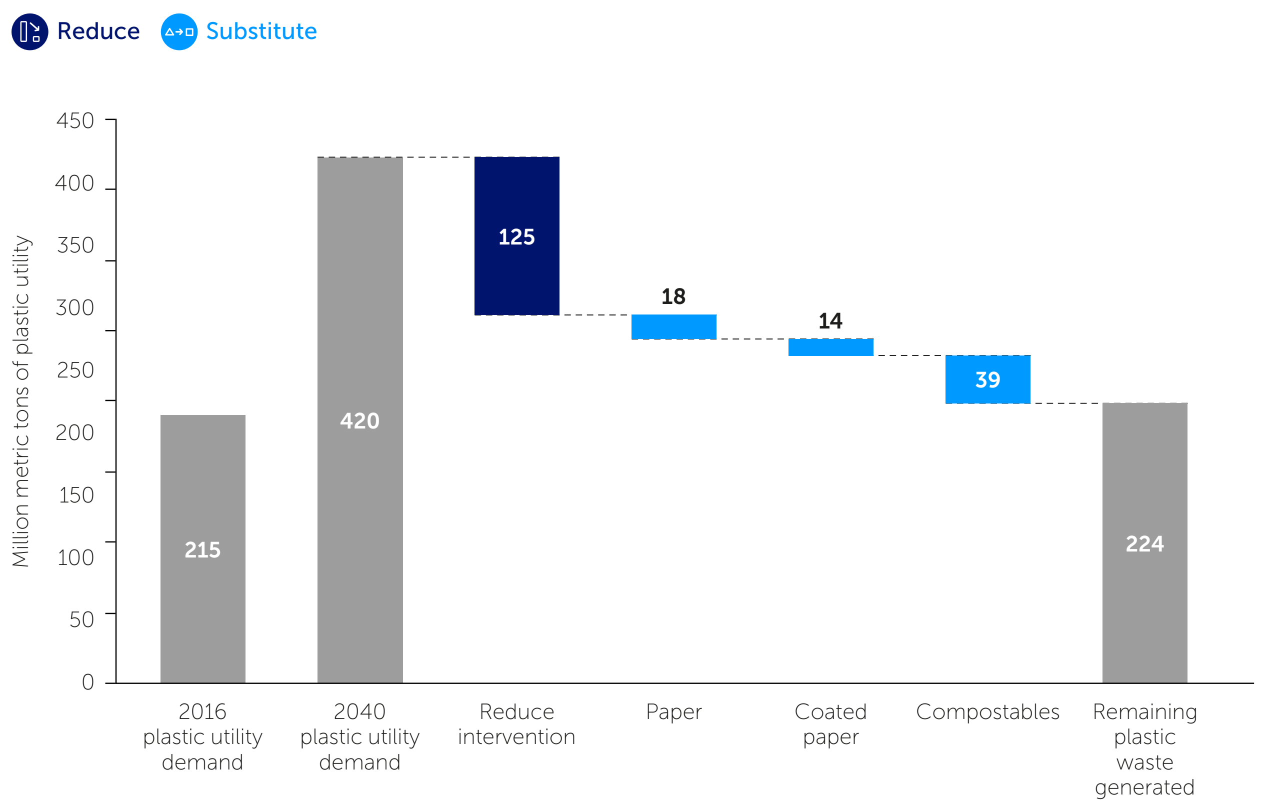
The use of any substitute material will involve significant economic costs in both production and end-of-life disposal, as well as environmental impacts and other trade-offs to balance. The Substitute intervention is therefore applied only to the plastic in each of the 15 plastic subcategories that remain after the three Reduce levers have been applied. Substitutions were made only with materials expected to be less likely to leak into the environment in 2040, focusing on substituting nonrecyclable items, monomaterial flexible plastic, and multilayer plastic, which have high leakage rates.

The analysis of this system intervention is based on three selected substitution material levers: (a) paper; (b) coated paper with a maximum 5 per cent by weight of plastic coating, which is acceptable to recyclers;[79] and (c) certified and appropriate compostable materials, including compostable plastic and nonplastic materials (see Table 3). Compostable materials make up the largest proportion of substituted plastic (see Figure 28).

The three material substitutes were selected because they are the most prevalent ones available today for replacing problematic plastic films and multilayer flexibles, which have low recycling rates and high leakage rates, particularly in LI and LMI countries. We also analysed glass, aluminium, and aseptic containers as possible substitutes for rigid monomaterial plastics, such as bottles, but these alternatives were not selected for modelling for two reasons: first, because rigid monomaterial plastics are less problematic than flexible plastic as they have comparatively high collection and recycling rates and, second, because single-use glass, aluminium, and aseptic cartons were found to have potential negative trade-offs in costs, GHG emissions, and recycling rates compared with rigid monomaterial plastics. For example, aluminium cans and glass bottles are 33 per cent and 167 per cent more expensive than PET bottles, respectively,[91] although they may be suitable for

Figure 28: Utility demand in 2016 and 2040, and how it is met by the Substitute levers in the System Change Scenario

The System Change Scenario shows 17 per cent of plastic production substituted with alternatives by 2040



This figure shows plastic utility demand in 2016, 2040, and in 2040 after the Reduce and Substitute levers are applied.

Table 3: Substitute material levers selected, and examples of substitutions modelled

Substitute material lever	Definition and rationale	Examples of plastic products with available substitutes
Paper	Substitute with **recyclable paper**, or other pulp-based or fibre-based material, ensuring that it is sustainably sourced. Paper recycling is widespread globally; for example, 85 per cent of paper and cardboard packaging is recycled in the European Union compared with just 42 per cent of plastic packaging.[80] Paper substitutes are undergoing rapid innovation, leading to improved barrier properties and cost/weight performance. For nonfood applications, high recycled content is possible in current market conditions.	Plastic fruit and vegetable punnets, display trays, shrink wraps on drinks,[81] paper substitutes for polystyrene foams,[82] paper food service items (plates, cutlery, straws), paper wet-wipes
Coated paper	Substitute with paper lined with a plastic **coating acceptable to paper recyclers**. Coatings improve the barrier properties of paper, making paper substitutes relevant to a wider packaging segment, particularly food applications. Plastic coatings of a maximum 5 per cent of weight are considered tolerable to recyclers today[83] but should be easily removable, with weak adhesives to facilitate acceptance in paper recycling streams. Our scenarios would add <0.3 per cent coatings by mass to today's global paper production of 409 million metric tons,[84] which we assume would be tolerable to recyclers, but further research is needed to confirm maximum allowable volumes of coated paper. **Rapid innovation is occurring that could replace plastic linings** with dissolvable, compostable or other ephemeral barrier coatings that could further increase coated paper recyclability and improve coated paper performance and suitability for new applications. Coated paper excludes laminated materials such as aseptics, beverage cartons, and coffee cups, for which the lamination weight or double-sided application mean they are only recyclable in a specialist recycling facility.	Confectionery wrappers, e.g., recyclable paper packaging for snack bars[85] and sachets for powdered drinks[86]
Compostables	**Existing materials and new formats** under development (including nonplastic compostable materials—cellulosics, alginates, banana leaves, edible and ephemeral packaging as well as compostable plastics) that are **approved to meet relevant local compostability standards** (for example, industrial composting standard EN 13432 where industrial-equivalent composting is available and effective). These materials should be capable of disintegrating into natural elements in a home or industrial composting environment, within a specified number of weeks, leaving no toxicity in the soil. Compostables are most relevant where composting infrastructure exists or will be built, and for substituting thin plastic films and small formats. Substitution with compostable materials is most appropriate for products with low plastic recycling rates and high rates of food contamination, making co-processing with organic waste a viable option.	Banana leaves for takeaway food, fibre-based compostable-ready meal trays,[87] seaweed pouches,[88] compostable chips packets[89] and tea bags[90]

reusable packaging. For these reasons, no clear picture emerged to indicate that these other substitutes would decrease the amount of material leaked to the ocean globally without creating unacceptable economic, social, or environmental outcomes.

The three substitutes modelled should not be considered predictions of change or recommendations, but as indicative of the possible future scaling of substitutes that already exist in the market. The potential mass of plastic substitution estimated in the System Change Scenario could be considered conservative, as further plastic replacement options could be derived from other materials, either already existing or thanks to new innovations. In a globalized system of food production and consumption, the GHG emission savings offered by lightweight plastic materials are important. However, if supply chains are shortened, transport is decarbonized, or reuse and recycling rates are high, other substitute materials, such as glass and metals, may perform well.

To avoid unintended consequences, local authorities, brands, and manufacturers should consider the local

Table 4: Global substitution potential of plastic in 2040 for the six plastic subcategories with the largest substitute potential by mass

Plastic subcategory	Paper	Coated paper	Compostables	Explanatory notes
Per cent of plastic subcategory substituted in 2040; million metric tons of plastic substituted in 2040				
1. Monomaterial films 41%; 45 million metric tons	6.5%; 7 million metric tons	9%; 10 million metric tons	25.5%; 28 million metric tons	Paper/coated paper where water barrier properties not necessary; compostable plastic, cellulosics, or alginates where transparency is essential or food contamination risk is high
2. Other rigid monomaterial packaging 23%; 9.5 million metric tons	18.5%; 7.5 million metric tons	0%	4.5%; 2 million metric tons	Subcategory does not require food contact; paper and compostable substitutes readily available for expanded polystyrene and other protective packaging
3. Sachets and multilayer films 7%; 4 million metric tons	2%; 1 million metric tons	3%; 2 million metric tons	2%; 1 million metric tons	Coated paper and compostable alternatives available today with adequate performance for dry or short-life goods
4. Carrier bags 13%; 4 million metric tons	3%; 1 million metric tons	0%	10%; 3 million metric tons	Compostable bags where water resistance required (for meat, fish, etc.); paper bags widespread today
5. Pots, tubs, and trays 12%; 3 million metric tons	5.5%; 1 million metric tons	6.5%; 2 million metric tons	0%	Paper punnets for fresh produce; coated paper for other
6. Food service disposables 17%; 2 million metric tons	4%; 0.5 million metric tons	4%; 0.5 million metric tons	9%; 1 million metric tons	Widely available alternatives, e.g., bamboo cutlery, paper/coated paper clamshells and cups, banana leaf wraps
Column total	**18.5 million metric tons (out of a total 19 million metric ton paper potential)**	**14 million metric tons (out of a total 14 million metric ton coated paper potential)**	**35 million metric tons (out of a total 38 million metric ton compostables potential)**	Columns may not sum to column total due to rounding of decimals

conditions and trade-offs of any substitute materials before making any switches, such as by using full life-cycle analysis conducted by neutral bodies to recognized standards. Local considerations include the sustainability of sourcing raw materials; capacity for collection, recycling or composting; GHG footprint; and likelihood of the materials leaking either now or in the future.

Quantifying the potential for plastic substitution followed a similar method as the Reduce intervention, scoring each solution for each product application according to technology readiness, performance, convenience, and cost (see Figure 23). Our analysis shows that 95 per cent of the potential material substitutes for plastic are for just six plastic subcategories (see Table 4). The largest subcategory is monomaterial plastic films, an estimated 41 per cent of which could be substituted by 2040 without sacrificing performance. This is a significant finding because plastic films contribute more than half of the plastic entering the ocean today.

In the System Change Scenario, paper, coated paper, and compostable materials can substitute 17 per cent of plastic waste generated by 2040, equivalent to 71 million metric tons of plastic, without fundamentally decreasing the performance, affordability, or social and environmental acceptability of packaging and single-use items.

Box 4: The case for substitute materials

- **Doesn't plastic lower transport emissions?**
  Plastic is lightweight, but transport GHG emissions are overwhelmingly driven by both the weight of a package's contents and the amount of space that goods occupy in trucks or crates. The substitutes we modelled, if applied astutely (see Box 5), overall have a lower GHG footprint in the production and end-of-life disposal phases than plastic, which would create emission savings. Therefore, adding 30-50 per cent more weight by switching to paper or compostable packaging should not significantly increase overall emissions. For much heavier substitutes, such as glass, managing emissions trade-offs requires reducing transport distances, decarbonizing transport, or switching to reuse models. Ultimately, more localized supply chains and seasonal consumption could drive down emissions and packaging amounts even further.

- **Do plastic alternatives have the same barrier properties?**
  Plastic does have important barrier properties (especially for food preservation), so we applied substitutes to products that have long shelf lives, that can be produced locally or with shorter supply chains so as to lessen the preservation required, or for which substitute materials with adequate barrier properties are already available or being brought to market. Our estimates could be conservative because we did not, for example, substitute any cheese or meat packaging due to strict barrier requirements, although even meat trays have recyclable cardboard alternatives (with a peel-off plastic layer) that do not increase food waste.

- **Won't food costs skyrocket without plastic?**
  Our analysis substitutes only 17 per cent of packaging, making it theoretically possible to implement the entire Substitute intervention on only nonfood packaging. However, where producers do choose to substitute food packaging, it represents only a small fraction of the overall product cost. For example, the price of a plastic drinks bottle is less than US$0.07,[92] typically less than 10 per cent of the overall product price. In the future, if producers are charged through Extended Producer Responsibility schemes for full end-of-life costs, alternative materials could become even more cost-competitive. For reusable packaging, metal and glass could be even cheaper options per use, due to their nonporosity and durability.

- **Will consumers accept substitutes?**
  Convenience does not need to be sacrificed. In fact, in some markets, consumers prefer nonplastics.[93] Achieving the projected level of material substitution cannot rely on eco-conscious buying behaviour alone: The transition must be accelerated by innovation, business leadership and marketing of alternatives, consumer education, and policy.

- **Would we be creating new streams of waste?**
  Paper collection and recycling are already widespread. The acceptability of coatings on paper to recycling facilities outside HI archetypes is unclear; recyclers may need to adapt their practices, or paper coatings may need to be better optimized for recycling, to mitigate this risk. Compostable packaging could introduce new formats of waste and require scale up of higher standard and compatible composting systems worldwide (see Table 5).

- **Are substitutes safe for food contact?**
  There are risks for both plastic and nonplastic materials; food safety is an area that will require better regulation and further research.

If managed carefully, it is possible to meet the material requirements of the Substitute intervention, but unintended consequences need astute monitoring

In selecting any substitute material, it is important that a broad range of environmental and health impacts are assessed holistically—from land and water use to GHG emissions and pollution—and that any life-cycle assessment also takes into account human health and end-of-life impacts on biodiversity.

A key concern when switching to paper is whether the additional material requirements can be met sustainably. On average, 1 metric ton of plastic packaging needs to be replaced with 1.5 metric tons of paper,[94] meaning that the Substitute intervention requires 45 million metric tons of paper per year by 2040. Globally, this represents an 11 per cent increase above 2016-17 paper production.[95]

The primary risk is that the benefits of paper would be negated if this increase causes deforestation, highlighting the importance of sustainable forest management, especially in specific middle-/low-income countries where paper demand is a driver of deforestation today.[96] To minimize the risk of deforestation, our analysis indicates that a strong effort in paper recycling makes it possible to meet the additional paper needed for the Substitute intervention globally without expanding virgin paper input. This step requires increasing paper's global average recycled content from today's 56 per cent[97] to 60 per cent. Southeast Asia already surpasses this level of recycled content;[98] other regions must follow suit. Avoiding deforestation will also require careful selection of the applications where virgin paper is absolutely necessary for food contact safety to avoid chemical migration into food from recycled sources,[99] increasing recycled content in all other paper applications where possible, and tackling inefficiencies in paper recycling.[100]

Sourcing compostable materials could also trigger land use change if not managed holistically. Today, approximately 2 million metric tons of bio-based plastic (plastics made in whole or partially from renewable biological resources) is produced using less than 0.01 per cent of arable land.[101] Our model requires 52 million metric tons of compostable material substitutes per year, be they compostable plastic (sourced from fossil fuels or from biomass) or nonplastics such as fibre- or leaf-based packaging. However, options exist to expand biomass availability without unsustainable land use. These include the use of by-products and discards from the timber and agricultural industries, and alternative fibre sources from plants grown on marginal land. For example, compostable plastic is already being created from waste methane[102] and food waste.[103] Table 5 summarizes other considerations when expanding compostable packaging.

Substitute materials come with higher costs, but could have lower emissions

On average, substitute materials come with higher production costs (up to two times more for compostables), but different stakeholders bear the costs and garner the savings. Some of the cost differential is due to government subsidies or perverse incentives, such as extraction subsidies on fossil fuels, that drive down the price of plastic. There is a net increase in end-of-life collection and disposal costs because of the heavier mass of substitute materials. But the Substitute intervention could produce an overall reduction in GHG emissions compared with BAU by 2040, driven by switching to sustainably sourced paper (see Box 5). Emissions will vary depending on location, and substitutes should be assessed on a case-by-case basis, considering the likelihood of recycling and composting and trade-offs such as chemical use (see Box 6 on health concerns), sourcing, land use, and energy and water requirements involved in paper manufacturing. Efforts must be made to bring the GHG emissions of substitute materials down over time, for example, by sourcing from waste or recycled content and expanding composting. For estimates of GHG implications of each substitute, please refer to Figure 20.

Table 5: Expanding compostable packaging—opportunities and obstacles

Opportunities	Obstacles and mitigation measures
• Composting provides a circular end-of-life treatment option to return nutrients and food waste to the system. Compostables could be suitable where a plastic application is unlikely to be recycled or collected. • Where high food contamination is likely to make food packaging nonrecyclable, compostables provide a solution and could boost the diversion of organic waste away from residual waste. • In some HI countries, incentives towards separate organic waste treatment means access to composting is increasing and is cheaper than landfill.[104] • Composting could bring cost savings in middle-/low-income countries via decentralized community-based composting that avoids collection costs, making it particularly suitable for rural and remote locations with high plastic leakage rates. A directional estimate suggests that this could be done for US$20 per metric ton, which is cheaper than landfill. Substituting 9 per cent of plastic with compostable packaging would contribute only 6 per cent to the organic waste stream globally, which should not damage key performance indicators of the composting processes, which have been tested with levels up to 25 per cent compostable packaging.[105]	• Lack of definitions, standards, and consumer confusion around the term "bioplastics" and "biodegradable," which includes noncompostable plastic.[106] • Compostable materials should meet strict national standards according to the end-of-life processing technologies that exist in the country, and safe, effective standards need refinement, for example, to ensure soil fertility. • Considerable investment and policies are needed to expand organic waste collection and processing facilities that can accommodate and safely process compostable packaging, particularly in middle-/low-income countries. • There is a risk that compostable plastic could be perceived as acceptable to litter[107] and that it could contaminate conventional mechanical recycling,[108] making distinctive labelling, consumer education, and appropriate collection and composting infrastructure essential. • In high-leakage archetypes, leakage risks should be considered. Some compostable plastic may not biodegrade under certain environmental conditions,[109] so nonplastic alternatives are lower risk. As industrial composting is not typically available in low- and middle-income archetypes, home-compostable materials suitable for decentralized composting are required; industrially compostable materials (such as PLA [polylactic acid]) would not be suitable.

Box 5: A careful use of substitutes could save GHG emissions, if key impact considerations are well-managed

- **Packaging weight considerations**
  Comparing different life-cycle analyses of GHG emissions is notoriously challenging, due to different boundary conditions. Some studies assume that plastic is replaced with materials such as glass that weigh many times more than plastic, driving up transport emissions. However, the lower weight substitutes we have modelled minimize this effect because they weigh only up to 1.5 times more than plastic on average. Applications such as paper bags require much more weight, as paper lacks tensile strength; our assessment has therefore switched only 3 per cent of all plastic bags towards paper. Our approach suggests that making carefully considered plastic substitutions with paper or compostable materials could offer GHG savings. This assessment excludes the transport emissions of packaging; however, these are expected to be insignificant compared with the emissions savings of moving from a fossil fuel-based product (plastic) to a largely renewably sourced one.

- **Sustainable sourcing**
  Emissions estimates vary widely according to how a material is sourced, processed and treated at end of life. Sourcing can be from fossil fuels, from waste, or from sustainably sourced biomass or recycled paper. End-of-life treatment varies widely by country, with higher recycling rates decreasing emissions. Paper has one of the highest recycling rates in the world, with a global average of 58 per cent.[110] For paper, our assessment of emissions per metric ton of plastic substituted is based on HI paper emissions per metric ton, where it is sourced sustainably, and paper production often uses renewable energy. If not managed correctly, paper emissions could be higher in some geographic archetypes.

- **Technological advances**
  Our analysis suggests that, under certain assumptions, emission savings could be achieved from paper substitutes. Emissions from early-stage compostable plastic is assumed to be slightly higher than traditional plastic today but could be expected to improve over time. For example, some improved manufacturing processes decreased emissions ~50 per cent in just three years[111] through improved manufacturing processes. Emissions could decrease further if manufacturers source from waste materials, decarbonize energy use, or if composting infrastructure is scaled.[112] For example, in Europe, the life cycle of compostable materials could offer 65 per cent emissions savings compared with plastic if the optimum end-of-life treatments were used.[113]

Enabling conditions

Policy, economic, and innovation drivers required to accelerate this intervention include:

- Economic incentives that help level the playing field between plastic and other materials across the life cycle, such as the removal of extraction subsidies for oil and gas, taxes on virgin plastic content, or Extended Producer Responsibility-type schemes with modulated fees for different packaging formats.
- Funding for innovation in new materials, packaging designs, and barrier coatings.
- Policies and voluntary commitments to accelerate the expansion of paper collection and recycling, increase recycled content in paper, reduce contamination, and scale separate organic waste treatment that can accept compostable packaging.
- Standard-setting that defines acceptable compostable materials according to locally available waste infrastructure and provides clarity around definitions of terms such as "biodegradable."
- Certification of sustainable sourcing of biomass, and the adoption of strict criteria by brands and producers to ensure that substitutes contain recycled content and are sourced responsibly.
- Commitment from brand owners to transfer innovations and new materials across geographic archetypes.

Box 6: Substitutes also have health concerns that present key areas for innovation

- Paper production and recycling are associated with the release of particulate matter (PM), nitrogen oxides (NOx), sulfur oxides (SOx), wastewater containing chlorine for bleaching paper, lead, and dioxins/furans.[114] Technologies such as chlorine-free bleaching and "DryPulp" could mitigate the risks from wastewater that is not properly treated. Recycled content in paper can also lead to health concerns for food-contact packaging, such as from mineral oils in dyes.[115] Coated paper, in which the coating is plastic, poses the same chemical migration concerns for health as any other plastic packaging, and PFAS coatings may be of concern.[116]
- Compostable materials generally have fewer known pollutants or risks.[117] However, compostable materials vary widely, from fossil fuel-based to bio-based feedstocks, and continued research and regulation are required to ensure the food safety of new materials, additives, and coatings.[118] New materials should be thoroughly assessed to ensure that their introduction does not generate more serious environmental and health problems.

Macroplastic system interventions

SYSTEM INTERVENTION 3

Design products and packaging for recycling to expand the share of economically recyclable plastic from an estimated 21 per cent to 54 per cent by 2040

INTERVENTION SUMMARY

- Flexible and multimaterial plastics currently make up only 59 per cent of plastic production but are responsible for 80 per cent of macroplastic leakage, highlighting the urgent need to target these formats through redesign.
- Only 15 per cent of plastic is currently recycled—and this figure varies significantly by type; designing plastic for recycling can help increase this percentage through two separate but synergistic benefits: 1) increase the share of recyclable plastic; and 2) improve the economics (and hence likelihood) of recycling.
- Design for recycling interventions can increase both the yield and value of recycled plastic, improving the economics by US$120 per metric ton and virtually doubling recycling profitability; a shift from multimaterials to monomaterials plays a fundamental role in increasing material recyclability.
- Removing pigments from plastic can increase their recyclate value by approximately 25 per cent.

Highly applicable | Somewhat applicable | Not applicable

Most relevant geographic archetypes

HI Urban	UMI Urban	LMI Urban	LI Urban
HI Rural	UMI Rural	LMI Rural	LI Rural

HI: High-income **LMI**: Lower middle-income
UMI: Upper middle-income **LI**: Low-income

Most relevant plastic categories

Rigid	Flex	Multi

Main responsible stakeholders

- Consumer goods brands

kyrychukvitaliy/Adobe Stock

Many plastic items are designed in ways that make recycling difficult, uneconomical, or even impossible. This problem is exacerbated by the centralized design and production of mass consumption products for all global markets, which is incompatible with the local waste management systems into which these products are introduced after use.

Design for recycling can increase recycling rates worldwide by raising the yield and value of recycled plastic, thereby improving the profitability of the mechanical recycling industry. Only 21 per cent of today's plastic is economically recyclable, and therefore of higher value, and current industry trends show that, going forward, this share is expected to decrease under BAU.[119] Both the formal and informal recycling sectors target plastic with the highest market value, often leaving the low-value materials to go uncollected or be mismanaged if collected.

The low value of discarded items is dictated by their inherent lack of recyclability, their degradation during use, and the limited demand for their reuse. The mix of polymers, additives, and dyes that make up low-value plastic dilute the quality of the recycled output and limit its viability as recycled content in many applications. Designing plastic for recycling in local settings is the easiest way to increase its inherent value while improving the profitability of the mechanical recycling industry. Boosting the uptake and quality of recycled content also reduces the need for virgin plastic input and thereby cuts GHG emissions from virgin plastic production.

Low-value flexible and multilayer plastic currently contribute a disproportionate amount of leakage to the ocean: They make up 59 per cent of production but constitute 80 per cent of macroplastic leakage (see Figure 29). This finding highlights the urgent need to target these formats through redesign.

The inherent design of many plastic products makes recycling difficult and costly, but streamlined changes to improve the quality of the output will strengthen the secondary market while reducing costs in the recycling process. For materials for which recycling economics are already almost profitable, design for recycling can help make them profitable through a combination of levers.

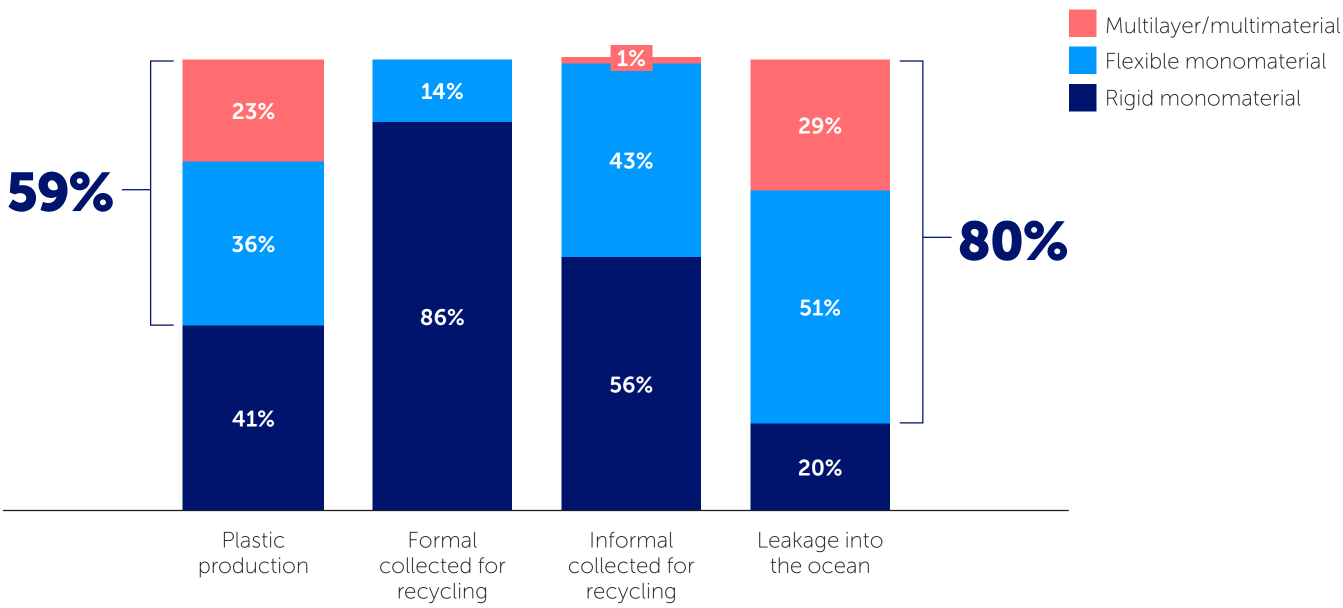
We identified five principal design for recycling levers to achieve this goal:

1) Switch 50 per cent of multimaterial flexibles to monomaterial flexibles by 2030 and 100 per cent by 2040

Multimaterial flexibles often exist to meet the toughest packaging requirements but are not mechanically recycled due to poor economics. Reduction and substitution solutions are available for some of this packaging type in the System Change Scenario, but for the remaining multimaterial flexibles that cannot be reduced or substituted, we have applied an ambitious design for recycling intervention. Research is already gathering speed in this area, with one industry expert reporting that technical monomaterial solutions are in development that could meet 100 per cent of barrier property requirements of multimaterial flexibles as

Figure 29: Global production, collection, and leakage rates by plastic category, Business-as-Usual, 2016

Flexible monomaterials and multilayer/multimaterials represent 59 per cent of plastic production but contribute 80 per cent of plastic leakage to the ocean



Flexible and multilayer plastic make up 59 per cent of plastic production, while collectively contributing to 80 per cent of the plastic leakage. The plastic that is collected for recycling by both the formal and informal sectors is predominantly rigid.

soon as 2030.[120] We therefore assume that it is possible to switch 100 per cent of the multimaterial flexibles that remain, which will increase the proportion of recyclable plastic waste and its value, driving higher recovery and recycling rates. We have not modelled replacing single-use flexibles with single-use rigid packaging as this would increase packaging weights significantly, but this could be suitable in some instances after holistically assessing cost and environmental trade-offs. A switch towards monomaterial flexibles must go hand in hand with an expansion in their collection.

Example: One brand owner has developed a resealable monomaterial pouch that could be recycled alongside polyethylene (PE) films once collection and sorting has scaled. Currently it is recyclable through store take-back.[121]

2) Switch 5 per cent of multimaterial rigid household goods to monomaterial rigids by 2030 and 10 per cent by 2040

Shifting multimaterial household goods to monomaterials is more challenging due to the unique performance properties required. Switching 10 per cent of rigid household goods from multimaterial to monomaterial will further increase the proportion of recyclable plastic waste, driving higher recovery and recycling rates.

Example: Household items such as brushes, combs, brooms, cases, and spatulas could transition towards recyclable monomaterials such as PP if the switch would not decrease the longevity of products. Some items require multiple material components, which could be designed for disassembly.

3) Redesign (or remove) dyes, plastic pigments, and additives

This is a vital transition as it represents one of the biggest barriers preventing recyclers from creating recycled quality that can compete with virgin output. Plastic often contains additives, from colourants to stabilizers and flame retardants. These additives are difficult to trace or remove and can contaminate plastic or make it unsafe or unusable in new products. Colour is typically used for marketing purposes, but this results in two conflicting problems. First, the post-consumer plastic available for recycling is made up of many colours, creating a complex mix that is impossible to separate into single colours. Second, the demand is for recycled plastic in neutral colours (similar to virgin plastic). To create a circular loop between plastic and products, many more items need to be made from unpigmented plastic and new marketing approaches need to be developed, such as using recyclable inks and labels. Through design for recycling, more plastic material can be profitable to recycle (for example, clear PET recyclate has a 25 per cent higher sales value than coloured), while other improvements to streamlining will reduce the cost of closed-loop recycling as sorting losses decrease.

Example: A soft drinks company operating in Latin America is using one clear bottle design for its full range of multibranded products and distinguishing among them using paper labels. Bottling facilities are equipped to take back bottles, wash off paper labels, then clean, refill, and rebrand bottles with fresh labels.[122]

4) Increase homogeneity and cleanliness of recycling inputs and eliminate problematic polymers and packaging formats

There are currently thousands of different plastic types (even under a single-polymer name) and multiple formats, which inhibits the quality guarantee of the recyclate. By eliminating hard-to-recycle polymers that would otherwise contaminate the rest of the plastic waste stream (such as PVC, PS, EPS) and by reducing the number of polymers used, both the sorting and recycling of plastic will be improved. These changes will decrease the complexity of sorting (for both consumers and sorters) and simplify recycling processes, ultimately increasing recycling yields and reducing costs.

The type of plastic is a key factor in determining what is economically recyclable, but specific format types and the scale at which they are placed on the market and collected are also important for any mechanical recycling. Certain packaging formats are particularly problematic and should either be fundamentally redesigned to allow them to be economically collected and recycled at scale, or eliminated through reduction and substitution mechanisms. Examples include small format packaging such as sachets, which also have a high propensity to leak into the environment and are difficult to economically collect at scale.

Example: With all components made of the same plastic type, not only is this design made of 100 per cent recycled plastic, but it is also 100 per cent recyclable.[123]

5) Improve labelling

The purpose of labelling is to help both the consumer and the sorter to place products into the correct recycling stream. Labelling should therefore conform to clear national or international standards that take the practical recyclability of the materials into account. The packaging industry should also ensure that "labelling for recycling" is intuitive, especially when multiple polymers are used, to maximize recycling efforts from consumers, pickers, and sorters, as well as from recyclers themselves. For example, a box made of high-density polyethylene (HDPE) with a lid made of low-density polyethylene (LDPE) should have each component labelled separately, as opposed to the current practice in which, for the sake of aesthetics, HDPE and LDPE are both mentioned on the bottom of the box.

By improving labelling practices, the complexity of sorting and recycling processes will decrease, which will ultimately increase the share of waste collected for recycling, increase recycling yields, and reduce costs during sorting and recycling.

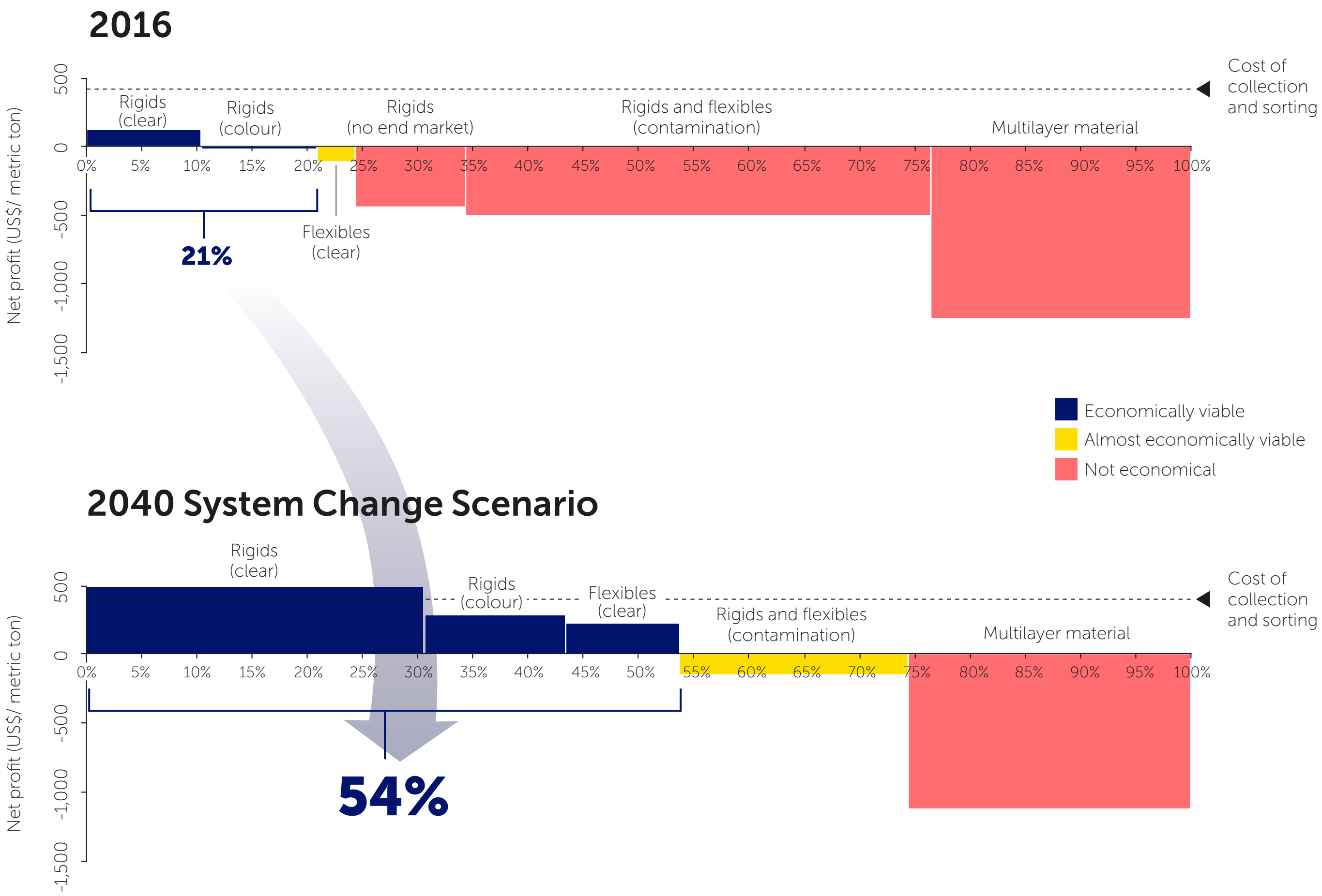
Taken together, the five design for recycling levers outlined above could significantly expand the share of plastic that is economically recyclable mechanically. In high-income countries, an estimated 54 per cent of plastic waste could be economically recyclable within system restraints by 2040, up from 21 per cent today, as shown in Figure 30 (this assumes that collection and sorting costs are not paid for by the recycler but by the government, local authority taxes, or covered by Extended Producer Responsibility schemes, as is usually the case in HI countries).

The five design for recycling levers also improve the economics of recycling by US$120 per metric ton,[124] virtually doubling recycling profitability (see Figure 31).

In addition to economically benefiting the recycling system, this intervention is expected to deliver social and environmental benefits. The first benefit is greater profits for the informal collection sector through both increased collection and the sale of higher-value products. The second benefit relates to lower levels of air and water pollution from unknown chemical compounds as a result of increased standardization of additive and polymer use. Moreover, increasing recycling and offsetting the use of virgin plastic reduces GHG emissions by 48 per cent relative to depositing plastic in landfills (and even more relative to incineration), which is equivalent to a reduction of 1.9 tCO_2e per metric ton of plastic recycled (see Figure 20 for details).

Figure 30: Mechanical recycling economies for different material types in high-income countries, 2016 versus 2040

The share of plastics that is economically recyclable mechanically could grow from 21 per cent in 2016 to 54 per cent in 2040



In 2016, the share of plastic that is economically recyclable is estimated to be 21 per cent. By 2040, we estimate this figure can expand to 54 per cent. The analysis represents the System Change Scenario, thereby including Reduce and Substitute, design for recycling and improvements in collection. Net profit is "US$ per metric ton of collected plastic," which is calculated as sales price minus the cost of recycling for different material types. Cost of recycling factors in mass losses in sorting (20 per cent) and recycling (27 per cent). No taxes are included, and the costs of collection and sorting have been excluded given that these are often covered by governments. Contamination is defined as the share of plastic that is not collected separately for recycling. This analysis represents high-income countries, where the share of uncontaminated waste is higher than in middle-/low-income countries. "No end market" includes PVC, PS and EPS. Commodity prices are assumed to remain stable.

Enabling conditions

Several enabling conditions can help accelerate the design-for-recycling system intervention and help achieve its full potential. These include:

- Strong policy interventions that promote the use and increase the value of recycled polymers and incentivize producers to develop products with end-of-use considerations. Examples include fee modulation based on recyclability in Extended Producer Responsibility schemes; design for recycling standards; recycling targets; minimum recycled content targets; taxes on the use of virgin plastic feedstock; regulatory mandates on certain pigments, polymers and additives; disclosure mandates; and the regulation of recycling labelling practices.
- Greater industry collaboration and engagement, including:
  - Development of new polymer production and packaging designs in coordination with recycling and sorting technology companies.
  - Collaboration with ink manufacturers over the development of re-extrudable inks and new printing processes to enable brand differentiation without the contamination associated with inks, additives, and mixed polymer use.
  - Harmonization of materials and packaging formats across companies. Coordination to improve and standardize recycling bin designs.
- Increased public- and private-sector R&D investment into design for recycling and associated technology, including:
  - Investments in products that meet recycling specifications without sacrificing product safety, stability, or purity.
  - Support for further innovation in sorting technologies to address pigments, additives, inks, and labels.
- Shifting consumer preferences driving higher demand for recycled content and higher recyclability of plastic products.
- Voluntary commitments by producers and retailers to increase recyclability and integrate recycled content in plastic products.

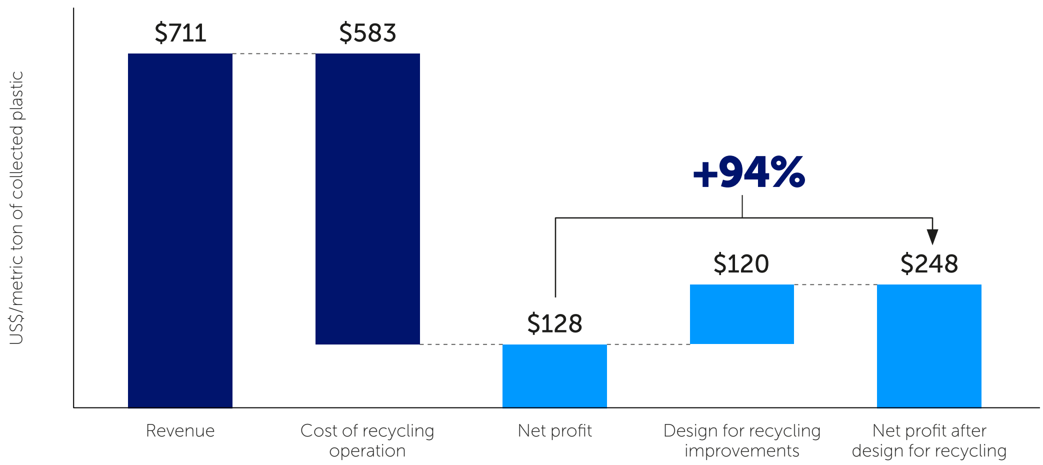
Limiting factors

There are also barriers to scaling up design-for-recycling solutions that need to be considered and overcome, for example:

- Product differentiation is often established through multiple levels of packaging and labelling. New product branding devices will be needed.
- Some applications need multilayers because they currently have no technical alternatives, although this represents a small proportion.
- Some consumers may prefer smaller format packaging due to limited space or because they can only afford smaller volume products. For such products that are unlikely to ever cross the barrier to becoming collected at scale and profitable to recycle, solutions may lie in new delivery models, at an equivalent or lower cost, rather than design for recycling.
- Barriers and additives in plastic are often important for food and drug preservation and extended shelf life. Innovation and research are needed to design more recyclable alternatives that avoid spoilage.
- Plastics can be contaminated by the substances that they held, which can lead to the accumulation of hazardous chemicals in recycled material. Better separation of food contact and nonfood contact packaging would help reduce contamination.

Figure 31: Recycling per metric ton of input in high-income countries, 2016 US$

Design for recycling could almost double the profitability of mechanical recycling



Source: Ellen MacArthur Foundation (2017), *The New Plastics Economy: Catalysing Action*

Revenue is based on a blended price of high-value plastics (PET, HDPE, and PP). The recycling costs include opex and capex. Revenue per metric ton of collected plastic factors in mass losses in sorting (20 per cent) and recycling (27 per cent); cost per metric ton of collected plastic factors in 20 per cent sorting losses. No taxes, subsidies, or gate fees are included. This represents an archetype average; economics may vary based on local regulations, incentives, costs, and waste composition/quality.

Macroplastic system interventions

SYSTEM INTERVENTION 4
Expand waste collection rates in middle- and low-income countries to 90 per cent in all urban areas and 50 per cent in rural areas by 2040, and support the informal collection sector

INTERVENTION SUMMARY

- We estimate that 22 per cent of global plastic waste is left uncollected; this figure could grow to 34 per cent by 2040 under BAU.
- By 2040, approximately 4 billion people need to be connected to collection services (2 billion who lack it today[125] and 1.7 billion population growth). Closing this gap would require connecting approximately 500,000 people to collection services per day, every single day, until 2040.
- Although rural areas make up 28 per cent of waste generation, they represent 57 per cent of uncollected waste, as collection is more difficult and costly.
- The informal sector plays a critical role in reducing plastic pollution; in 2016, it collected an estimated 27 million metric tons of plastic that may have otherwise leaked. About 59 per cent of all plastic recycled globally is collected by the informal sector.

Highly applicable | Somewhat applicable | Not applicable

Most relevant geographic archetypes

HI Urban (Not applicable)	UMI Urban (Highly applicable)	LMI Urban (Highly applicable)	LI Urban (Highly applicable)
HI Rural (Somewhat applicable)	UMI Rural (Highly applicable)	LMI Rural (Highly applicable)	LI Rural (Highly applicable)

HI: High-income
UMI: Upper middle-income
LMI: Lower middle-income
LI: Low-income

Most relevant plastic categories

Rigid (Somewhat applicable)	Flex (Highly applicable)	Multi (Highly applicable)

Main responsible stakeholders

- **Local governments**

kyrychukvitaliy/Adobe Stock

Collection under Business-as-Usual

By 2040, under BAU, we estimate that the mass of uncollected macroplastic waste will grow from 47 million metric tons per year (22 per cent of total plastic waste) to 143 million metric tons per year (34 per cent of total plastic waste)—the vast majority in middle-/low-income countries—with profound implications for communities and ecosystems. Closing this collection gap is one of the most critical interventions needed to achieve a meaningful reduction in ocean plastic pollution. Expanding plastic waste collection to the extent modelled in the System Change Scenario will take significant funding and innovation.

As populations and wealth increase across middle-/low-income countries, it is reasonable to assume, based on historical trends, that the amount of macroplastic waste generated will increase faster than the ability of governments to plan waste management systems and develop infrastructure. The proportion of collected waste will therefore likely stall or decrease as governments struggle to keep pace. This explains why the mass of uncollected waste, and the leakage to the ocean that flows from it, is expected to grow so rapidly. In our BAU Scenario, we assume that collection rates remain constant or are constrained not to grow faster than global GDP growth, averaged at 3 per cent per annum.[126]

Collection under the System Change Scenario

In the System Change Scenario, we assume that LI, LMI, and UMI countries will achieve a similar collection rate to HI countries when they reach the same per capita GDP level. Effectively, this means that we assume collection rates (formal and informal) will reach 90 per cent in urban areas of middle-/low-income countries and 50 per cent in rural areas. We assume that informal collection will grow at the same rate as under BAU, and hence that most growth in collection will be through the formal sector.

Achieving these aspirational collection rates will require tremendous resources from governments and industry throughout the world. HI countries are probably equipped to absorb these additional costs, but middle-/low-income countries will have much more difficulty.

Rural areas generate a disproportionate share of plastic entering the ocean, accounting for 45 per cent of leakage in 2016, but 28 per cent of total waste generated; it is therefore critical that the expansion of collection services is focused on rural as much as urban communities.

Box 7: The economics of formal and informal macroplastic waste collection

Collection can be classified into service-driven collection and market-driven collection.

Service-driven collection is usually carried out by the formal sector, at the behest of municipal authorities who provide waste management as a service to their citizens. Service-driven collection is strongest in HI countries and the urban centres of LMI, UMI, and LI countries. Most plastic waste is collected mixed with other waste streams (mainly organics), but some can be separated at source for recycling and collected separately (usually with other dry recyclables).

Market-driven collection is usually carried out by the informal sector, whose participants "cherry-pick" the most valuable materials from household waste, either at the kerbside from waste bins or from dumpsites and landfills. Although increasing service-driven collection rates requires funding from governments, increasing market-driven collection rates can be achieved by raising the value of materials. A material's value is the key driver of its collection rate. The result of this cherry-picking is that lower value and lighter items of plastic waste (mainly flexible monomaterials such as bags and films, and multimaterial or multilayer items such as sachets and beverage cartons) are more likely to remain uncollected and ultimately are burned openly or leaked into the environment. Focusing system interventions on these materials is therefore a top priority for reducing the negative environmental impacts of waste plastics globally.

There are three reasonable methods to estimate the cost of collecting plastic per metric ton in middle-/low-income countries.

Method 1: Allocated cost of plastic collection (through formal sector)

Macroplastic waste has a low bulk density, which means it occupies significant space on waste collection vehicles compared with other, denser materials. Although the lightness and high ductility of plastic products is beneficial during the use phase, its impact on waste collection costs is profound. In this method, we estimate the cost of plastic collection to be between US$54 and US$156 per metric ton across LI, LMI, and UMI countries (detailed figures per archetype can be found in the technical appendix).

Method 2: Full cost of waste collection (through formal sector)

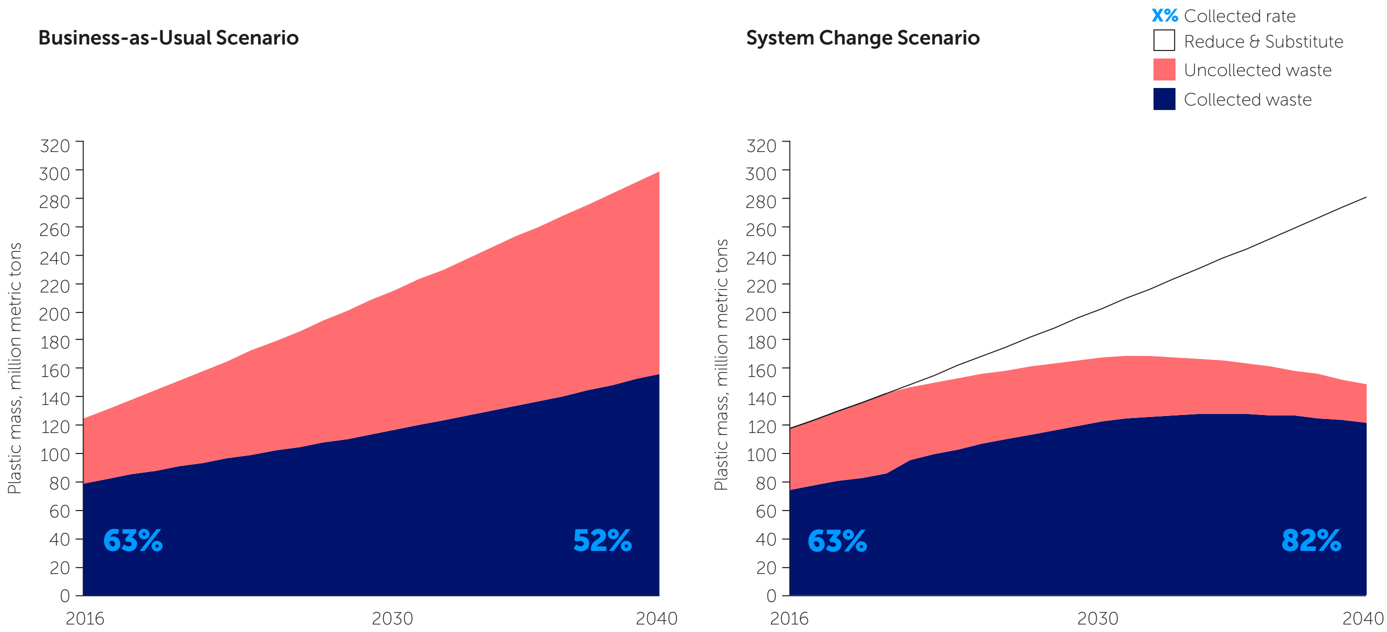
In most cases, plastic is mixed with other waste streams and cannot be collected in isolation (in other words, collection is a "bundled system"). To collect 1 metric ton of plastic, one must therefore effectively also collect 9 metric tons of nonplastic waste, which costs US$43-US$123 per metric ton (collecting mixed waste is cheaper per metric ton than plastic in isolation). The cost of collecting 1 metric ton of plastic as MSW therefore actually costs on average US$770 per metric ton across middle-/low-income countries. This method more accurately reflects the real costs for governments to collect a metric ton of plastic.

Method 3: Collection through informal sector

Another option is to collect waste through the informal sector. We estimate this cost at US$315 per metric ton. This method does not need to account for other waste streams because waste collectors can choose what they collect.

Figure 32: Collection rate under the Business-As-Usual and System Change Scenarios in middle-/low-income countries

The System Change Scenario could significantly increase 2040 collection rates relative to BAU without increasing collection mass significantly thanks to the Reduce and Substitute system interventions



The System Change Scenario could significantly increase 2040 collection rates relative to BAU (from 66 per cent to 87 per cent) without increasing collection mass significantly thanks to the Reduce and Substitute system interventions. Although substitutions (e.g., paper) also require collection (and this cost has been accounted for in our model), these materials have significantly higher collection rates relative to plastic because of paper's higher recyclability.

Improving effectiveness of collection through better governance

Our model estimates that 25 per cent of the macroplastic that enters waterways every year is dumped there directly by collection vehicles whose operators want to avoid landfill taxes and/or the cost and time of travelling to controlled treatment or disposal facilities (or because no facility is available). Evidence to support the underlying assumptions behind this estimate is scant and anecdotal at best[127] because the activity is generally illegal and participants are understandably reluctant to share information. However, it is a phenomenon that can easily be observed in many areas in the middle-/low-income countries.

In the System Change Scenario, we ambitiously estimate that direct dumping of post-collected waste could be reduced by 80 per cent by combining existing technological innovation and stronger regulatory oversight. For instance, the movement of waste collection vehicles could be monitored with the help of new developments in telemetry that allow the cost-effective tracking of vehicles. This technology is becoming cheaper and has already been employed in some cities in middle-/low-income countries.[128]

Informal recycling sector participants are exposed to unacceptably high levels of risk from hazards, such as airborne particulate matter from open burning, contaminated medical sharps, nonmedical sharp objects, and bio-aerosols, to name a few.[133] Furthermore, waste pickers are often stigmatized and even criminalized for their work, which is mostly unrecognized by other agents.[134] Discouraging waste-picking on the grounds of poor working conditions would deprive entrepreneurs of vital income. Conversely, encouraging the proliferation of the informal recycling sector as a cost-effective waste management service is to be complicit with sometimes unacceptably hazardous working conditions.

Rather than propose either of these opposing options, our System Change Scenario assumes that the informal recycling sector will grow at the same rate as the global urban population; this means a 58 per cent increase in both the number of waste pickers and the macroplastic they collect by 2040.

For the expansion of the informal sector to become a socially just solution to plastic pollution, its participants need to be remunerated fairly and their working conditions improved. In many areas, waste pickers have been shown to reduce municipal spending on waste management. If even a proportion of these savings could be allocated to their direct remuneration and improving working conditions, there would be potential for the sector to develop, reduce risk, and professionalize its activities. Improving the situation for waste pickers will help solve a host of chronic social and economic problems and contribute towards meeting several Sustainable Development Goals.

Box 8: The informal recycling sector: huge potential for curbing macroplastic leakage

Waste pickers are responsible for 60 per cent of global plastic recycling. Yet, to date, the huge contribution of the informal sector to reducing ocean plastic pollution has largely gone unrecognized and underpaid. An increase in plastic material value through design for recycling, as well as the implementation of new technologies, can significantly increase the retained value for waste pickers and contribute to social justice.

For the purpose of this project, we defined the informal recycling sector (waste pickers) as individuals or enterprises who are involved in private-sector recycling and waste management activities that are not sponsored, financed, recognized, supported, organized, or acknowledged by the formal solid waste authorities, or which operate in violation of or in competition with formal authorities.[129]

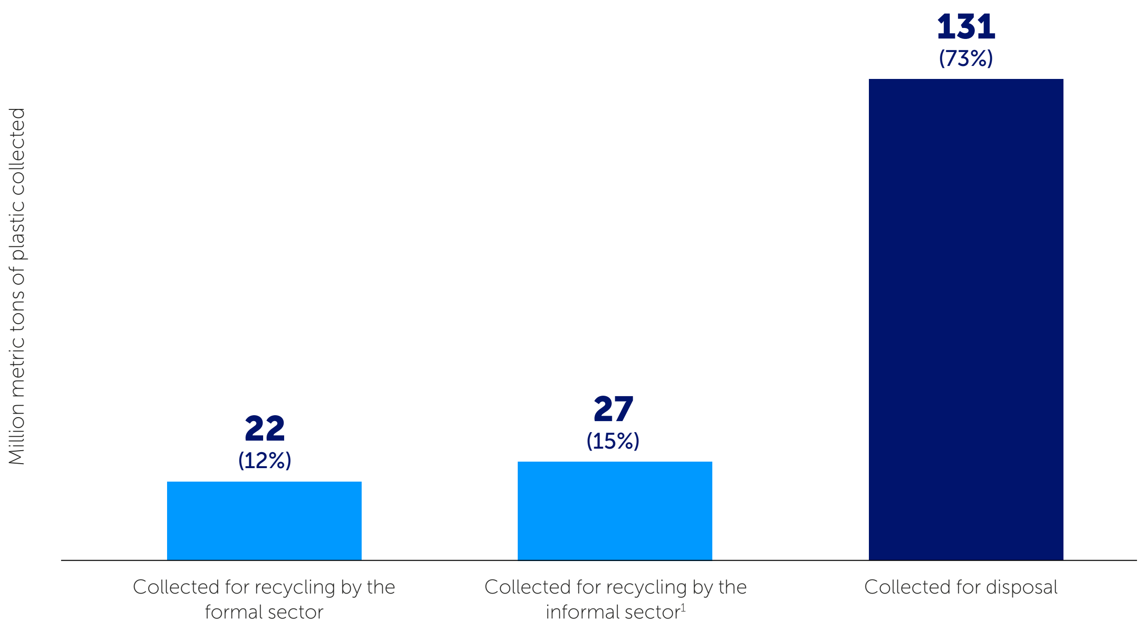
Waste pickers in the informal sector work in diverse ways.[130] They may operate independently, collecting and separating recyclable materials and selling them to intermediaries or directly to reprocessors.[131] In many countries, waste pickers have organized in cooperatives, associations, federations, and networks.[132] In other parts of the world, waste pickers have created unions and are integrated as informal workers in the formal collection, separation, and recycling of plastic waste.

The complex landscape of the informal recycling sector, and the inherent lack of documentation and paucity of reliable data, make it very difficult to report on the sector with sufficient accuracy. We estimate the number of (full-time equivalent) participants worldwide to be 11 million in 2016, collecting a total of 27 million metric tons of macroplastic waste each year, 12 per cent of all the municipal solid waste produced annually.

Worldwide, the informal sector could be responsible for collecting more plastic for recycling than the formal sector, underlining its key importance (Figure 33). In all but the HI archetype, the informal sector is the main actor in the recycling business, as the formal sector focuses on mixed collection, which is largely landfilled.

Figure 33: Global collection by type, 2016

Globally, the informal sector collects more plastic for recycling than the formal sector



[1] Includes collection from households, streets, and dumpsites.

Box 9: Health and environmental risks of open burning

There are many significant risks associated with uncollected waste, many of which stem from the open burning of plastic waste. Our model shows that, in 2016, 49 million metric tons of uncollected macroplastic waste was burned openly, either as fuel or as a means of disposal in the absence of a waste management provision. By 2040, our model anticipates that this figure could increase to 133 million metric tons under BAU.

Combustion is rarely complete in open burning, leading to the formation of fine particulate matter, coated in oily materials such as tars and polyaromatic hydrocarbons (PAH). Particulate matter, particularly PM 2.5 PAH, is both mutagenic and carcinogenic, causing developmental and immunological impairments as well as reproductive abnormalities. Air pollution is responsible for as many as 3.7 million deaths per year[135] and open burning is believed to be a significant contributor. Plastic waste combustion also contributes to climate change because plastic is almost entirely made from fossil carbon. The partial combustion of plastic releases black carbon aerosols, which may have as much as 5,000 times the global warming potential of CO_2.[136] The negative impacts on health and the wider environment make open burning an entirely unacceptable disposal option.

Enabling conditions

Several enabling conditions can help accelerate the scale-up of collection and help this system intervention achieve its full potential. These include:

- **Innovation and technology**
  Innovations in waste collection can help solve a range of challenges. New models for the aggregation of waste (including decentralized management and deposit schemes), enhancing communication with waste producers, and better logistics for collectors could all improve the microeconomic viability of waste collection in less accessible areas. Decentralized waste storage, processing, and treatment can empower local people while diverting resources away from disposal and reducing the chance of mismanagement. New business models can also play a role. Companies are piloting business models that incentivize consumers to collect and separate at source by sharing the value of collected products. Advances in telemetry to monitor collection vehicles, in combination with regulatory enforcement, can be used to reduce the direct dumping of collected waste into waterways.

- **Governance, quality of collection, and planning**
  Dumping waste in the natural environment is illegal in many countries, but progress is needed to increase compliance with regulations, combat corruption, and boost the enforcement capacity of governments. Results-based financing, including contract instruments such as capping fees and performance-based remuneration, may be effective both in improving the quality of waste collection and in preventing illegal dumping.

- **Increasing the value of materials**
  For market-driven collection to expand, the value of materials must be higher than the cost of collection. Examples of ways to increase the material value of waste include:

  - Mandating the use of recycled content to increase demand for secondary materials.
  - Designing more plastic for recycling (see System Intervention 3).
  - Reducing the variety of polymers to lessen the need for sorting.
  - Creating and developing local or regional markets to provide better access for the informal recycling sector.

Limiting factors

Several limiting factors also need to be addressed:

- **Funding**
  Waste collection is already a significant cost burden for municipal authorities throughout the world, typically accounting for 19 per cent of municipal budgets in LI countries, 11 per cent in LMI and UMI countries, and 4 per cent in HI countries.[137] Central governments shoulder much of the burden of investment in treatment, disposal, storage, and collection infrastructure. Plus, investment is often most needed where monetary resources are least available. The billions of dollars of investment in collection and storage equipment, let alone the operating expenditure necessary to keep collection systems running, are unlikely to become available from taxation in middle-/low-income countries over the next 20 years. Governments will need to source funds elsewhere. One option is to increase industry funding through Extended Producer Responsibility, a virgin plastic tax, or other mechanisms.

- **Chronic lack of collection in rural areas, unlawful settlements, and slums**
  Rural and remote areas have significantly lower collection rates and higher collection costs, while some settlements may have no waste collection services at all,[138] meaning that residents have to manage their waste informally. Similar issues affect many of the lowest-income and slum areas. Extending and expanding collection in these areas is critical to reducing plastic pollution, but will rely on funding, policy, and innovation.

- **Addressing organic waste**
  Although this report focuses on plastic, it is important to acknowledge that formal collection services target all waste streams, not plastic alone. The solutions available (or not) for other waste streams, and particularly organic matter, will have a fundamental impact on the value of plastic because mixing organic and plastic waste in bins is one of the leading causes of plastic value loss due to contamination. Crucially, the need to collect organics is also the largest cost driver when expanding collection coverage because organics are the largest waste stream, often making up more than 50 per cent of municipal waste.[139]

Macroplastic system interventions

SYSTEM INTERVENTION 5
Double mechanical recycling capacity globally to 86 million metric tons per year by 2040

INTERVENTION SUMMARY

- Today's plastic recycling system is failing us: Only 20 per cent of plastic enters recycling systems and, after accounting for sorting and recycling losses, only 15 per cent of global plastic waste is actually being recycled.
- Recycling today is less economical than landfill or incineration, but it has the potential to be US$350-US$540 per metric ton more profitable in the future across all archetypes because, unlike landfill and incineration, it generates revenue.
- Mechanical recycling capacity can scale up to address 86 million metric tons per year of plastic waste by 2040, equivalent to opening 107 recycling plants of 20,000 metric tons per year capacity globally every year from 2021 until 2040. By 2040, 33 per cent of total plastic MSW would be mechanically recycled (after Reduce and Substitute interventions). Even in this aspirational scenario, 67 per cent of plastic waste remains unrecycled due to limitations on expanding collection, on what can be profitably recycled, and on material losses.
- Each reprocessing cycle degrades the material, which means that even a product designed for recycling is only kept out of the managed disposal or improper disposal pathways for a limited amount of time. Contamination and degradation prevent the material from continuously staying in play.
- Each metric ton of recycled feedstock offsets 48 per cent in GHG emissions (1.9 tCO_2e/t) relative to virgin plastic production.

Highly applicable | Somewhat applicable | Not applicable

Most relevant geographic archetypes

HI Urban (Highly applicable)	UMI Urban (Highly applicable)	LMI Urban (Highly applicable)	LI Urban (Highly applicable)
HI Rural (Highly applicable)	UMI Rural (Highly applicable)	LMI Rural (Somewhat applicable)	LI Rural (Somewhat applicable)

HI: High-income **LMI**: Lower middle-income
UMI: Upper middle-income **LI**: Low-income

Most relevant plastic categories

Rigid (Highly applicable)	Flex (Somewhat applicable)	Multi (Not applicable)

Main responsible stakeholders

- **Waste management companies**

This system intervention quantifies how far mechanical recycling can go towards managing the plastic waste that remains after the upstream Reduce and Substitute interventions have been applied and after design for recycling has been ambitiously applied. The analysis clearly illustrates that, although we cannot recycle ourselves out of the plastic pollution problem, mechanical recycling is an important part of the integrated solution.

Today, many industry efforts and commitments are being directed towards recyclability, but mechanical recycling has historically struggled due to a combination of factors, most notably fragile economics. This fragility is driven by three important factors:

- **Volatile and low prices for recycled plastic, linked to low global commodity prices for oil and virgin plastic:** Recycled plastic prices have been volatile, and this has limited investments in collection and recycling capacity, reducing raw recyclate material and restricting growth.
- **Consistency and grade:** Recycled plastic has traditionally not matched the consistency and grade of virgin plastic and is usually traded at lower prices, which limits the value generated from the recycling supply chain.
- **Low disposal costs:** Landfill and incineration options have historically been attractively inexpensive, stifling the demand for alternative methods of treating waste.

Today's recycling system has failed to cope with current volumes and types of plastic waste, resulting in 15 per cent of global plastic waste being recycled. Moreover, this figure is probably an overestimation because reported figures for plastic recycling include exported waste, which is assumed to be fully recycled, although anecdotal evidence indicates that this is not always the case.[140] Even when plastic is recycled, open-loop recycling makes up an estimated two-thirds of global capacity, highlighting the lack of circularity in the system. Materials need to be recycled to the highest standard and level of purity to be able to be used for a wide variety of products and for recyclates to become a valuable commodity.

There is an intrinsic limitation on how much of the plastic waste stream can currently be recycled. 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.[141] There are currently four factors that limit how much of the plastic waste can therefore be defined as recyclable:

1. **Many product designs are technically problematic** for mechanical recycling, for example, composite or multilayer designs made up of different materials or polymer types.
2. **Local infrastructure and technology** to collect, sort, and recycle the product after use is often lacking.
3. **Plastic often becomes contaminated** with other waste, making recycling unviable because it can become too costly to clean and separate the plastic fractions.
4. **Some plastic is not economically recyclable within reasonable system constraints** due to the additional costs required for certain product types, e.g., small, lightweight items with high collection and separation costs.

Box 10: Why is fixing our recycling system such an important part of the solution?

- Even after reducing and substituting wherever feasible, there is still a significant amount of single-use plastic required, for which a circular end-of-life system should be developed.
- Achieving the true potential of plastic recycling—through better product design; new collection, separation and recycling technologies (chemical and mechanical); and smart policies—will contribute to the expansion of plastic waste collection.
- When it operates at a profit, recycling can provide a financial incentive for stakeholders to fund additional material recovery. Improving recycling economics can drive increased material recovery and reduce leakage of plastics to the ocean.
- Landfill capacity is limited and under high pressure in many places, creating a disincentive for increasing waste collection rates. Recycling can counter this disincentive by taking landfill-bound waste out of the waste stream.
- Recycling allows us to move away from linear plastic production by maximizing the longevity of previously extracted hydrocarbons, thereby reducing the need for additional extraction. This improved circularity addresses not only climate change (through a reduction of 1.9 tCO_2e per metric ton of plastic recycled relative to virgin plastic production), but ultimately also the growing concerns regarding land use (e.g., for landfills or sourcing of feedstock for bio-based plastics), biodiversity, and intensive resource extraction.
- Recycling has a GHG emissions benefit compared with landfilling or incineration, neither of which drive a reduction in emissions by offsetting the need for virgin plastic production.

Material losses inherent in the system mean that there is a further important distinction between what is collected for recycling and how much is actually recycled. These sorting and recycling losses collectively lead to a 42 per cent loss in material in high-income countries. The prevalence of the informal sector and manual sorting in middle-/low-income countries results in a lower cumulative loss rate of 31 per cent, because the sorted plastic waste is generally of a higher quality.

Even if we could significantly increase recycling rates, this would not automatically translate into lower leakage to the ocean. If we increase recycling rates in areas that already have secure disposal of waste—as in most high-income countries—ocean plastic pollution will barely be impacted because the feedstock is landfill-bound (or incinerator-bound) plastic, not ocean-bound plastic. This is not necessarily the case for plastic that is exported, and as such it is important for high-income countries to increase their own local recycling infrastructure (see System Intervention 8). There are many other reasons why recycling plastic is better than landfilling or incinerating it, even in situations where it does not directly reduce plastic pollution, including reducing GHG emissions and natural resource extraction.

If recycling is to contribute to reducing leakage, it is important to build a profitable recycling and sorting industry that can cover the cost of plastic collection and implement it at scale in the places that contribute the most to leakage.

Not accounting for landfill tipping fees, the recycling of many plastic types is currently less economical than landfill or incineration, which means they are recycled only when either:

a) Collection and/or sorting are subsidized by the government or funded through Extended Producer Responsibility schemes; or

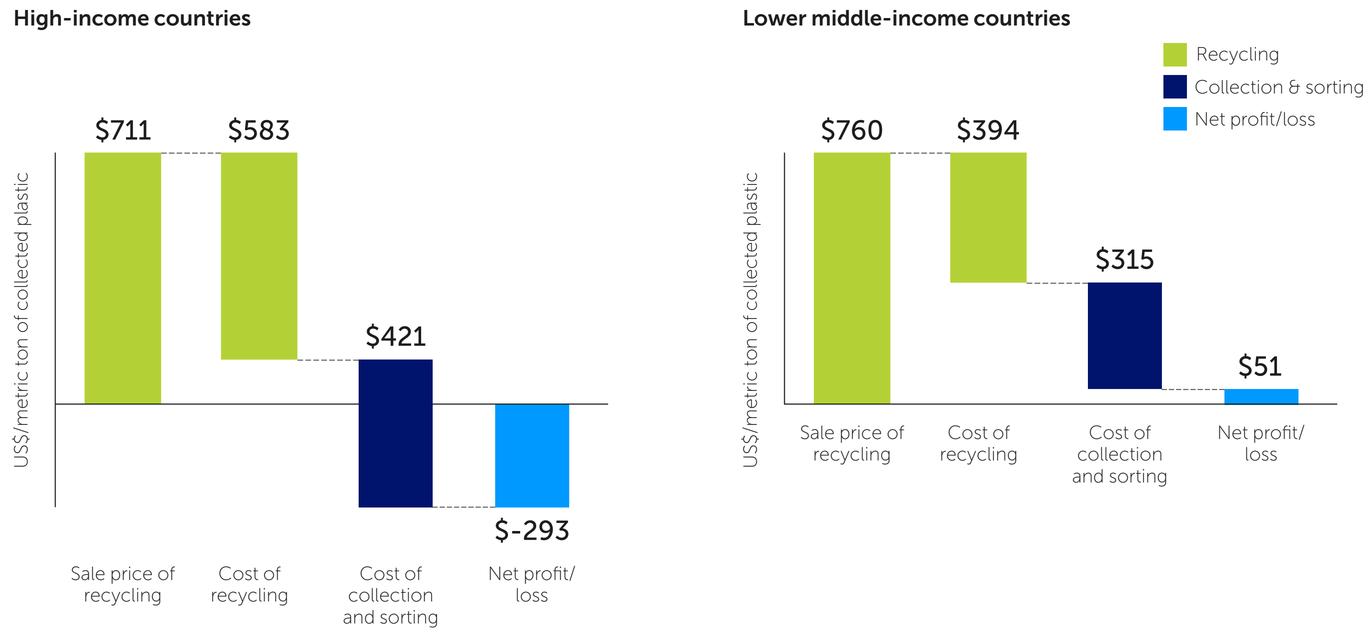
b) Informal and private-sector collectors target the plastic types with highest value for recycling and build private collection systems and supply chains—often "piggy-backed" onto formal waste systems where materials have already been aggregated in waste transport vehicles, transfer stations, or dumpsites.

Currently, mechanical recycling could generate a net system profit in LMI countries of US$51 per metric ton of collected plastic, while recycling in HI countries would result in a loss of US$293 per metric ton of collected plastic, if collection and sorting is included (see Figure 34).

Landfilling and incineration are always likely to incur a net cost because they do not generate sufficient revenue, but recycling has the potential to break even and even become net profitable across all archetypes if design for recycling is implemented, collection systems are improved and expanded, and technology improves (see Figure 35).

Figure 34: End-to-end closed-loop recycling economics in high-income and lower middle-income countries, 2016

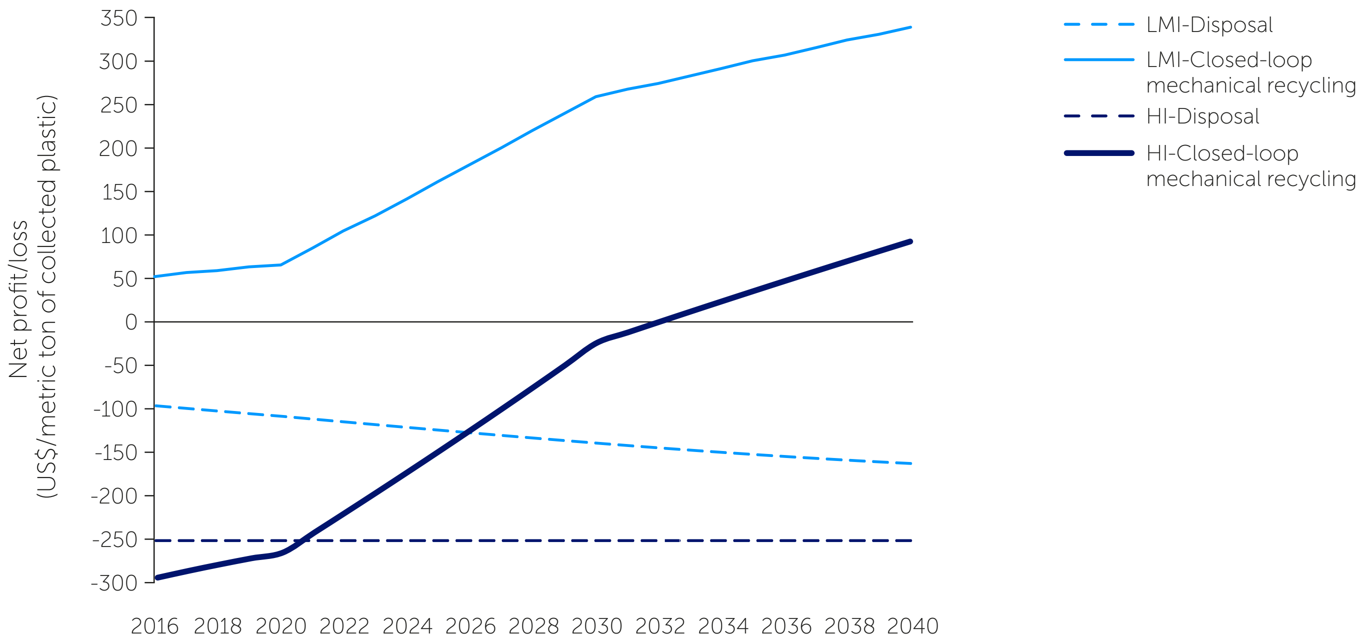
Mechanical recycling is not profitable in high-income countries if the cost of collection and sorting is accounted for



With the cost of collection and sorting included, mechanical recycling produces a net loss of US$293 per collected metric ton in HI, and a profit of US$51 per metric ton in LMI. The sales price is a blended price of high-value plastics (PET, HDPE, and PP) and appears higher in LMI due to lower system losses (because prices/costs are calculated per metric ton of collected plastic). No taxes/subsidies or landfill gate fees are included. Costs include both opex and capex costs. Revenue per metric ton of collected plastic factors in mass losses in sorting (20 per cent) and recycling (27 per cent); cost per metric ton of collected plastic factors in 20 per cent sorting losses. Mechanical recycling in LMI assumes informal collection, while HI is calculated using formal collection costs. In HI, the public sector pays for collection and sorting.

Figure 35: Development of net system loss/profit per technology, 2016-2040

Closed-loop mechanical recycling could be net profitable in all regions without subsidies



Mechanical recycling could be net profitable over time in both LMI and HI, while disposal (incineration/landfill) will always be net cost. Net profit/loss includes full life-cycle costs, including the cost of collection and sorting. The revenue is based on a blended price of high-value plastics (PET, HDPE, and PP). No taxes/subsidies or landfill gate fees are included. The material losses throughout the life cycle have been incorporated by representing the net loss/profit as a function of a metric ton of collected plastic. Mechanical recycling in LMI assumes informal collection, while HI is calculated using formal collection costs. Disposal costs increase over time to account for the increasing cost per metric ton of collection with increasing coverage.

Pathway to the System Change Scenario

We estimate that in the System Change Scenario, mechanical recycling capacity could scale up globally to address 86 million metric tons per year of plastic waste by 2040, equivalent to 38 per cent of total plastic MSW worldwide (after the Reduce and Substitute wedges have been applied). This is an increase from the 43 million metric tons, or 20 per cent of total plastic waste, in 2016, and will require opening 107 recycling plants of 20,000 metric tons per year capacity globally every year from 2021 until 2040.

The resulting increase in recycling could allow 14 per cent of virgin plastic demand to be offset by 2040, equivalent to a 59 million tons CO_2e reduction in GHG emissions annually. However, even in this aspirational scenario, 67 per cent of plastic waste remains unrecycled (mechanically) due to limitations on expanding collection, limits on what can be profitably recycled, and technical limits on material losses. In other words, we cannot simply recycle our way out of our plastic problem.

Enabling conditions

Several enabling conditions can help accelerate this system intervention and allow it to achieve its full potential.

- **Improved recycling economics:**
  - Increased demand for recycled plastic, such as the need for fast-moving consumer goods (FMCGs) to meet voluntary public commitments and policy requirements in terms of recycled content. This would lead to higher prices paid for recycled content.
  - Machinery for mechanical recycling coming down in cost due to the commoditization of recycling technology.
  - Virgin plastic and landfill/incineration gradually being made more expensive via taxation to the degree that recycling is more financially competitive.[142] It is important that this taxation be paired with good enforcement to avoid open dumping/illegal disposal. Historically, increases in landfill tax have reduced landfill rates and incentivized recycling.[143]
- **Increased and improved investments:**
  - Targeted investment in recycling technology, especially the types that have not yet reached commercial viability, including improved technology

to reduce sorting and recycling losses, to address capacity restraints and to create higher quality output able to meet food-grade standards.

- More investment in infrastructure capacity across archetypes to accommodate increasing waste.

- **Higher demand for recycled content:**
  - Legislation and effective enforcement aimed at driving demand (e.g., recent announcements on recycled content taxes in the United Kingdom and France, virgin feedstock tax, minimum recycled content requirements under European Union legislation, potential eco-modulation of Extended Producer Responsibility schemes according to recycled content).
  - Public procurement policies, which can leverage volume to create increased demand for recycled content/recyclable products.
  - Industry commitments by plastic producers and retailers (e.g., New Plastics Economy Global Commitment by consumer goods companies and retailers).
  - Long-term agreements with both the private and public sectors to guarantee demand for recycled polymers and mitigate investment risks.
  - Enhanced matchmaking mechanisms to enable secondary markets for recycled materials.

- **Incentives and policies aimed at improving collection systems:**
  - Optimizing convenience and quality of collection services (e.g., one drop-off centre in a town captures notably less material than curbside collection).
  - Developing country-specific Extended Producer Responsibility schemes to provide price support for the informal sector to collect more low-value plastic, while improving working conditions.
  - Increasing source separation in collection systems through regulation.
  - Simplifying source separation in collection systems through education, incentives, and improved labelling standards.

Limiting factors

It is important to recognize that mechanical recycling has several limiting factors:

- Volatile prices linked to commodity prices for oil and virgin plastic.
- Losses of material (to a landfill or to incineration) in the sorting and recycling chain.
- Losses in material properties during mechanical recycling, which limits most plastic to two or three recycling loops before quality deteriorates.
- Quality of mechanically recycled plastic often inadequate for current packaging standards, thus limiting its potential utility (two-thirds of all recycled packaging is estimated to be food-grade).
- Recycled materials can contain hazardous chemicals from diffuse or unknown sources, including chemical additives used in plastic products. Recycling can therefore lead to increased human exposure to hazardous chemicals. This is a major concern and barrier for circularity, especially for food packaging, and requires work to improve transparency regarding the chemical composition of products.

Due to all these limiting factors, mechanical recycling cannot process all plastic within reasonable system constraints, even under the System Change Scenario, because:

- Even in countries with a developed collection system subsidized by the government, recycling economics vary massively by material and contamination level.
- Anticipated growth in new plastic types and designs (e.g., compostable plastic or compostables that aesthetically look like plastic) could drive up costs due to additional sorting technology requirements and could dilute the quality of the recyclate stream.

Plastic moves through a recycling facility.
Albert Karimov/Shutterstock

Macroplastic system interventions

SYSTEM INTERVENTION 6

Develop plastic-to-plastic conversion, potentially to a global capacity of up to 13 million metric tons per year

INTERVENTION SUMMARY

- We estimate that chemical conversion could achieve a global capacity of 26 million metric tons per year by 2040, up from 1.4 million metric tons today, about half of which will be converted back into plastic (and the other half turned to fuel). Expanding the plastic-to-plastic component to 13 million metric tons per year is equivalent to opening roughly 32 plastic-to-plastic plants (of 20,000 metric tons per year capacity each) every year from 2021 until 2040.
- The end-to-end economics of plastic-to-plastic using pyrolysis are only estimated to generate a net system profit by 2040 for LMI countries, while in HI countries it is economically viable only if governments or industry subsidize collection and sorting.
- Chemical conversion has a role to play in stemming plastic leakage to the ocean because it could create an economic sink for certain low-value plastic types that make up a high proportion of plastic pollution and cannot be readily reduced, substituted, or mechanically recycled. However, for chemical conversion to help reduce plastic entering the environment, it needs to be profitable enough to cover collection costs; otherwise, the feedstock will come from plastic that is already collected for landfilling, not from the unmanaged waste bound for the ocean.
- Chemical conversion through pyrolysis is synergistic to, not in competition with, mechanical recycling because each method handles different feedstocks. When used together, the economics of both are improved. Chemical conversion technology should only ever use feedstock that cannot be reduced, substituted, or mechanically recycled.
- The GHG emissions generated to produce 1 metric ton of feedstock through plastic-to-plastic is 19 per cent lower than a metric ton of virgin plastic destined for incineration and 9 per cent higher than 1 metric ton of virgin plastic destined for a landfill.

Highly applicable / Somewhat applicable / Not applicable

Most relevant geographic archetypes

HI Urban (Highly applicable)	UMI Urban (Highly applicable)	LMI Urban (Highly applicable)	LI Urban (Not applicable)
HI Rural (Not applicable)	UMI Rural (Not applicable)	LMI Rural (Not applicable)	LI Rural (Not applicable)

HI: High-income
UMI: Upper middle-income
LMI: Lower middle-income
LI: Low-income

Most relevant plastic categories

Rigid (Not applicable)	Flex (Highly applicable)	Multi (Highly applicable)

Main responsible stakeholders

- **Waste management companies**
- **Petrochemical industry**

kyrychukvitaliy/Adobe Stock

The term chemical conversion refers to any reprocessing technology that uses chemical agents or processes to break down plastic into basic chemical building blocks that can be used to make new plastic or other materials. This contrasts with mechanical recycling, which uses physical methods to re-form plastic pellets for plastic manufacturing. Due to the limitations of mechanical recycling for some plastic types, new recycling technologies are being advanced that can handle lower-value plastic, such as film and multimaterials, and plastic that has been contaminated.

Several chemical conversion technologies are being developed that can chemically treat waste plastic back into petrochemical compounds that can then be reintroduced into the petrochemical process to produce plastic feedstock with the same properties as virgin plastic—a route known as plastic-to-plastic chemical conversion and considered a type of recycling. These feedstocks can also be refined into alternative fuels, such as diesel—a route known as plastic-to-fuel and that we consider to be a type of disposal as it does not allow carbon to be utilized for additional anthropogenic loops (see System Intervention 7).

Many companies are actively considering plastic-to-plastic chemical conversion, for several reasons:

- It expands feedstock options beyond what mechanical recycling tolerates, including mixed polymers, low-value and contaminated plastic, and pigments. It is important to note that chemical conversion still has limitations on feedstock, as shown in Figure 36.
- In contrast to mechanical recycling, in pyrolysis-based technologies, the polymer is broken down rather than preserved, which allows for infinite reprocessing cycles.
- It creates a new revenue stream and the potential to charge a price premium for plastic derived from recycled content, while still meeting regulatory requirements for recycled content.
- For many food companies, plastic-to-plastic chemical conversion currently represents the only way to incorporate recycled content into their packaging because there is no food contact-approved mechanically recycled content apart from PET and minimal HDPE. Chemical conversion therefore provides a pathway to meet the growing demand for virgin-quality, food-grade recycled plastic.
- It partially "de-risks" the petrochemical industry, which is seeking ways to source plastic feedstock in a 1.5°C world.

For the time being, however, chemical conversion has not been proved at scale. Compared with mechanical recycling, it has higher costs, energy requirements, and GHG emissions. Although its viability at scale should be developed and evaluated, its expansion should be contingent on the decarbonization of energy sources, and natural lead times and limitations of emerging technologies must be recognized.

Chemical and mechanical recycling synergies

Mechanical recycling and chemical conversion are complementary—not competing—technologies as they handle different feedstock. For low-value or contaminated plastic not suitable for mechanical recycling, chemical conversion has the potential to provide a method of reintroducing the plastic polymers back into the system and closing the loop. However, for chemical conversion to contribute to the reduction of plastic leakage to the ocean, its economics must account for the cost of collection; otherwise, the waste plastic feedstock will likely come from plastics that are bound for landfills, rather than those destined to leak into the environment.

Deploying mechanical and chemical recycling technologies together creates many synergies as feedstock acceptability expands and the economics improve due to higher recycling yields and lower transportation costs. Synergies may be maximized when mechanical recycling and chemical conversion are co-located because, together, they can deal with almost the entire plastic waste stream. Recent modelling of this kind of co-location arrangement estimates that a combined facility could increase revenue by 25 per cent compared with a best-in-class mechanical recycling plant on its own.[144] Chemical conversion could act as an end market for many materials that cannot be mechanically recycled profitably. However, if there is a mechanical recycling end market for the same material that pays better, material would be expected to flow there instead.

Chemical conversion technologies

Many chemical recycling technologies exist, but there are three main types, and they differ significantly in how they work and the outputs they produce:

- Solvent-based purification is a process in which plastic is dissolved in a solvent and a series of purification steps are undertaken to separate the polymer from additives and contaminants. The resulting output is the precipitated polymer, which remains unaffected by the process and can be reformulated into plastics. Solvent-based purification does not change the constitution of the polymer itself, so there are ongoing discussions as to whether this technology should be defined as mechanical rather than chemical recycling, or as a separate class (see also ISO 15270:2008).
- Chemical depolymerization yields either single monomer molecules or shorter fragments often called oligomers. This can provide recycled content for PET.
- Thermal depolymerization is any thermal process that converts polymers into simpler molecules. The two main processes for this are pyrolysis and gasification. The products of pyrolysis or gasification can easily integrate into existing chemical processing supply chains. Feedstock recycling can provide recycled content for all our polypropylene (PP) and polyethylene (PE) packaging.

For the purpose of this system intervention, we modelled the economics of pyrolysis because this technology is the most mature and therefore has the most reliable data. It can handle feedstock made up of mixed plastics that cannot be reduced, substituted, or recycled, and there is no limit to the number of times plastic can be reprocessed as the polymer is not degraded. The output can be used to deliver food-safe recycled content. The plants can be modular, which increases the potential for global scale-up by allowing the supply chain economics to work.

Figure 36: Feedstock tolerance comparison for mechanical recycling versus pyrolysis

Chemical conversion expands feedstock tolerance

Value of plastic: High → Low

		PET	HDPE	PP	LDPE + LLDPE	PVC	PS	Multi-layers
Clean/sorted waste	Mechanical recycling	✓	✓	✓	(✓)	✗	✗	✗
	Pyrolysis	✗	✓	✓	✓	✗	✓	✓
Contaminated waste	Mechanical recycling	(✓)	(✓)	(✓)	(✓)	✗	✗	✗
	Pyrolysis	✗	✓	✓	✓	✗	(✓)	(✓)

✓ Technically feasible
(✓) Feasible under some circumstances
✗ Technically not feasible

Pyrolysis is better suited to address low-value or contaminated plastics than mechanical recycling. Mechanical recycling includes both open- and closed-loop recycling capabilities. Contamination is defined as contamination by other waste (i.e., organics) or inks, additives, and mixed polymers. Mechanical recycling of LDPE/LLDPE is mostly open-loop recycling. All polymers containing oxygen or nitrogen are considered impurities in pyrolysis; these polymers will need to be below a certain threshold to avoid CO_2 or NO_2 formation as this will decrease the yield significantly.

A controversial technology

Chemical conversion is a controversial technology because it is still in its early stage of development, has high energy requirements, and accurate assumptions about its impacts and contributions cannot yet be made. Critics fear that it is being positioned by some advocates as a panacea; however, our analysis illustrates that, despite having an important role to play for low-value plastic, plastic-to-plastic chemical recycling can only tackle 6 per cent of plastic waste by 2040 and certainly cannot solve the crisis on its own. Concerns about the technology include:

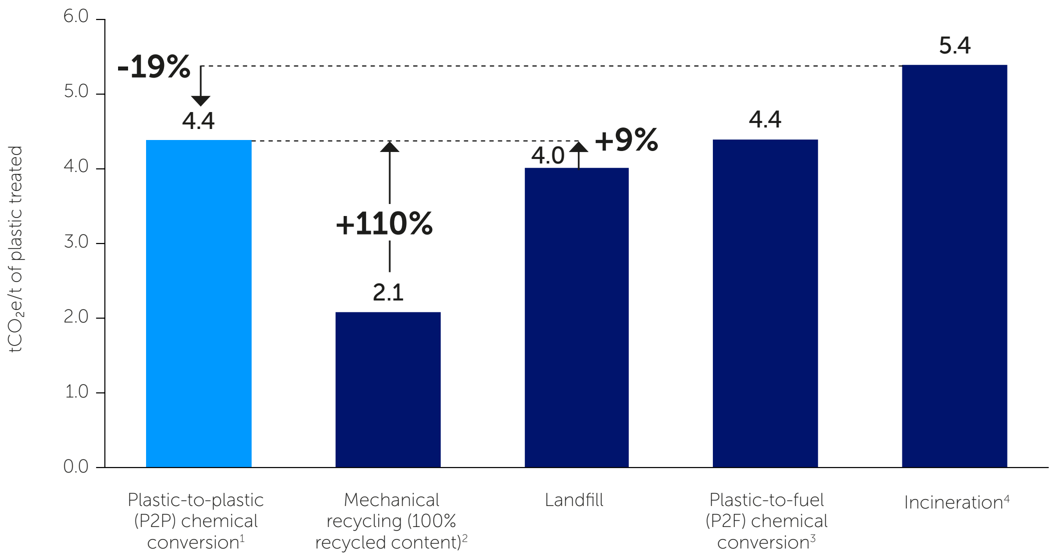
- Chemical conversion investments could generate potential "lock-in effects" and "path dependency," which means that cities that buy into the model then have to stick with it for many years because large amounts of capital have been deployed and contracts to provide certain quantities of waste have been agreed. This could even lead to perverse incentives for governments not to decrease plastic waste generation, particularly if they are locked into "deliver or pay" contracts. This was observed in Oregon, where the presence of a pyrolysis plant was used to argue against a partial ban on polystyrene.[145] Likewise, lock-in scenarios can mean other innovative and potentially better systems have less chance to develop. This situation was observed in Scandinavia and Germany, where heavy investment in incineration plants 20 years ago prohibited further development in alternative waste management until recently, when plants were reaching the end of their lives.[146]

- Plastic-to-plastic chemical conversion has high energy requirements, leading to GHG emissions that are 110 per cent higher than mechanical recycling, and 9 per cent higher than landfilling—albeit 19 per cent lower than that of plastic that is incinerated (see Figure 37). This is predominantly because the feedstock is reintroduced into the same plastic production process as virgin plastic. However, it should be noted that data for the GHG emissions of these technologies is severely limited and that further transparency and monitoring is needed to improve assessments. Currently, chemically recycled plastic could have a higher level of embedded carbon than virgin plastic. Furthermore, if decarbonization of electricity requirements does not occur in line with International Energy Agency projections, the emissions from this technology would be considerably higher. As such, its expansion should be contingent on the decarbonization of energy sources.

- Plastic-to-plastic chemical conversion could risk diverting research and development financing away from better, more efficient solutions. Several chemical companies are funding the R&D of plastic products that can be mechanically recycled more easily.[147] Promoting pyrolysis could eliminate the incentives for these R&D efforts. Likewise, it risks diverting corporate attention and investments away from more sustainable reuse solutions.

Figure 37: Greenhouse gas emissions of 1 metric ton of plastic utility

Chemical conversion emits more greenhouse gases than most other treatment types



The GHG emissions associated with each pathway are calculated from the point at which plastic waste is generated to the fulfilment of 1 metric ton of plastic utility. One metric ton of plastic utility is defined as the material/services required to provide the equivalent value as 1 metric ton of plastic.

1. Emissions include the repolymerization of naphtha as well as the pyrolysis process itself. It should be noted that data for GHG emissions for this technology are limited.
2. Valid for both closed-loop and open-loop recycling. This assumes 100% recycled content, which entails the collection and sorting of a larger proportion of waste to account for losses.
3. Does not include the emissions from burning the fuel, as we assume that it replaces regular fuel with a similar GHG footprint. It should be noted that data for GHG emissions for this technology are limited.
4. The emissions for incineration are adjusted to reflect the emissions replaced from generating an equivalent amount of energy with average emissions.

Pathway to the System Change Scenario

Although it has limitations, chemical conversion could have a role to play in stemming ocean plastic pollution because of its ability to create an economic sink for certain low-value plastic items that represent a high proportion of plastic leakage and cannot be readily reduced, substituted, or mechanically recycled. In fact, chemical conversion may be the only path able to contribute to paying for their collection. We estimate that global chemical conversion capacity today is 1.4 million metric tons per year, of which we calculate that the vast majority is plastic-to-fuel. Under the System Change Scenario, we project that chemical conversion could grow to 26 million metric tons per year by 2040, of which 13 million metric tons per year will be plastic-to-plastic chemical conversion. This is equivalent to opening about 32 plastic-to-plastic chemical conversion plants (of 20,000 metric tons per year capacity each) every year from 2021 until 2040. This rate of growth is based on a high compound annual growth rate of 16.5 per cent, a rate seen for technologies that were similarly capital expenditure-intensive and aggressively pushed by governments (see the technical appendix).

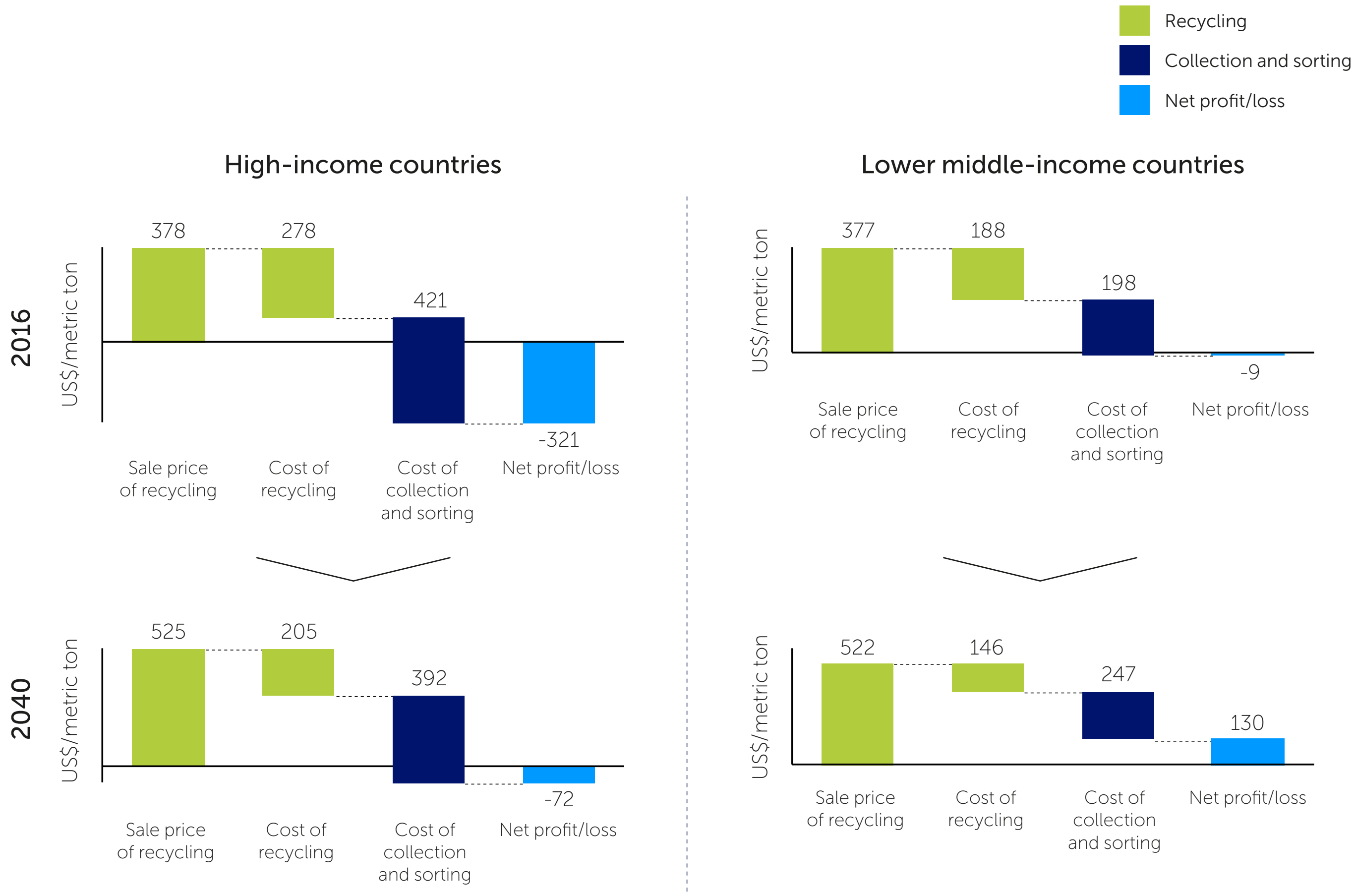
The growth of plastic-to-plastic chemical conversion at scale is only likely to commence from 2030 onward, with the growth of plastic-to-fuel creating a pathway to achieving it. Although the technologies to convert to fuel and plastic are similar, plastic-to-plastic chemical conversion has a more focused offtake market that requires a large scale. The infrastructure will require significant capital investment to develop and, as such, plastic-to-plastic chemical conversion needs a longer time horizon to both attract the funding and build the infrastructure for its typically large plant size requirement. Based on our estimates, plastic-to-plastic chemical conversion has the potential to offset 5 per cent of virgin plastic demand by 2040, addressing waste that would otherwise go to landfills or incineration. In middle-/low-income countries, plastic-to-plastic chemical conversion could eventually reduce ocean plastic pollution, but only if supply chains are put in place to take ocean-bound plastic and prices for collected plastic are sufficient to fund collection.

The end-to-end economics of plastic-to-plastic chemical conversion using pyrolysis indicate that only lower middle-income (LMI) countries could generate a net system profit in 2016 and 2040 (see Figure 38). In high-income countries, this technology is currently profitable only because collection and sorting are being subsidized by governments, and additional revenues from tipping fees are collected.

By 2040, both operational expenditure and capital expenditure costs are estimated to have decreased over time to account for efficiency improvements, technological innovation, and scale. With less material lost owing to an increasing yield over time, the price per metric ton of collected plastic for the

Figure 38: End-to-end chemical conversion (plastic-to-plastic) economics through formal collection, 2016-2040

Chemical conversion economics can significantly improve globally by 2040 with scale and innovation



With the cost of collection and sorting included, plastic-to-plastic makes a net loss of US$321 per collected metric ton in high-income countries, and US$9 per metric ton in LMI. By 2040, lower middle-income countries could be net profitable, while HI would still make a loss if collection and sorting costs are included. This result is driven by an improvement in material losses, as well as a reduction in costs over time. In high-income countries, the public sector pays for collection and sorting. The US$130 per metric ton net profit in LMI countries by 2040 refers only to 20 per cent of the feedstock most suitable for chemical recycling, as shown in Figure 11. These costs do not include taxes/subsidies or landfill gate fees because they reflect the techno-economic costs only.

recycled feedstock would consequently increase. As a result, chemical conversion could generate a net system profit in LMI countries of US$130 per metric ton of collected plastic. This could create an opportunity to reduce plastic pollution further by using this revenue to fund the collection and sorting of the remaining uncollected and mismanaged waste.

Enabling conditions

Several enabling conditions can accelerate this system intervention and help achieve its full potential, including:

- Increasing flows of R&D funding and blended capital to finance and take on the risk of infrastructure build-up, especially until the technology reaches commercial viability.
- Mechanisms to verify and trace output so that the output can be marketed as recycled content, which will strengthen demand.
- Legislation to drive higher demand for recycled content (e.g., recent announcements on recycled content taxes in the United Kingdom and France, and virgin plastic taxes) and industry commitments (e.g., New Plastics Economy Global Commitment). This is especially important for food-grade applications because the supply of recyclate that meets these quality standards through mechanical recycling alone is limited. Demand signals from customers, such as offtake agreements of a certain volume and price point, will be an important mechanism to trigger the growth of plastic-to-plastic chemical conversion.
- Reaching sufficient scale to penetrate the market for naphtha (which requires high volumes). The biggest barrier is therefore the scale rather than the economics, as formal collection systems need to be set up first to guarantee sustained supply. The informal sector is an important part of the solution, with chemical conversion having the potential to boost the demand for including the informal sector in waste collection.
- Collaboration between suppliers and end-customers to share the risk through both feedstock agreements and oil price contracts.

Limiting factors

It is important to recognize that plastic-to-plastic chemical conversion cannot entirely plug the gap as a solution for low-value plastics due to a combination of limiting factors. In addition to the significant problems outlined above relating to lock-in effects, high GHG emissions, pollution, and steep infrastructure costs, there are additional limitations that need to be considered:

- This technology is in its infancy and therefore we cannot yet make accurate assumptions about its impacts, economics, and contributions. The GHG emissions, water and energy consumption, and health implications all need to be fully understood prior to its scale-up.
- Growth is restricted to urban areas due to the high density of feedstock required to make collection economical.
- The sales price of the output will be vulnerable to swings in commodity prices, specifically, the price of oil. Excluding the costs of collection and sorting, our analysis shows that a 27 per cent reduction in naphtha prices would eliminate a pyrolysis plant's profitability.
- Given the scale requirements for plastic-to-plastic chemical conversion, it is likely that plastic-to-fuel will continue to be the preferred solution for low-value plastic in the short term. However, as the scale of plastic-to-plastic chemical conversion infrastructure matures, the capacity is eventually expected to attract plastic-to-plastic off-take customers. It is important to address the factors that could jeopardize the transition from plastic-to-fuel to plastic-to-plastic chemical conversion:

    1. Plastic-to-plastic chemical conversion requires a sustained and consistent amount of quality feedstock to function effectively. In areas of middle-/low-income countries without a formal collection system, the volume of plastic feedstock available through cost-effective channels is more limited and unorganized, and inadequate supply chains and lack of synergies among different actors are significant problems. Although the informal sector plugs this gap for mechanical recycling, the small formats and flexibles destined for plastic-to-plastic conversion are more time-consuming and relatively more expensive to collect and sort, so the informal sector alone cannot guarantee the feedstock required at this scale.
    2. Plastic-to-fuel is more flexible and, in countries where demand for oil is high and no ethylene cracker plants exist, it is often preferred because the output can be more readily utilized—whether for fuel or for chemicals such as ethanol/methanol.
    3. In land-locked areas, transportation to shipping ports could become cost-prohibitive for the plastic-to-plastic value chain.

If plastic-to-fuel does not lead to a transition to plastic-to-plastic chemical conversion, then it risks locking us into a technology with high GHG emissions that would lead to the loss of material and perpetuate the linear, fossil-fuel economy, without the benefits of plastic-to-plastic conversion. There is significant R&D investment underway in this space. Some of the investment directly targets accelerating the scaling of plastic-to-plastic facilities or modifying large-scale cracker plants to accept smaller quantities. However, other investments seek to stimulate large-scale plastic-to-fuel facility construction. Because plastic-to-fuel allows for only one additional use of the initial plastic—as opposed to the completely circular solution offered by plastic-to-plastic chemical conversion—it is important that enabling policies be focused on plastic-to-plastic chemical conversion to advance the circular economy.

Mechanical recycling and chemical conversion are complementary—not competing—technologies as they handle different feedstock. For low-value or contaminated plastic not suitable for mechanical recycling, chemical conversion has the potential to provide a method of reintroducing the plastic polymers back into the system and closing the loop. However, for chemical conversion to contribute to the reduction of plastic leakage to the ocean, its economics must account for the cost of collection; otherwise, the waste plastic feedstock will likely come from plastics that are bound for landfills, rather than those destined to leak into the environment.

Box 11: Health implications for chemical conversion

Chemical conversion with a pyrolysis unit poses a risk to human health mainly due to five types of pollutants released: heavy metals (e.g., arsenic and cadmium), dioxins, NOx, SOx, and volatile organic compounds (VOCs).[148] The quantity of the pollutants released is a function of the input to a pyrolysis plant and the emission controls that are put in place.

These pollutants have been reported to cause respiratory infections and irritation.[149] In addition, longer-term exposure may also increase the risk of cancer, kidney damage, and neurotoxicity leading to damage to the central nervous system.[150]

Preliminary research, however, indicates that well-designed pyrolysis units can potentially destroy harmful pollutants in the combustion process.[151] The validity of such research should be further investigated to understand the full health implications of chemical conversion.

Macroplastic system interventions

SYSTEM INTERVENTION 7
Build facilities to securely dispose of the 23 per cent of plastic that still cannot be recycled

INTERVENTION SUMMARY

- Landfills, incinerators, and plastic-to-fuel chemical conversion should be used only as a last resort, after the Reduce, Substitute and Recycle wedges have all been exploited to their fullest potential, particularly because incinerators and chemical conversion plants have significant health risks. However, it is probably unrealistic to assume that end-of-life disposal of plastic waste will no longer be necessary in 2040.
- A significant amount of plastic entering the ocean is plastic that has been collected but mismanaged; building some disposal capacity to close leakage points may be required as a bridge solution.
- The System Change Scenario shows that global landfill expansion can peak by 2030 at 73 million metric tons per year of new landfill capacity.

Highly applicable | Somewhat applicable | Not applicable

Most relevant geographic archetypes

HI Urban	UMI Urban	LMI Urban	LI Urban
HI Rural	UMI Rural	LMI Rural	LI Rural

HI: High-income
UMI: Upper middle-income
LMI: Lower middle-income
LI: Low-income

Most relevant plastic categories

Rigid	Flex	Multi

Main responsible stakeholder

- **National governments**

kyrychukvitaliy/Adobe Stock

Our model indicates that 39 per cent of land-based macroplastics entering the ocean comes from waste that has been collected and subsequently mismanaged (see Figure 7), accounting for 3.8 million metric tons of macroplastic leakage into the ocean in 2016. Of this mass, about one-third, or 1.2 million metric tons per year, is macroplastics that move from dumpsites to the ocean through the wind or water. This system intervention focuses on the infrastructure that needs to be built to mitigate this risk and provide a secure disposal route for the plastic waste that remains after the implementation of the upstream and recycling interventions.

The International Solid Waste Association defines a dumpsite as "a land disposal site where the indiscriminate deposit of solid waste takes place with either no, or at best very limited, measures to control the operation and protect the surrounding environment."[152] In our model, we extend this definition to include facilities described as "unsanitary landfills," where the waste is not prevented from escaping by using either daily and intermediate covers to reduce the likelihood of leakage to the environment.

Our BAU Scenario suggests that the amount of macroplastic waste being deposited in dumpsites or unsanitary landfills in 2016 was 49 million metric tons, or 23 per cent of all macroplastic waste generated, and that without intervention this figure is expected to grow to 100 metric million tons per year by 2040. The majority of this waste is deposited in middle-/low-income countries, where even when landfills are lined and access is restricted, daily cover is rarely implemented, allowing waste to travel into the surrounding environment either via surface water or through the air, as shown in Table 6.

Reducing the number of open dumpsites in the world is a core ambition of many governments, not only because dumpsites lead to significant plastic pollution, but also because of their GHG emissions and negative health consequences, including a significant number of reported deaths.[153] Our System Change Scenario projects a reduction in the mass of plastic deposited in dumpsites from 23 per cent in 2016 to 10 per cent in 2040 (see Table 6).

In the System Change Scenario model, we assume that the Dispose wedge—including sanitary landfills and incineration as well as plastics-to-fuel chemical conversion—is a last resort to be used only after the Reduce, Substitute and Recycle wedges have all been implemented to their maximum potential. We use historic trends to project the proportion of residual plastic waste going to landfills and to incineration, and show that this volume could be reduced from 54 million metric tons to landfills per year and 80 million metric tons to incineration per year under BAU to 50 million metric tons per year and 39 million metric tons per year, respectively, under the System Change Scenario in 2040.

Table 6: Total plastic waste flow deposited in dumpsites, million metric tons

Income group	2016	2040 BAU	2040 SCS
HI	3	3	0.2
UMI	23	51	6
LMI	21	41	12
LI	2	5	5
Global	**49**	**100**	**22**

Box 12: Landfill—pros and cons

Landfill is a simple and effective method of containment ("secure disposal"). As the most cost-effective waste disposal method, it has been popular for centuries. However, landfilling plastic is acknowledged to have significant drawbacks:

- If landfills are not managed effectively with daily and intermediate cover, plastic waste may be just as likely to leak into the environment as in an open dumpsite. Coastal erosion also threatens to release pollution from historic landfill sites.
- Although macroplastics are unlikely to breach landfill liners, microplastics may pass through, and even the most modern sanitary landfills carry the risk of leachate contaminating groundwater. The long-term stability of landfill liners is unknown, but they are unlikely to fully function beyond 100 or 200 years.[154]
- Although plastics are almost completely inert in landfill (although some plastic leaching does occur), they are almost always co-disposed with biological materials that generate methane, a powerful GHG. Even with capture systems, approximately 10-65 per cent[155] of methane can escape, depending on how comprehensively landfills are engineered and managed.
- Landfills are modular and can reduce the potential for path dependency and technology lock-in from building large, long-lasting incinerators.

Box 13: Incineration—pros and cons

Incineration is often being used as an alternative to a landfill; in the European Union, it was used to treat more than 68 million metric tons of MSW (not just plastic) per year in 2016.[156] It is effective at stabilizing biological material and reducing both volume (by 90 per cent) and mass (by 80 per cent).[157] Modern incinerators also produce electricity and heat, which can be used as an alternative to purely fossil-based sources, although its effectiveness at electricity generation is well below other methods, at approximately 20-35 per cent efficiency, compared with up to 50 per cent for coal.[158] Many drawbacks with incineration are recognized, including:

- Plastic incineration releases CO_2 and other GHGs into the atmosphere, along with some nonfossil emissions from biogenic wastes ("skyfill"). Under the System Change Scenario, incineration accounts for 4 per cent of the cumulative GHG emissions (2016-2040).
- Inert material/slag for landfill remains as bottom ash.[159]
- Unlike landfills, incinerators require continuous feedstock to remain alight. Because their lifetime is about 25 years (or longer), incinerators create a "lock-in" effect that can block out newer technologies or act as competition for recycling feedstock.[160]

Box 14: Health implications of incineration

Historically, incinerators have had a poor reputation for environmental pollution as they were operated without any form of emissions cleaning or monitoring, relying on dispersion and dilution in the atmosphere as a control mechanism. By contrast, modern gas cleaning systems are highly effective at reducing harmful emissions from incinerators. However, these systems require comprehensive management and monitoring that may not be carried out in regions where expenditure, regulatory standards, and enforcement are insufficient.

Combustion of municipal solid waste results in the release of pollutants such as dioxins, furans, polycyclic aromatic hydrocarbons (PAH), halogenated flame retardants, particulate matter (PM), SOx and NOx.[161] Exposure to these pollutants has been linked to an increase in the risk of asthma, heart disease, reproductive health complications, respiratory infections, cancer, and neurological damage, as well as damage to the central nervous system.[162]

In well-managed incinerators, atmospheric emissions are abated by controlling the temperature, the composition of input material, and the speed of material flow in the furnace, and by cleaning the flue gas.[163] Incinerators produce two solid outputs. The first is bottom ash, which represents approximately 25 per cent of the input mass and is mostly inert.[164] The second is fly ash, which consists of airborne emissions and is hazardous. Fly ash must be disposed of in hazardous waste landfill sites, where it is stored indefinitely, creating a negative legacy for future generations. The availability of appropriate and secure disposal facilities in middle-/low-income countries is a significant concern.

Limiting factors

Lack of financial resources is the main limiting factor underpinning the inadequacy of both incineration and landfill capacity in middle-/low-income countries, but particularly for incineration, which is cost-prohibitive for most economies. Although incinerators generate some revenue, landfills generate nothing (except for methane capture systems, which are broadly irrelevant for plastic waste), and they are both a net cost to governments. Under the System Change Scenario, the present value of global government spending on landfill and incineration from 2021 to 2040 is estimated at US$44 billion.

Because there are few market incentives to ensure that these facilities are well-managed, both forms of treatment require strong public governance to ensure that they are effective at their respective functions while minimizing harm to the environment. This oversight is particularly relevant in middle-/low-income countries, which may have limited capacity to enforce environmental legislation.[165] Poor administrative capacity and accountability is likely to be an ongoing barrier to implementing more formal national regulatory frameworks.

Public perception also plays a big role. Understandably, dumpsites are unwelcome in most communities, while incinerators also have a poor reputation, and landfill sites are unpopular in areas of high population density due to odor, space, and land use concerns. Furthermore, both access-controlled landfills and incinerators have attracted criticism because they block the informal recycling sector from accessing materials that people rely on for income.

Macroplastic system interventions

SYSTEM INTERVENTION 8
Reduce plastic waste exports into countries with low collection and high leakage rates by 90 per cent by 2040

INTERVENTION SUMMARY

- Current exports of plastic waste from HI countries to LMI, UMI, and LI countries amount to 3.5 million metric tons per year in 2016. Much of this volume is expected to end up as mismanaged waste, with a portion of it leaking into the ocean.
- We estimate that 90 per cent of this mass could be reduced by 2040 if the right policies are implemented and if infrastructure is built to deal with this plastic locally or regionally.

Highly applicable | Somewhat applicable | Not applicable

Most relevant geographic archetypes

HI Urban	UMI Urban	LMI Urban	LI Urban
HI Rural	UMI Rural	LMI Rural	LI Rural

HI: High-income
UMI: Upper middle-income
LMI: Lower middle-income
LI: Low-income

Most relevant plastic categories

Rigid	Flex	Multi

Main responsible stakeholder

- **National governments**

kyrychukvitaliy/Adobe Stock

The international trade in waste plastic has been ongoing for the past three decades, characterized by exports of often unsorted mixed plastic from high-income countries to countries in Asia. In recent years, however, there have been growing concerns that the residues from sorting and recycling of these materials are being handled under uncontrolled conditions, with poor working conditions, and that they are leaking into the environment. There are also fears that criminal and legal vulnerabilities within Extended Producer responsibility schemes could lead to the illegal dumping of plastic by HI countries in middle-/low-income countries.[166]

The exact impact of exports on plastic pollution in the ocean is hard to quantify because there is little evidence on the fate of the estimated 3.5 million metric tons per year of plastic exported from HI countries to UMI, LMI, and LI countries every year. Anecdotal evidence suggests that 5-20 per cent of the scrap plastic exported has little market value and is often mismanaged through open burning or illegal dumping.[167]

Crucially, the losses or residues from sorting and recycling in middle-/low-income countries are not reported by the HI countries of origin. This means that 100 per cent of plastic exported for recycling is erroneously added to recycling rates in the country of origin. This administrative discrepancy creates a misleading impression of high resource efficiency in HI countries when, in fact, there is evidence that some of this material is actually polluting destination countries, to the detriment of local people and the environment.

The China import ban

For the past 30 years, the international market for waste plastic has been dominated by China,[168] which has imported 45 per cent of all internationally traded plastic waste since the early 1990s.[169] In January 2018, however, China ceased trading, banning imports of post-consumer plastic almost entirely. This decision by the most important global trader in waste plastic has had huge repercussions, particularly for high-income countries that had previously had a large export market for plastic that was expensive to sort and recycle domestically.

Businesses in India, Indonesia, Malaysia, Taiwan, Thailand, Turkey and Vietnam were quick to respond to the Chinese ban, viewing it as an opportunity to attract high-grade material.[170] However, some of these alternative destinations have also implemented restrictions, temporary freezes, or bans on material imports over fears that their waste management systems may become overwhelmed by the additional mass entering the country. They are also increasingly returning containers of "illegal" plastic waste that does not meet standards.[171]

In 2019, governments agreed to amendments to the Basel Convention that introduced stricter requirements for trade in plastic waste (see Box 15). A reduction in trade may result from these amendments; we do not, however, model the impact of these under the Current Commitments Scenario because it is not possible to predict whether countries will reduce exports significantly, obtain prior informed consent to continue exporting mixed plastic waste, or choose to better sort plastic wastes prior to export. For the System Change Scenario, we model a 70 per cent and 90 per cent reduction in exports from HI to UMI, LMI, and LI countries by 2030 and 2040, respectively. The result is shown in Figure 39.

There are good arguments for restricting the trade in plastic waste, given that it predominantly flows from HI countries to those with higher rates of waste mismanagement and inadequate enforcement capacity. There is also a need for greater transparency and better monitoring of plastic waste trade flows. However, the recent bans and restrictions imposed in many middle-/low-income countries have also had negative short-term impacts in high-income countries,

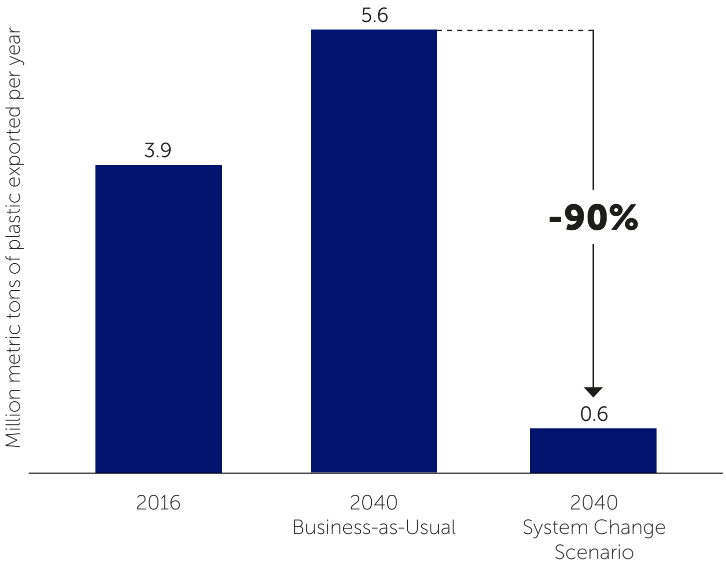
Box 15: Amendments to the Basel Convention

Amendments to the Basel Convention, which will enter into force in January 2021, introduce new requirements for trade in plastic waste. The most impactful changes are as follows:[172]

- Mixed plastic waste that contains anything other than PP, PE, and/or PET will be added to Annex II of the Convention. Similarly, halogenated plastic, including PVC, will be added to Annex II. This change means that the exporter will need to obtain consent from the government of the recipient country for exports of these plastic waste types, improving transparency and facilitating monitoring of plastic waste trade.
- Sorted single-polymer waste plastic can continue to be permitted for export, without any requirement for consent from the importing country, as long as it is destined for recycling in the recipient country.
- To avoid these controls, exporters will therefore need to carefully sort different polymers prior to export, with the exception of mixtures of PE, PP, PET; be sure that all such plastic exports are going only to recycling (no final disposal, no energy recovery); and are free of nontarget contaminants (e.g., paper or metal). Due to additional European Union legislation, all exports of Annex II listed plastic (e.g., mixed or contaminated plastic wastes) will be prohibited to countries that are not members of the Organisation for Economic Co-operation and Development (OECD). Because the United States is not a party to the Basel Convention, exports of mixed plastic wastes from the U.S. will also be prohibited to non-OECD countries unless bilateral agreements are in place.

Figure 39: International exports of plastic waste between geographic archetypes

The System Change Scenario would reduce inter-archetype plastic exports by 90 per cent



which have reportedly had to incinerate some waste or direct it to landfills because they could not find a market overseas.[173] Another unintended consequence of restricting the international trade in waste plastic may be a switch to virgin material whenever the supply of recyclate is disrupted or becomes more costly. Moreover, imports can sometimes help build or expand recycling capacity in places where this would otherwise not be possible.

Ultimately, building a circular economy closer to the point of waste generation will help create a sustainable sink for material and free up infrastructure in countries that previously imported large amounts of plastic, enabling them to process their own domestic waste. Therefore, despite the sparse data available to quantify its impacts, we believe that this system intervention is critical to reduce the amount of plastic entering the ocean in the long term, despite its short-term risks. Future research should also examine the trade in plastic raw materials, products, and packaging, and how upstream trade policy interventions can play a role in preventing plastic pollution.[174]

Building a circular economy closer to the point of waste generation will help create a sustainable sink for material and free up infrastructure in countries that previously imported large amounts of plastic, enabling them to process their own waste.

Recycled plastic waste pressed into bales.
alexanderuhrin/Adobe Stock

Microplastic system interventions

ROLL OUT KNOWN SOLUTIONS FOR FOUR MICROPLASTIC (<5MM) SOURCES—TYRES, TEXTILES, PERSONAL CARE PRODUCTS, AND PRODUCTION PELLETS—TO REDUCE ANNUAL MICROPLASTIC LEAKAGE TO THE OCEAN BY 1.8 MILLION METRIC TONS PER YEAR (FROM 3 MILLION METRIC TONS TO 1.2 MILLION METRIC TONS) BY 2040

Key takeaways

- Eleven per cent of total plastic entering the ocean in 2016 comes from the four key sources of microplastics we selected to model (tyre dust, pellets, textile micro-fibres, and microplastics in personal care products).
- The largest contributor to 2016 microplastic leakage into the ocean is tyre dust, contributing 78 per cent of the leakage mass; pellets contribute 18 per cent; and textiles and personal care products (PCP) contribute 4 per cent combined.
- There is a different pattern in terms of the number of microplastic particles entering the ocean, with tyres and textiles being the main sources of leakage.
- In the System Change Scenario, where we implement all significant, known microplastic solutions at scale, microplastic leakage can be reduced by 1.8 million metric tons per year (from 3 million metric tons to 1.2 million metric tons) by 2040, a 59 per cent reduction compared with BAU.
- Solutions should focus on reducing microplastics at source because this is more cost efficient and feasible than collection of microplastic particles in the environment. This should be done through innovation in tyres and textiles design, a revolution in transportation, decreasing plastic production, regulatory and corporate measures to prevent pellet leakage, and bans on using microplastic ingredients in PCPs.
- New solutions will be required to reduce leakage further than modelled under this scenario, especially for tyres, and to address the other sources of microplastic emissions not modelled here.
- Microplastics represent 60 per cent of leakage in HI countries, and hence should be a top priority in this geographic archetype.

Microplastic sources	Leakage mass	Feasibility of leakage reduction	Modelled uncertainty
Tyre dust	High	Low	High
Pellets	Medium	High	Medium
Textile microfibres	Low-medium	Medium	Medium
Microplastic in PCPs	Low	High	Medium-high

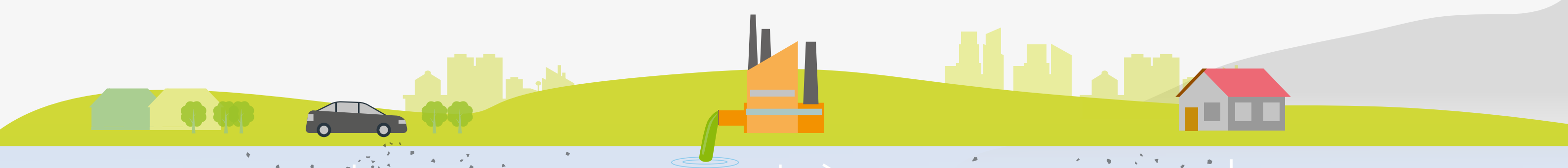
Microplastics are defined in our report as pieces of plastic between 1 micrometre and 5 mm in size that enter the environment as microsized particles—widely called primary microplastic.[175] We do not include secondary microplastics, created through the breakdown of mismanaged macroplastic waste, as its mass is already accounted for in the system interventions on macroplastics. Neither do we quantify nanoplastics, defined as particles smaller than 1 micrometre created through the breakdown of microplastics, due to data limitations.

Of the ~20 potential sources of primary microplastic, we modelled four sources, representing an estimated 75-85 per cent of microplastic leakage: tyre abrasion/dust, pellet loss, textile microfibres, and microplastic ingredients in PCPs (including the full size range of PCP ingredients).[176] We selected these four sources based on existing research, the relative leakage mass, and the ease and understanding of potential solutions for each source. The results of our model relate to the four modelled sources only, and do not represent total microplastic emissions.

To model flows of the four microplastic sources, individual system maps were developed (see the technical appendix) showing where releases from each of the modelled sources occur during the use and/or production phase, from which they are distributed to different pathways (e.g., combined sewers and drainage systems for tyres and pellets, wastewater treatment for textiles and PCPs) and then on to their final destinations, either controlled disposal (e.g., engineered landfills, incineration) or mismanaged (e.g., dumpsites, terrestrial pollution through land application of sewage sludge, and leakage to the ocean). For detailed system maps illustrating our methodology for each of the four sources, see the technical appendix.

Microplastics and the ocean

About 11 per cent of today's total flow of plastic into the ocean comes from only four sources of microplastics–tyre abrasion, production pellets, textiles, and personal care products–released into the environment as microsize particles (<5mm). Rapid action and innovation are needed to stop them from leaking into the ocean and, more broadly, into the environment.



2016

How much do microplastics contribute to ocean plastic pollution?

The four sources of microplastics we analyzed now contribute about **1.3 million metric tons** of microplastic leakage into the ocean annually, growing to **3 million metric tons** in 2040.

Tyre dust contributes **78%** of microplastic leakage by mass

~1,200,000 TRILLION PARTICLES

Pellets contribute **18%** of microplastic leakage by mass

~10 TRILLION PARTICLES

Textiles & personal care products contribute **4%** of microplastic leakage by mass combined

~144,000 TRILLION PARTICLES

Where does microplastic leakage come from?

The microplastics analyzed represent about **60% of total leakage** in high-income countries.

High-income countries leak

365 grams

of microplastic per capita

Middle-/low-income countries leak

109 grams

of microplastic per capita

2040 System Change Scenario

How can we reduce microplastic leakage?

With concerted action beginning in 2020 across the entire plastics system, microplastic leakage can be reduced by ...

~1.8 million metric tons per year or **59% by 2040**

compared to Business-as-Usual.

Solutions include:

- **Better designed** tyres and textiles
- **Modal shifts** in transportation to reduce mileage driven per capita
- **Decreased** plastic production
- **Regulatory and corporate measures** to prevent pellet leakage
- **Extend** wastewater treatment
- **Bans** on using microplastic ingredients in personal care products

Additional innovation is necessary to reduce the remaining 41% of plastic leakage, particularly in tyre design.

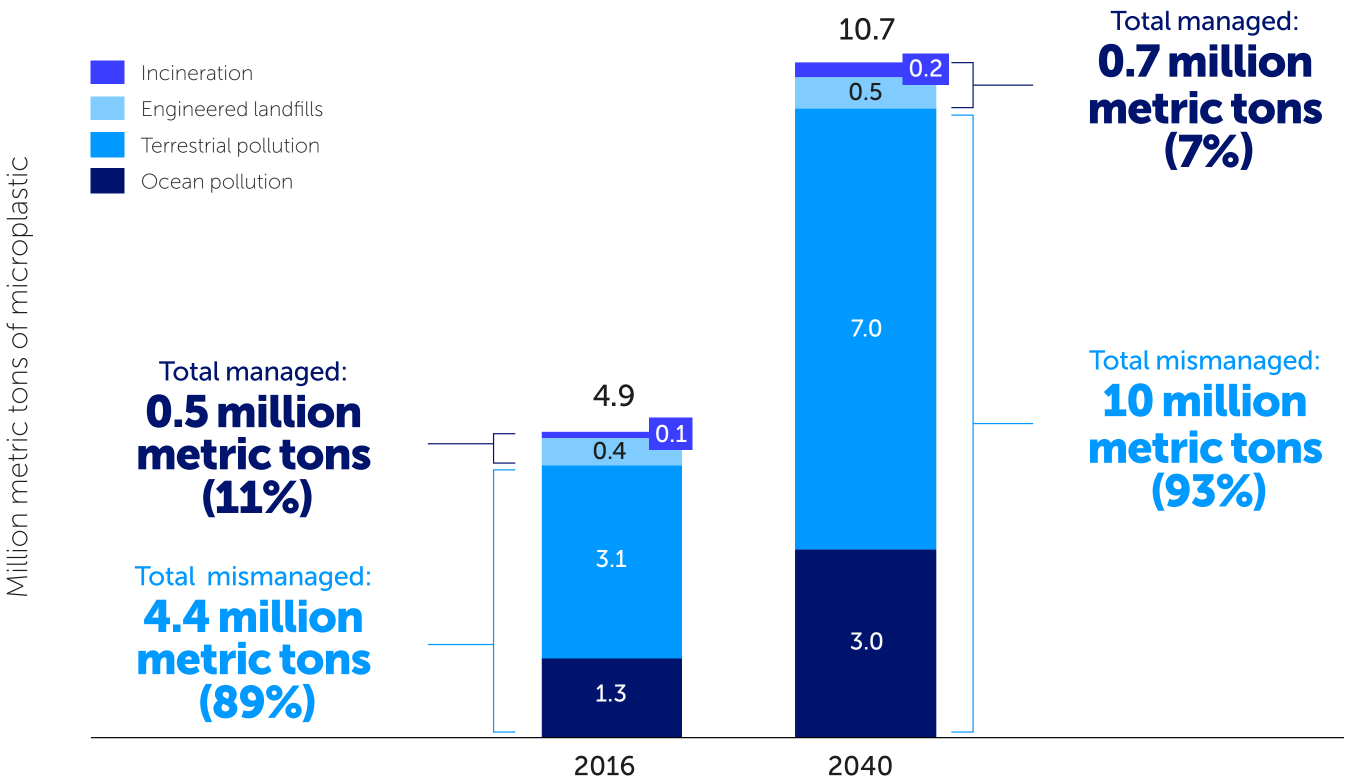
Microplastic emissions under a Business-as-Usual Scenario

We estimate that microplastic leakage from the four modelled sources could grow from 1.3 million metric tons in 2016 to 3.0 million metric tons by 2040 under BAU, a growth of 2.4 times, largely driven by increased transportation, plastic production, and synthetic textile use in the middle-/low-income countries. This means that microplastics would contribute 11 per cent, by mass, of the total annual global leakage of plastic to the ocean by 2040.

We estimate that 26 per cent of all microplastics released (during production or use, onto roads, into wastewater drains, or into the environment) ends up as leakage to the ocean. An additional 63 per cent of releases end up leaking into other environments, including soil and air. This mismanaged terrestrial leakage includes the direct releases of tyre particles into soil near roads; microplastics captured in road runoff or wastewater facilities that leak to soil or that re-enter the terrestrial environment through the land application of sewage sludge;[177] and the direct disposal of wastewater to farmlands due to water scarcity.[178] As illustrated in Figure 40, the managed microplastics captured from wastewater treatment and sent to sanitary landfills or incineration only amounted to 0.5 million metric tons per year (±0.1 million metric tons per year), or 11 per cent of total microplastics released from all sources modelled in 2016.

Figure 40: Microplastic pollution in the Business-as-Usual Scenario

Mismanaged microplastics could grow from 4.4 million metric tons in 2016 to 10 million metric tons by 2040



Solutions should focus on reducing microplastics at their source because this is more cost-efficient and feasible than collection of microplastic particles already in the environment. This approach could be done through innovation in tyres and textiles design, a revolution in transportation to decrease the total distance driven by cars, decreasing plastic production, regulatory and corporate measures to prevent pellet leakage, and bans on using microplastic ingredients in personal care products.

Box 16: Uncertainty of modelling microplastic leakage

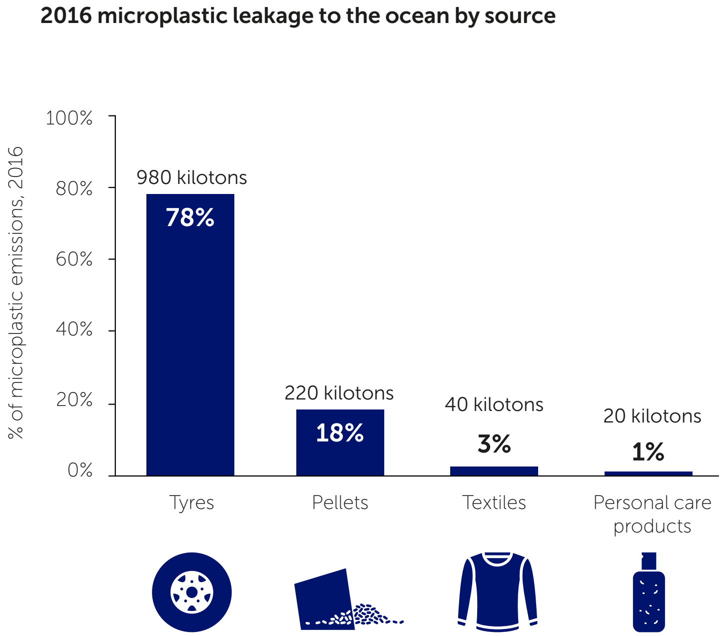
Modelling microplastic leakage to the ocean is a challenge due to a lack of standardized methods for sample collection and analysis and insufficient understanding of degradation to nanoplastics, leading to knowledge gaps about their distribution and pathways in the environment.[179] Key areas of uncertainty vary for each source. Tyre wear is a well-established fact, but where the particles end up is highly uncertain (they could settle in soils, leak to waterways, be transported by rivers to the ocean, etc.).[180] On the other hand, the state of knowledge about pellet loss rates shows high uncertainty, even though their distribution pathways are better understood. Reported pellet loss rates range from 0.0002 per cent spilt per metric ton to as high as 0.9 per cent (according to a survey undertaken in Denmark).[181] The losses and pathways of both microfibres and microplastic ingredients in PCPs appear to be better documented, at least in high-income countries, where a large share of the population is connected to wastewater treatment.[182] The fate of these two sources in middle-/low-income countries, where it is more common to wash laundry directly in rivers and use wastewater for irrigation, may be different.[183] Our findings estimate current high modelled uncertainty, with the highest uncertainty for tyres (17 per cent), followed by PCPs (11 per cent), pellets (9 per cent) and textiles (8 per cent).

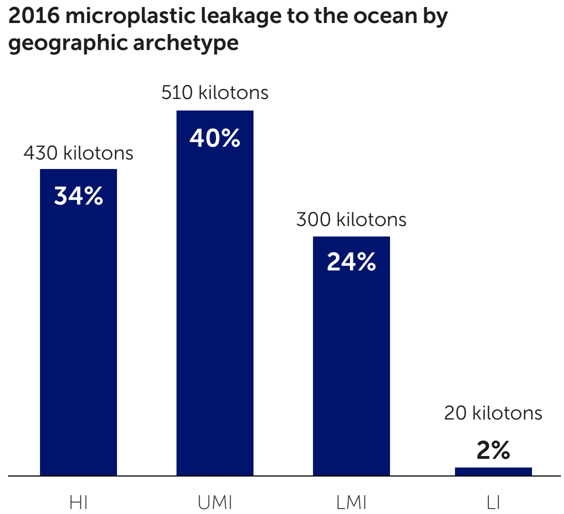
A sensitivity analysis was conducted to quantify the impact of model assumptions on output of tyre leakage, the highest source of microplastic ocean leakage. The shares of road and runway runoff distributed directly to waterways have been identified as the key drivers influencing the ocean leakage from tyres. Additional runoff captured and safely removed in combined sewers would change the amount of runoff directed to waterways. The sensitivity analysis results indicate that additional research is needed in the area of road runoff and tyre particle distribution to validate or improve our assumptions.

Of the four sources modelled, by far the largest contributor to microplastic leakage into the ocean and waterways in 2016 is tyre abrasion, which contributes 78 per cent of the leakage mass; pellets contribute 18 per cent of the leakage mass; and textiles and PCP contribute 4 per cent of leakage mass combined (Figure 41). However, the estimated contribution of microplastic particles to ocean plastic pollution may potentially represent a different pattern, with tyres leaking about 1,200,000 trillion particles, textiles about 140,000 trillion particles, PCPs about 4,000 trillion particles, and pellets about 10 trillion particles in 2016. The relative contribution of different sources, and the magnitude of leakage to the ocean, could change if we modelled additional distribution pathways. For example, transfer through air of microfibres released from textiles during the production and use phases may be a significant component of environmental leakage[184] as microfibres are found worldwide, including in remote places such as the High Arctic, proving that they can be transported over long distances.[185] Notably, our estimates of microfibre release rates are much smaller than some other studies because the most recent data on fibre loss during washing shows much lower release rates—on average, 108 milligrams per kilogram (mg/kg) textile washed (see the technical appendix), while the rates used in some previous studies were as high as 900 mg/kg.[186] More research on microplastic emissions and pathways is needed to obtain a complete picture of the microplastic pollution problem.[187]

Figure 41: Microplastic leakage to the ocean by source and geographic archetype

Tyres are the largest source of microplastic leakage





We estimate that the majority of the microplastic entering the ocean in 2016—0.8 million metric tons or 66 per cent—originates in the middle-/low-income countries, and that 81 per cent of the growth of microplastic leakage by 2040 could also come from these regions under BAU. The main drivers responsible for this in our model are population growth (slower for HI than the rest of the world), the projected increase in vehicle driving (expected to triple in UMI and LMI), and the growth of plastic production (expected to nearly triple in UMI, LMI, and LI). The other factors are related to the limited improvements in downstream solutions for capturing microplastic in middle-/low-income countries, for example, by installing road runoff treatment systems that safely remove and dispose of captured microplastic.

However, HI countries account for about a third (34 per cent) of all microplastic emissions in 2016 and, on a per capita basis, microplastic emissions to the ocean in HI countries are 3.4 times higher than the rest of the world today (an average of 365 grams in HI in 2016 compared with 109 grams in other archetypes), mainly driven by higher driving rates, plastic consumption, and textile washing in HI countries. In fact, microplastics represent 60 per cent of leakage in HI countries, and therefore solving this challenge should be a priority for this archetype.

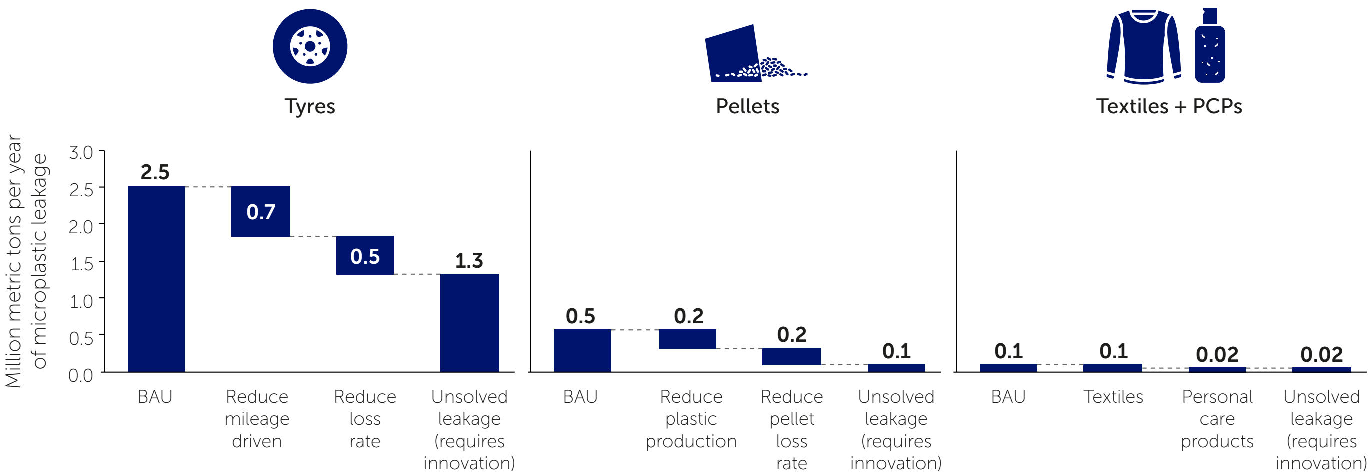
Microplastic solutions—System Change Scenario

In the System Change Scenario, where we implement all significant, known microplastic solutions at scale, we estimate that microplastic leakage can be reduced by 1.8 million metric tons per year—or approximately, with a conservative estimate, 1,600,000 trillion microplastic particles—by 2040 compared with BAU (see Figure 42 and Table 7). However, notably, even with all known solutions, microplastic emissions in 2040 are similar to the 2016 leakage rate. This result means that, under the System Change Scenario, microplastic could be a significant part of the remaining total plastic entering the ocean in 2040, at 23 per cent. This is because there are fewer known solutions for certain sources of microplastic compared with macroplastic.

Implementing all known solutions for microplastic could potentially reduce 59 per cent of annual modelled microplastic leakage to the ocean, with the highest reduction potential for pellets (86 per cent reduction), followed by textiles (77 per cent), PCPs (77 per cent) and tyres (54 per cent); see Figure 42 and Table 7.

Figure 42: Microplastic leakage to the ocean under Business-as-Usual in 2016 and leakage reduction potential for four sources under the System Change Scenario in 2040

Microplastic solutions are relatively well understood for most sources, but not for tyres



Three of the modelled sources have more readily implementable solutions with low societal impacts. For example, by implementing relevant regulations, and with monitoring and enforcement of prevention measures across the supply chain, pellet loss could be readily addressed by 2040. Similarly, textile leakage, which is the third-largest source of microplastic pollution in terms of mass, has high potential to be improved by switching to already existing textiles, for example, natural or synthetic yarns with lower shedding rates. Third, even though microplastic ingredients from PCPs cause the lowest leakage of the four sources modelled, they can be banned, as has already occurred in several countries, without societal risks.

By contrast, additional innovation will be required to further reduce leakage from tyres, which are responsible for 93 per cent of the remaining microplastic entering the ocean in 2040 after all system interventions have been applied. To further reduce microplastic pollution, the tyre industry, supported by government research programmes, should invest in innovation and redesign, for example, on biodegradability, while maintaining the tyre properties that are essential for safety (e.g., rolling resistance, slip resistance, and wear resistance).[188]

Table 7: Microplastic leakage to the ocean under Business-as-Usual and System Change scenarios with reduction potential rates and levers required to reach estimated reduction rates

Microplastic source	BAU leakage, million metric tons per year	SCS leakage 2040, million metric tons per year (per cent reduction relative to BAU)	Interventions required to reach estimated reduction rates
Tyres	**2016:** 1.0 (±0.2) **2040:** 2.4 (±0.5)	**2040:** 1.1 (±0.3) (54% decrease)	An ambitious programme to reduce microplastic emissions from tyre particle abrasion could contribute a reduction of 1.3 million metric tons (±0.5 million metric tons) of plastic leakage by 2040. Several factors influence tyre wear, including tyre, vehicle, and road surface characteristics (tyre size, profile, vehicle weight, road roughness, etc.) and "eco-driving" behaviour (speed, acceleration, tyre pressure).[189] The most effective solutions are the reduction of kilometres driven and decreasing tyre loss rate. Significant reductions in kilometres driven per capita can be achieved by modal shifts in transportation, for example, using automated, shared, or public transport;[190] rail or barge transport;[191] airborne transportation,[192] etc. Existing tyres show high ranges of durability, so by choosing the less abrading types and brands, together with promoting eco-driving habits, we could significantly reduce microplastic pollution from tyres. Implementation of standardized testing of tyre abrasion rate and tyre design regulations should be considered. Interventions modelled include: • **Substitution of tyre material to improve durability:** Assumes 50 per cent of countries legislate that, by 2040, new tyres must have 36 per cent lower release rates than today (eliminates worst-performing tyres). • **Reduction in km driven:** High-income countries reduce by 50 per cent per capita by 2040 (e.g., for passenger cars, from 11,921 km/capita under BAU to 5,960 km/capita under the System Change Scenario); middle-/low-income countries reduce by 20 per cent per capita by 2040 (e.g., for passenger cars, from 2,553 km/capita under BAU to 2,042 km/capita under the System Change Scenario). • **Eco-driving** adds 6 per cent reduction to tyre loss rates. • **Controlled disposal of sedimentation in drainage systems** in urban areas in the middle-/low-income countries reaches similar levels as high-income urban areas.
Pellets	**2016:** 0.2 (±0.02) **2040:** 0.5 (±0.05)	**2040:** 0.07 (±0.006) (86% decrease)	Solutions for reducing the leakage of plastic pellets to the ocean have the potential to reduce 0.4 million metric tons (±0.05 million metric tons): • Nearly half of pellet leakage can be remedied by reducing the loss of pellets at every stage of the supply chain via the **implementation of best practices**, mandated by regulation. We model a conservative 70 c before departing a facility; monitoring emissions within and near factories, and in waste effluents from drains; and using bags that prevent leakage and securing them during transport.[194] • The remaining pellet leakage is reduced through the **reduction of plastic production due to System Change Scenario macroplastic** reduction and substitution interventions.

Microplastic source	**BAU leakage, million metric tons per year**	**SCS leakage 2040, million metric tons per year** (per cent reduction relative to BAU)	**Interventions required to reach estimated reduction rates**
Textiles	**2016:** 0.04 (±0.003) **2040:** 0.07 (±0.005)	**2040:** 0.02 (±0.001) (77% decrease)	There are four levers driving reduction in leakage of microfibres to the ocean that could reduce annual microfibre emissions by 0.05 million metric tons (±0.005 million metric tons) under the System Change Scenario: • Decrease microfibre loss rate from textiles through **redesign and shifting to textiles with lower loss rates** or through use of natural fibres, cutting to avoid raw edges, woven construction, filament yarns, and coatings.[195] The introduction of standardized testing of microfibre shedding rates and textile design regulations should be considered. • **Mandatory treatment of textile factory effluent.** About 50 per cent of all microfibre losses occur during the textiles production phase, and yet there are no regulations to target microplastics in factory effluent.[196] We model that 95 per cent of countries mandate that all factories must use on-site treatment equivalent to tertiary treatment by 2040. • **Installing machine washing filters in households**; Household washing machine filters can capture 88.5 per cent of microfibres,[197] however, the effectiveness of this lever largely depends on manufacturers being obliged to install filters, retrofitting filters to existing machines, and consumer behaviour. We model that 95 per cent of countries legislate that new washing machines must have filters capturing 88.5 per cent of microfibres by 2040, and assume that 50 per cent of consumers use these correctly. • **Extend wastewater treatment.** The expansion of household connections to wastewater treatment with at least secondary treatment could help reduce microplastic pollution in wastewaters.[198] We assume all archetypes meet the Sustainable Development Goal of halving untreated wastewater by 2030.
PCPs	**2016:** 0.2 (±0.002) **2040:** 0.03 (±0.003)	**2040:** 0.006 (±0.001) (77% decrease)	PCP microplastic leakage is the lowest of the four sources modelled, but solutions are readily available to reduce it still further and, if implemented more widely, they would reduce 0.02 million metric tons (±0.001 million metric tons) of total leakage: • **A ban on the use of microplastic ingredients and substitution with natural alternatives.** We model that 95 per cent of microplastic ingredients in wash-off PCPs and 30 per cent of microplastic ingredients in stay-on PCPs are banned by 2040. Legislation banning some microplastic ingredients in certain products has already been implemented by several local and national governments.[199] However, it is important to emphasize that most of these efforts focus on the larger plastic beads in rinse-off cosmetics that constitute only a small part of the total microplastic ingredients used in products. Alarmingly, some companies have replaced these microbeads with unverified polymers of concern of unknown size.[200] There should be concerted action to completely remove all microplastic ingredients from all PCPs to achieve near-zero leakage from this source, as they are also known to pass through wastewater treatment. [201] • **Extending wastewater treatment according to the Sustainable Development Goals.**

Costs and emissions

We calculated annualized indicative implementation costs for seven (of 11) microplastic intervention levers. Medium indicative costs, below US$10,000 to reduce a metric ton of microplastic per lever, were estimated for preventing pellet loss, substituting microplastic with natural ingredients in PCPs, using better-performing tyres, and reducing plastic production, with the last two being possible cost savings. High costs, above US$10,000 per lever, were estimated for eco-driving courses, shifting to textiles with lower shedding rates, and installing washing machine filters.

The other four levers are driven by the Sustainable Development Goals and their wider human benefits (reduce kilometres driven, expand treatment of municipal wastewater and wastewater from textile production, introduce sustainable drainage systems for urban road runoff in the middle-/low-income countries). They were not quantified because they are not primarily driven by the desire to reduce microplastic pollution. For example, the expansion of wastewater treatment—undertaken primarily to improve sanitation and health in communities—will reduce leakage of all analysed microplastic sources. Similarly, as we continue to experience modal shifts in transportation and the growth of the sharing economy—driven predominantly by an ambition to reduce GHG emissions, economic reasons and consumer preference—less tyre abrasion, and, by extension, microplastic pollution, will be a positive side effect.

Maritime sources of leakage

Key takeaways

- High uncertainty exists about exactly how much plastic leaks into the ocean from maritime sources, preventing the inclusion of this category in our quantitative analysis, but it is estimated to be between 10 per cent and 30 per cent of total macroplastic leakage.[202]
- Abandoned, Lost, or otherwise Discarded Fishing Gear (ALDFG) ranks among the most damaging to marine ecosystems among all sources of ocean plastic pollution and is, by definition, usually lost in areas with the highest concentration of fish.[203]
- Known levers that reduce maritime sources of leakage could be very effective but are difficult to enforce and require strong stakeholder cooperation.
- The most important areas for further research and monitoring are the annual production and loss rate per gear type, as well as the volume of waste returned to port.

Maritime sources of ocean plastic pollution, defined in this report as all plastic that enters the environment from seagoing vessels (including from fishing activities), are some of the most visible contributors to ocean plastic pollution.[204] Although the lack of robust estimates of different maritime sources of leakage prevents the inclusion of this category in our quantitative analysis, addressing this source of pollution is of utmost urgency. There is sufficient data available to indicate the relative magnitude of this source of leakage, the main solution areas, and where more research is needed.

Existing estimates of maritime sources of ocean plastic pollution vary between 0.3 million metric tons and 5.91 million metric tons per year.[205] These are based on two different approaches. On the one hand, some estimates establish the relative share of different maritime sources as a percentage of the total plastic collected in coastal clean-ups, arriving at an estimate of 10-30 per cent of total ocean plastic pollution.[206] Doing this for some fishing gear is relatively straightforward, but not for all fishing gear (such as buoy lines and ropes), and estimating other plastic pollution originating from vessels is difficult, as they are hard to distinguish from land-based sources. On the other hand, global extrapolation of estimated leakage as a share of total waste generated at sea annually in the European Union shows that between 1.3 million metric tons and 1.8 million metric tons of plastic waste per year is generated at sea.[207] This approach addresses the issues of relative contributions and source attribution, but does not offer information on how European Union leakage rates compare to the rest of the world. Combining recent estimates by other organizations (midpoint estimate for at-sea sources: 1.75 million metric tons)[208] with our estimates for total municipal solid plastic waste leakage from land (9.8 million metric tons) indicates that maritime sources could be responsible for about 15 per cent of total ocean plastic pollution today, but it should be noted that this estimate is highly uncertain.

Abandoned, lost or otherwise discarded fishing gear (ALDFG)

Of all the sources of ocean plastic pollution, ALDFG—also known as "ghost gear"—ranks among the most damaging to marine ecosystems.[209] ALDFG's damaging properties, such as high entanglement risk, are the direct result of their original design to trap and kill fish and other marine species. On top of this, ALDFG is—by definition—most intensely leaked in areas with high densities of marine wildlife, as this is where fishing is concentrated. Multiple sources have tried to quantify the annual leakage rates, with estimates ranging from 640,000 to 1,150,000 metric tons, and this value is expected to increase as a result of growth in fishing effort and aquaculture.[210]

It should be noted that ALDFG is not the only plastic waste to enter the marine environment from fishing vessels; the other types are covered under the section on shipping litter.

It is crucial to note that multiple types of fishing gear exist that are very different in their respective likelihood of loss, ubiquity of usage, and potential impacts on wildlife when lost.[211] The likelihood of loss can depend on a complex interaction of factors, including spatial and operational pressures that lead to gear conflicts, poor weather conditions, economic pressures that disincentivize onshore disposal, and the presence of illegal, unreported and unregulated (IUU) fishing.[212] It has been estimated that 29 per cent of lines are lost each year, 8.6 per cent of all traps and pots, and 5.7 per cent of nets.[213] A more specific assessment of fishing nets finds gillnets to have the highest risk of being lost, while bottom trawls are considered low risk, and purse seines and midwater trawls are in the lowest risk category.[214] However, although we have some information on the loss rates of different fishing gear, no comparable data exist on how much of each gear type is produced or used each year. Landed catch per gear type is one possible proxy because global data is available, and combining this data with the likelihood of loss would suggest that the two highest priority gear types for research and prevention of ocean plastic leakage are gillnets and bottom trawls.[215] However, given the differences in catch rate per unit of effort across different gear types, this approach also has its limitations. Better information on production and usage rates per gear type, and the volumes returned to port as waste, is needed to better quantify the contribution of different gear types to ocean plastic pollution.

ALDFG reduction levers

There are two main categories of intervention levers to reduce the presence of ALDFG in the marine environment: preventive and remedial. A comprehensive assessment of levers can be found in the Food and Agriculture Organization (FAO) of the United Nations ALDFG report and the Global Ghost Gear Initiative (GGGI) Best Practice Framework for the Management of Fishing Gear.[216] We also include enabling conditions that would facilitate their respective implementation.[217] The preventive levers are expected to have significant impact but need wide-scale implementation to be effective. Remedial levers, on the other hand, are necessary but will be more labour and capital intensive than preventive levers.

Preventive levers

- Economic incentives to help prevent gear loss and increase proper disposal of unwanted gear. These may include accessible and no-special-fee port reception facilities, Extended Producer Responsibility for fishing gear, or disincentives for fishers to generate ALDFG by charging a fee for gear that cannot be accounted for.
- Adoption of gear-marking systems (local or global) that provide information on ownership and location as well as increased surface gear visibility.
- Design of gear and employment of technology that reduces the risk of gear loss, entanglement, and unwanted contact with the seabed.
- Regulation of gear used, location of gear use and gear use methods, as well as return-to-port and recycling targets.
- Stronger enforcement of existing regulations against IUU fishing, including the Port State Measures Agreement (PSMA). The PSMA, which entered into force in 2016, is the first binding international agreement to take aim at many facets of IUU fishing by denying port access to illegal fishing vessels and preventing illegal catches from being landed. By limiting capacity for IUU fishing, the PSMA can reduce intentional gear abandonment.[218]

Fish are tangled in abandoned commercial fishing nets.
Josephine Julian/Adobe Stock

- Increased awareness among stakeholders of best practices, existing rules and regulations and (economic) damage inflicted by ALDFG, for example, through training programmes.

Remedial levers

- Stronger incentives to report, retrieve, and deliver ALDFG encountered at sea, in combination with above-mentioned gear-marking technology.
- Increased awareness among stakeholders of how to report, retrieve, and deliver ALDFG encountered at sea, as well as on the benefits of these efforts.
- Development of targeted programmes for ALDFG detection, reporting, and safe retrieval.
- Establishment of programmes to reduce the ghost fishing of ALDFG, for example, by making gear biodegradable.

The magnitude of impact of the above levers is difficult to quantify, but two of them have undergone particularly close scrutiny as a result of associated legislative proposals in the European Union. Recent estimates for the effect of Extended Producer Responsibility in conjunction with a deposit scheme for fishing gear in the European Union found that it could result in a reduction of ALDFG from 12 per cent of total production today to 2 per cent, at a cost of 150-200 euros per metric ton.[219]

Enabling conditions

- More research into ALDFG, as outlined above, combined with understanding the effectiveness and feasibility of different measures.
- Increased international cooperation on ALDFG among governments, international organizations, and other regulators, for example, through the harmonization of reporting gear production and losses, codes of practices, and communication protocols, such as the newly adopted FAO guidelines in the PSMA and voluntary guidelines on the marking of fishing gear.[220]
- Inclusion of gear loss in sustainability criteria by fishery certification bodies.

Shipping litter

Shipping litter, the deliberate dumping of plastic from maritime vessels, defined as all plastic leakage generated as a result of human activity on seagoing vessels, is illegal under international law, with some exemptions (MARPOL Annex V). Nevertheless, the practice is believed to be widespread, and there is evidence that it has increased over the past 50 years in tandem with the growth in commercial shipping.[221] Shipping litter includes general plastic waste generated and accidentally or intentionally disposed overboard on shipping, fishing, and recreational vessels and cruise ships. Shipping waste can contain about double the share of plastic compared with our estimates of land-based MSW.[222] Combined with the fact that it is generated at sea, this could result in significantly higher leakage rates, although this is hard to confirm due to lack of on-vessel monitoring.

The most comprehensive research conducted to date, including not only an overview of the existing literature but also providing estimates of shipping litter in European Union waters, estimates that shipping litter accounts for between 54,000 and 67,000 metric tons of plastic annually in the European Union, or 35 per cent of total maritime sources. This estimate does not include waste from offshore platforms; the other 65 per cent is ALDFG.[223]

Shipping litter reduction levers

The measures available to combat shipping litter can be divided between land-based and maritime-based levers. The former includes levers that are part of wider efforts to reduce plastic pollution, while the latter focuses on specific levers for shipping litter.[224]

Land-based levers

- Reduction of plastic consumption through innovation in packaging, new delivery models, or improved resource efficiency.
- Substitution of plastic with materials that decompose at sea, such as paper.

Maritime-based levers

- Current best practices of regulation, based on EU Directive 2018/12/EC, include:
  - Targeted and increased inspection regime in ports and on vessels, including, for example, by fisheries observers already monitoring at-sea activities.
  - Mechanisms that ensure free disposal of waste at ports, funded through indirect fees on all ships depending on their expected waste generation.
  - Administrative fee systems, in which ships pay for docking and the amount of waste delivered, but get a refund on the docking fee when waste is delivered.
  - Digital reporting of waste notification and waste receipt information, harmonized and shared among governments.
- Enforcement of MARPOL Annex V to ensure appropriate capacity and quality of waste disposal facilities at ports, standardized reporting by ships and ports, and the inclusion of adequate waste storage facility on vessels.

Enabling conditions

- Improved data collection at ports and on vessels around the world is desperately needed to allow better understanding of the global extent of the problem. Existing efforts are already underway in Europe and should be supported and extended to other regions to address the global challenge of shipping litter more effectively.
- In parallel, increased international cooperation on shipping litter among governments, international organizations and other regulators is required, for example, through the harmonization of reporting waste, codes of practices, and communication protocols, as outlined in MARPOL Annex V.

Bridging the gap

Innovation is essential for a future with near-zero plastic pollution

Daisuke Kurashim/Shutterstock

Alternative worlds: sensitivities and design choices for pollution reduction strategies

The System Change Scenario represents one pathway to significantly reduce ocean plastic pollution but, of course, it is not the only one. We conducted multiple sensitivity analyses to understand what other sets of solutions can achieve similar reductions in plastic leakage levels and identify the possible trade-offs.

One analysis looked at the trade-off between Reduce and Substitute intervention rates (in other words, the amount of plastic removed from the system relative to Business-as-Usual 2040) and collection rates (the share of plastic waste that is collected by either the formal or informal sector). This analysis was undertaken to assess what the implications would be if there were less ambitious reductions in plastic production and consumption than those modelled under the System Change Scenario. To test this idea, we fixed the plastic leakage rate at the System Change Scenario level and modeled the collection rates that would be required to offset smaller plastic reductions.

To maintain the same level of plastic leakage reduction achievable under the System Change Scenario, but with the Reduce and Substitute interventions contributing only 9 per cent to leakage reduction (compared with 47 per cent under the System Change Scenario), collection rates would need to increase significantly across the archetypes in this alternate scenario. In the lower middle-income (LMI) rural archetype, for example, collection rates would need to increase to 80 per cent from the maximally foreseen assessment level of 50 per cent and from 33 per cent in 2016. Reaching 80 per cent collection in rural areas of LMI countries may be a very challenging, if not impossible, task given the pressure on government budgets and high collection costs in rural areas. To achieve this level of collection by 2040, an additional US$22 billion in cost per year would be required—which the plastics industry would probably need to pay for—and 40 per cent more GHG emissions would be generated relative to the System Change Scenario. Similarly, in the upper middle-income (UMI) rural archetype, collection rates would have to increase to 80 per cent relative to 45 per cent in 2016 and the maximally foreseeable rate of 50 per cent. Like the LMI rural areas, reaching this level of collection in the rural areas of UMI countries is a daunting task and would require an additional US$18 billion in cost per year by 2040 and would also emit 40 per cent more GHG.

Similarly, we tested how increasing design for recycling rates and making them even more ambitious than our System Change Scenario assumption would influence the Reduce and Substitute targets needed. In the LMI urban archetype, for example, recyclability of multimaterials would need to grow from 25 per cent under the System Change Scenario to 100 per cent to enable a reduction of Reduce and Substitute from 47 per cent to 40 per cent. This target would require making all multimaterial products recyclable, including laminated cartons, diapers, and household goods.

Based on our alternate scenario assessments, increasing the percentage of either collection or design for recycling incurs greater costs financially and from a climate perspective than employing Reduce and Substitute interventions at higher rates. The most practical solution may be to implement the Reduce and Substitute levels assumed in the System Change Scenario through eliminating unnecessary plastics, enhancing reuse and new delivery models, and substituting plastic for other materials.

None of the alternative pathways we analysed can achieve a plastic leakage reduction comparable to the System Change Scenario without hitting extremely high costs, rising GHG emissions, or other undesirable outcomes.

We constrained our analysis to modelling solutions that are available today, or under development, and assessing maximum foreseeable future targets. However, alternative worlds could become possible as new technologies and solutions emerge and allow positive disruptions to the plastics value chain. For example, breakthroughs in new service models tailored for packaging and household goods, compostable packaging and deployment of appropriate collection and composting infrastructure, other alternative materials, and improvements to the life-cycle emissions of existing substitutes, could all be game-changing. Transport and delivery automation and vehicle electrification, for example, could radically reduce the emissions of new delivery models, as well as collection costs and their associated emissions.

The innovation gap: near-zero leakage needs significant innovation

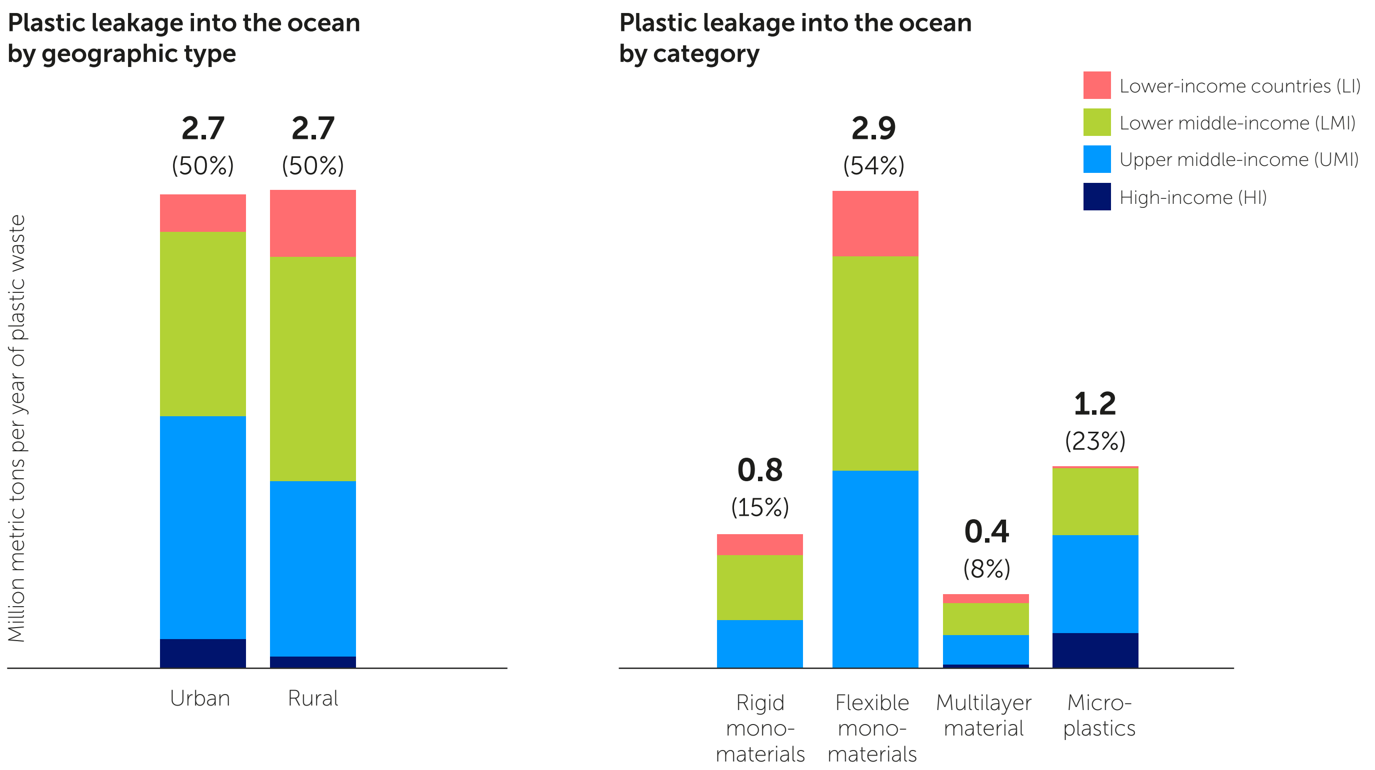
The System Change Scenario describes a viable pathway that could dramatically reduce ocean plastic pollution. But the ultimate goal is to achieve near-zero plastic entering the ocean, and to realize this vision we need to close the innovation gap. The massive innovation scale-up required to tackle the last 18 per cent of the projected plastic entering the ocean needs a focused and well-funded R&D agenda alongside inspirational moonshot ambitions.

Taken together, the eight system interventions described in Chapter 2 can have a massive impact on the global plastic system, not only by significantly reducing leakage to the ocean, but also by reducing GHG emissions and costs, and increasing employment relative to BAU. And yet, even if all significant known system interventions are applied concurrently, we estimate that 5 million metric tons of plastic would still be leaking into the ocean every year by 2040, and annual GHG emissions would be 54 per cent higher than 2016 levels, while the cumulative amount of plastic that will enter the ocean between 2016 and 2040 amounts to 248 million metric tons. Getting to near-zero leakage will require a concerted innovation thrust backed by a focused and well-funded research and development (R&D) agenda, a quadrupling or more of today's annual spending of US$22 billion on R&D.[225]

Plastic manufacturing is currently classified as a "medium R&D intensity" industry (spending 4 per cent of gross value added, GVA),[226] and the waste management sector is classified as "low R&D intensity" (spending 0.4 per cent of GVA). The System Change Scenario depicts a future in which these industries transition towards more competitive market dynamics, innovating rapidly to stay in business as markets evolve. For example, if the plastic manufacturing industry were to increase its R&D spending to the level currently spent by the machinery industry, this would mean R&D spending of US$95 billion per year by 2040—more than double the percentage of GVA invested under the BAU Scenario, if GVA doubles in line with BAU plastic production. This spending could go towards improving existing manufacturing and design, advancing recycling technologies, as well as investing in the development of new substitute materials and packaging services.

Figure 43: Remaining 2040 leakage by geographic archetype and plastic category under the System Change Scenario

Flexible monomaterials have disproportionate leakage after System Change Scenario interventions have been implemented, thus requiring most of the innovation focus



Bridging the remaining gap to near-zero leakage will require additional R&D investment and innovations that go beyond today's known solutions, furthering smart policies, alternative business models, new material substitutes, and more effective and faster scaling-up of reduction, collection and recycling, composting, and controlled disposal systems, especially in the middle-/low-income countries. Spending on R&D might be expected to exceed US$100 billion per year.

This R&D would need to come not only from the plastic manufacturing industry, but also from waste management, recycling, logistics companies, and new service providers. The scale of innovation required can be compared with what we have seen during the internet revolution of the past twenty years: We need a proliferation of hundreds of innovations competing with each other to achieve the best possible outcomes financially, socially, and for the environment.

To better understand the areas where innovation can be most effective, Figure 43 shows the remaining sources of leakage after all System Change Scenario system interventions have been implemented. New solutions must be developed that focus specifically on: 1) collection, especially for rural and remote areas; 2) flexible plastic and multimaterials (62 per cent of remaining leakage), with a focus on alternative delivery systems and materials and enhancing the material value of existing materials; and 3) tyre microplastic leakage (21 per cent of remaining leakage). Other missing pieces may include: further ways to scale the Reduce, Substitute and Recycling solutions; ability to achieve 100 per cent collection; green chemistry breakthroughs; and new technological, behavioural and business solutions. For a full list of innovation priorities, see Table 8.

The System Change Scenario requires a substantial shift of investment away from the production and conversion of virgin plastic, into the deployment of new delivery models, substitute materials, recycling and collection infrastructure, which are often less mature/financially viable technologies.

Table 8: Innovation areas that could reduce leakage below System Change Scenario levels

Intervention	Examples of key innovation areas for reduced leakage
Reduce	• Product redesign to packaging-free alternatives. • Further removal of cost, convenience, and solution-readiness barriers for reuse, packaging as a service, and new delivery models. • Systemic approaches such as shorter supply chains, eliminating the need for packaging.
Substitute	• New materials that are bio-benign, ephemeral, lower-cost and/or are coupled to available waste infrastructure for zero leakage. • Improved barrier properties of paper and compostable materials and reduction of paper coatings. • Enhanced deployment of composting infrastructure that accepts compostable packaging.
Collection	• Reaching 100 per cent collection in low-income areas (especially rural, remote, and other low-density areas) for which current technologies have prohibitive costs. • Improving profitability, productivity, and working conditions for the informal sector through technology, tools, and aggregation markets.
Design for recycling	• Enhanced barrier properties for monomaterials. • Design for recycling solutions for multimaterials, such as paper and aluminium laminations. • Household goods made from recyclable monomaterials, or modular products designed for disassembly and recycling.
Sorting and mechanical recycling	• New models for sorting and aggregation of waste (e.g., digital watermarking), including automated sorting in markets without manual sorting. • Scaling and simplification of source separation in collection systems through regulation, education, incentives, and improved standards. • Improved technology to reduce sorting losses, handle higher levels of contamination, or create higher-quality output affordably, particularly for food-grade outputs.
Chemical conversion	• Technology or financing solutions to reach widespread collection of low-value plastic in remote and low-income countries. • Improve process efficiency to increase the naphtha fraction and reduce energy requirements. • Development of technology to allow for a more varied feedstock composition and quality.

The role of innovation

Innovation is a key enabler across all system interventions modelled in this report, in all archetypes and for all plastic categories. Although the System Change Scenario is based on known solutions, innovation is still required to make these solutions more affordable, more scalable, more convenient for consumers, and to further reduce environmental and health impacts. Our model already takes into account assumptions about how average costs of technological solutions decrease over time as a result of increased experience. We assumed a 7 per cent average learning rate (the relative cost decrease of a year-on-year doubling of output) for capital expenditures for formal sorting, and closed- and open-loop mechanical recycling. For relatively new technologies, we assumed a 7 per cent average learning rate for both operational and capital expenditures (see the technical appendix for details). This estimate applies to both plastic-to-plastic and plastic-to-fuel chemical conversion, and to substituting with compostable materials. Additional breakthroughs could improve these costs further and faster than we have modelled.

The enablers of innovation

The enablers of innovation span economic, regulatory, legal, and financing enablers for systemic change, and will require building partnerships and coalitions for innovation, as well as an overall mindset shift over how the problem of packaging is seen.

- **Economic incentives** could be realigned to drive market demand for innovations or increase the financial incentives for incumbents to innovate (e.g., credits, subsidies, Extended Producer Responsibility fees, corporate and government procurement commitments, tax breaks on impact investing), or increasing the penalties for not innovating (e.g., plastic taxes or fees and levies that incentivize waste reduction or help sustainable solutions compete on a cost basis).
- **Regulatory drivers** could include creating or refining the "essential requirements" on the types of chemicals, plastic, and formats put on the market; mandating minimum recycled content; creating elimination, reuse, and recycling targets; incentivizing behaviour change, etc.
- **Efficient funding and financing** require coordinated direction and active innovator support. Thousands of innovations in green chemistry, new materials and chemicals exist at the level of basic scientific research, but transferring them into workable solutions requires infrastructure support, guidance on what the high-priority areas are, and access to capital.
- **Channelling funds** towards the "valley of death" stage (the gap between developing innovations and their commercial application in the marketplace) offers a particular opportunity to rapidly transfer technology and ideas out of labs and universities to reach early commercialization/implementation. These higher-risk investments require early-stage philanthropy, seed funds, impact investing, government grants, patient capital, nondiluted financing (i.e., grant and impact investing), and blended finance.

Notpla sachets are made from seaweed and plants, and are 100% naturally biodegradable.
Notpla

The time is now

Success requires all players to take rapid and concerted action

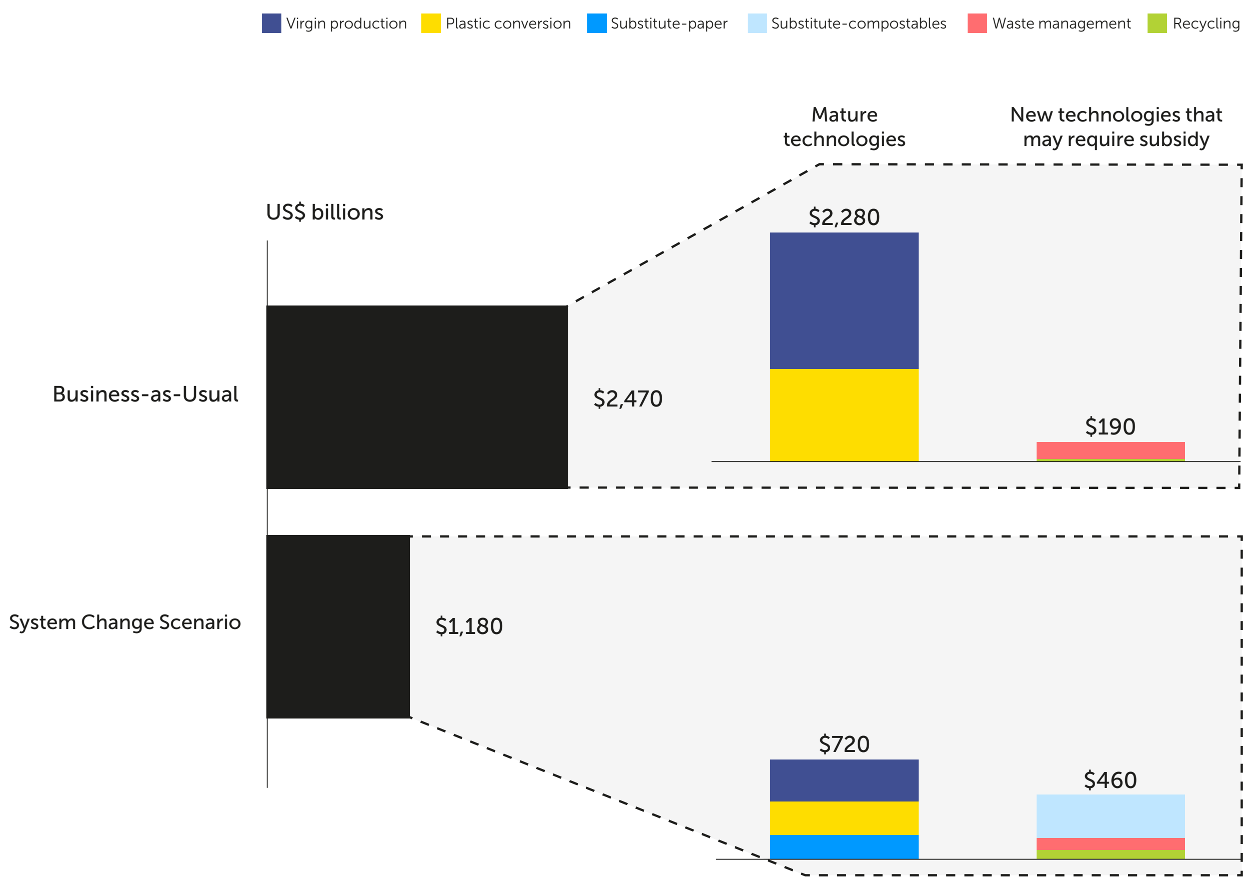
The Warriors of Waste, who are employed by Project STOP, go door to door collecting garbage from the community at Tembokrejo village in Muncar, Indonesia.
Ulet Ifansasti for Huffpost

A substantial transition: investments in the new system are significant, but returns are attractive

The System Change Scenario is economically viable for governments and consumers, but a major redirection of capital investment is needed. Although the present value of global investments in the plastic industry between 2021 and 2040 can be reduced from US$2.5 trillion to US$1.2 trillion, the System Change Scenario requires a substantial shift of investment away from the production and conversion of virgin plastic, which are mature technologies perceived as "safe" investments, into the production of new delivery models, substitute materials, recycling facilities, and collection infrastructure, which are often riskier and less mature technologies. This change will be possible only with government incentives and risk-taking by industry and investors.

Figure 44: Present value of global capital investments required between 2021 and 2040 in different scenarios

The System Change Scenario requires less capital investment than Business-as-Usual, but the investments are riskier



Values in this figure represent the present value of all capital investments needed per scenario between 2021 and 2040.

As Figure 44 suggests, a major challenge for shifting the investment portfolio of the plastic ecosystem is that many technologies are less financially viable or commercially proven than virgin plastic production, so the shift will not happen naturally. The current petrochemical industry also benefits from global fossil fuel subsidies, estimated at US$53 billion in 2017,[228] increasing the challenge of the transition.

Table 9 details the capital investment requirements under the System Change Scenario by activity, technological maturity, and the type of stakeholder who typically funds the investment. All costs are global, in present value terms, and refer to the period of 2021-2040.

Table 9: Total capital investments required under the System Change Scenario according to financial viability

System Change Scenario	2021-2040 investment in billions	Technological maturity	Who pays
Virgin plastic production	US$307B	Mature	Petrochemical industry
Plastic conversion	US$236B	Mature	Petrochemical industry
Formal collection & sorting	US$54B	Mature, yet requires subsidy	Governments
Recycling (mechanical)	US$32B	Somewhat mature	Recycling industry
Recycling (chemical)	US$35B	Not fully mature	Recycling industry
Incineration	US$10B	Mature, yet requires subsidy	Governments
Landfilling	US$20B	Mature, yet requires subsidy	Governments
Paper production	US$174B	Somewhat mature	Paper industry
Compostables production	US$312B	Not fully mature	New industry
Total	**US$1,180B**		

This table describes the present value of capital cost investment for different activities under the System Change Scenario, assuming a 3.5 per cent hurdle rate. It was calculated by quantifying the capacity additions required for each type of activity in this scenario and multiplying by the capital requirements per metric ton of new capacity. The calculation was done separately by geographic archetype and aggregated to the global level, given that waste infrastructure is typically local. Technological maturity was assessed as a high-level estimate for the level of risk involved with different investments. Subsidy refers to activities that require government funding.

From theory to action: Unprecedented and resolute action from all stakeholders is required to stop plastic pollution

As shown in this report, a shift to an integrated system in which plastic is consumed and managed responsibly benefits the environment, economy, and society. To realize the full benefits that could be reaped from this new plastics economy, resolute and collaborative action is needed: across the value chain, between public and private actors, between levels of governments, and across borders. This collaboration is critical because many organizations are willing to act, but only if other actors act, too. For example, a consumer goods company depends on the availability of recycled plastic to increase recycled content levels; recyclers depend on design and clear labelling to increase quantity and quality of feedstock; and investors depend on access to affordable capital. In other words, the success of each organization—and therefore of the system as a whole—depends on the actions of others. This chapter outlines the role of five key stakeholder groups in enabling and accelerating this transition: governments, industry, investors, civil society and consumers.

The role of governments

The changes required under the System Change Scenario are enormous and require massive shifts in the business models of firms creating plastics and their substitutes, large changes in purchasing behaviour and business delivery models of consumer goods companies that utilize plastic as an input to the services and products they provide, significant changes to the recycling and waste disposal industries, and changes in the behaviour of consumers. Although these changes are feasible, they are unlikely to materialize unless governments create significant incentives for more sustainable business models and level the playing field in which currently virgin plastic feedstock has a cost advantage over recycled materials. Although all players have a role, policies that create a clear and stable set of incentives, targets, and definitions are the lynchpin that will make the conditions required under the System Change Scenario possible.

Given the ubiquity of plastics in all aspects of our economic system, and the complexity of the problem, it is difficult to see how the voluntary actions of consumers and companies alone can achieve anything like the System Change Scenario. 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. Regulatory action is essential to drive system shifts across all archetypes, and national and subnational policy leaders can catalyse progress towards the System Change Scenario by: 1) facilitating the transfer of effective policy instruments to new geographies; 2) introducing the new innovative policies that will be required to address this issue at the urgency and scale needed; and 3) improving regulatory governance and investing in policy enforcement and compliance.

One of the most crucial roles that governments (and investors) can play in the coming years will be acting to curb the planned expansion of plastic production. Without this, the supply of large quantities of cheap virgin plastic to the market may undermine reduction and substitution efforts and threaten the economic viability of recycling, while making it even harder to close the collection gap. Table 10 includes illustrative examples of policy instruments that are being used to address plastic pollution around the world. A uniform mix of solutions will not apply across geographies, and the applicability of each solution should be considered within the context of local markets and governance systems. Maritime sources of waste will require a separate set of policies that are not included here, although indicative examples are given in Chapter 2.

Although these changes are feasible, they are unlikely to materialize unless governments create significant incentives for more sustainable business models and level the playing field in which currently virgin plastic feedstock has a cost advantage over recycled materials.

Flags fly outside U.N. headquarters in New York.
Alex Kazmierski/Adobe Stock

Table 10: Illustrative examples of policy instruments

Interventions by policy group	Reduce & Substitute	Collection	Recycle	Dispose	Microplastic
Producer accountability					
Extended Producer Responsibility (EPR) for take-back, recycling, and plastic disposal, with targets and fee modulation	●	●	●	●	●
Environmental pollution liability	●	●	●	●	●
Direct control regulations					
Plastic product bans (single-use bags, cups, other products, and microplastic ingredients)	●				●
Regulation on polymer types and product designs (D4R, PVC/PS ban, pigments, additives)	●	●	●		●
Design & labelling requirements (recycled content, durability, reuse, repairability, recyclability, textile/tyre design for microplastic avoidance)	●		●		●
Statutory targets (e.g., landfill, collection, reuse, recycling, recycled content)	●	●	●	●	
Regulatory supply chain standards for prevention of pellet loss					●
Waste or recycling trade regulations			●	●	
Market-based instruments					
Taxation on virgin plastic product and/or hard-to-recycle items, levies on single-use plastic	●	●	●		●
Increased landfill tipping fees and fees for waste to energy	●	●	●		
Deposit-return schemes, "pay as you throw" schemes		●	●	●	
Plastic recycling credit trading scheme		●	●		●
Removal of subsidies to plastic production and rationalization of trade tariffs	●		●		
Government support programs					
Subsidized plastic recovery (collection, sorting, recycling rebates)	●	●	●	●	
Public procurement of reusable items or suitable substitutes	●				
Funding for plastic alternatives R&D	●				
Incentives for increased personal collection, sorting and recycling efforts		●	●	●	
De-risking and blended-finance mechanisms to lower capital costs	●	●	●	●	●
Funding consumer education and training	●	●	●	●	●

To be effective, policy solutions need to be appropriately enforced, and their outcomes amplified through better integration across government departments. Governments also have a critical role to play in developing the funding mechanisms to support adequate waste management infrastructure—especially collection, sorting, and disposal—as shown in Figure 44.

The role of business

Businesses have a critical role to play in achieving the System Change Scenario. The specific actions required by business depend on where they exist across the supply chain, and whether they are in high-income or the middle-/low-income economies. Although there are considerable risks to businesses across all sectors, there are also commercial opportunities waiting for those ready to embrace change and position themselves as leaders in the new materials, products, and delivery systems that will thrive in a world with near-zero plastic pollution.

Understanding the risks

Businesses that do not act risk reductions in the value of their assets. Some of the key drivers of these risks, particularly to single-use plastics, are detailed in Figure 45.

Resin producers and converters

Figure 46 shows how feedstock for plastic services will be sourced over time if the System Change Scenario is implemented. It illustrates the dramatic shift from a world in which 95 per cent of plastic utility is made from virgin plastic to a world in which, by 2040, 43 per cent is sourced from virgin plastic. This represents an 11 per cent net reduction in the absolute metric tonnage of virgin plastic relative to 2016.

Our model also shows that under the System Change Scenario, we would hit peak virgin plastic production by 2027. Such a rapid global transition could leave significant petrochemical assets stranded, many of which are expected to come online by the mid-2020s. Resin producers and converters could therefore:

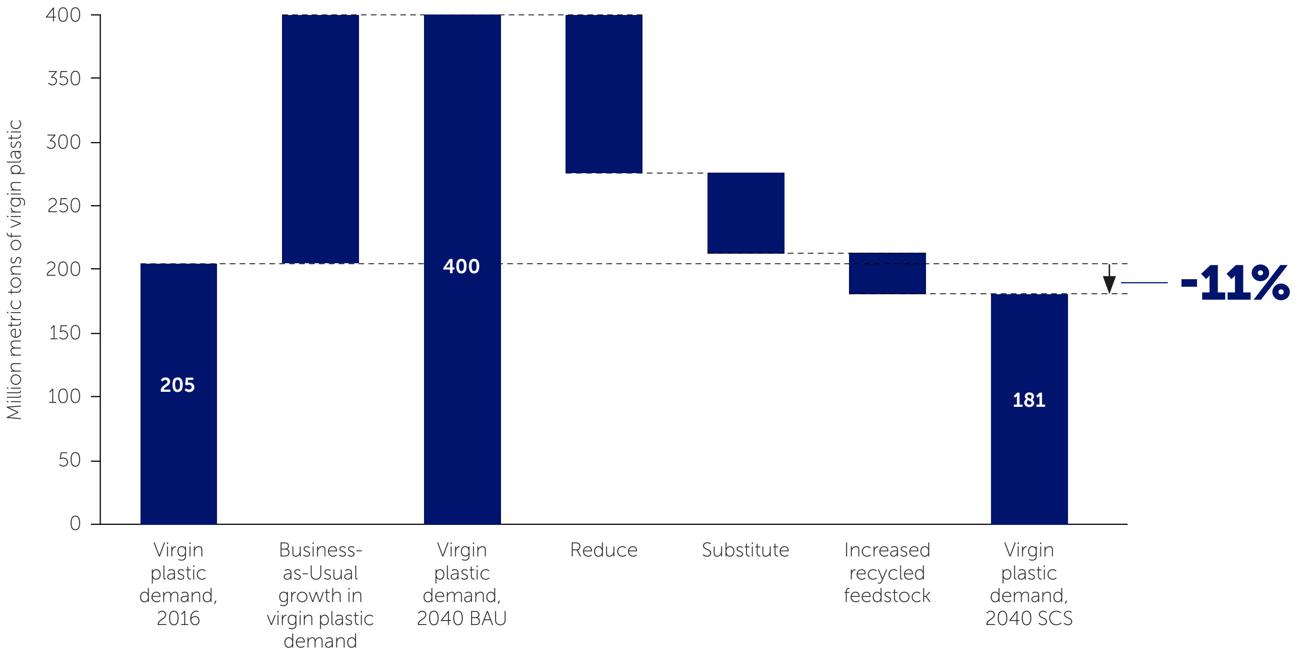
- Embrace the new system by preparing for a low-virgin-plastic world by:
  - Reducing investment in virgin plastic production plants—which are likely to become stranded—now.
  - Entering new value pools, such as recycling, more aggressively.
  - Working with chemical and mechanical recycling companies to incorporate recycled content into processes.
  - Designing out excess material and weight and eliminating avoidable packaging.
  - Being early movers and advancing certification and regulation on recycled content, food safety, and recycling definitions.
- Radically innovate for more recyclable and recycled plastic by:
  - Developing new materials, barrier coatings, and recycled content tracking systems.
  - Proactively producing products that meet recycling specifications without sacrificing product safety to pre-empt the risk of expected regulatory shifts against nonrecyclable plastic.

Figure 45: Potential future trends and challenges for single-use plastic and plastic packaging

Attitudes and policies	Waste and recycling system
Societal trends continue: • **Consumer concern grows,** increasing demand for “plastic free” solutions (following Europe) • **NGO activism grows** and targets major brands and plastics producers • **Government regulation spreads** on Extended Producer Responsibility and single-use plastics bans (following European Union, Africa, Chile, India, California) • **Health effects of microplastics in food chain and air** is becoming a focus for research and activism • **Waste exports further limited** by unilateral action (following China, India) or policy (Basel convention)	Growing system challenges: • **Domestic recycling struggles** on capacity and economics; sorted recyclables go to landfill or incineration • **Recycled content demand is frustrated** by supply, quality, and approval challenges • **Scepticism on 100% recyclability** claims as recycling systems do not keep up • **Landfill access limited and taxed highly;** landfill costs and externalities seen as a subsidy for poor design • **Incineration increasingly opposed** on cost, air quality, climate impact, low energy yield, lock-in • **Higher cost of waste management is passed on to companies** (following United Kingdom, European Union) and differentiated on recovery/recycling cost-flexible and multimaterial penalized

Figure 46: Virgin plastic demand under BAU and the System Change Scenario

By 2040, virgin plastic demand could fall by 11 per cent relative to 2016 in the System Change Scenario



Today, 95 per cent of plastic demand is fulfilled by virgin plastic. By 2040, we expect the demand for virgin plastic to reduce by 11 per cent relative to 2016 due to the significant reduction by Reduce and Substitute as well as an increase in recycled feedstock. This includes only plastic in municipal solid waste.

- **Mitigate the risk of products leaking into the environment to lessen their business risk by:**
  - Reaching 100 per cent collection and ensuring that products do not end up as plastic pollution.
  - Voluntarily paying for collection in geographies where producer responsibility is not mandated.
  - Operating Packaging Recovery Organizations (PRO) and enhance monitoring and control of pellet spillage throughout the supply chain.

Brand owners, fast-moving consumer goods (FMCG) companies, and retailers

Brands are under mounting international scrutiny to address the plastic pollution crisis. There are huge opportunities for companies that can translate today's costs into tomorrow's new markets. But seizing these opportunities, many of which require new business models, may require a significant shift in mindsets and leadership. Brand owners, FMCGs and retailers could:

- **Lead the transition to new delivery models by:**
  - Committing to reduce one-third of plastic demand through elimination, reuse, and new delivery models by embracing product redesign and supply chain innovations.
  - Signalling a shift in demand towards new delivery models, refill and alternative packaging materials to disrupt and catalyse investments across the entire value chain.
  - Enhancing disclosure to enable better tracking of materials and units produced, used, and sold.
  - Advancing the global uptake of innovative models by leveraging global reach and R&D budgets to facilitate change across geographic archetypes and industry sectors.
  - Working 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 by:**
  - Redesigning products and packaging to more ambitiously reduce and substitute away from plastic.
  - Restricting small formats, avoiding pigments or additives, and limiting production to high-value monomaterials, with intuitive labelling linked to local recycling capabilities.
- **Facilitate consumer action and provide accessible, cost-effective alternatives by:**
  - Creating products that are 100 per cent reusable, recyclable or compostable.
  - Facilitating new delivery models and integrating these in-store or through home deliveries for reuse.
  - Incentivizing shifts in consumer behaviour and consumption patterns by aligning marketing efforts towards more circular solutions, leveraging product placement, and improving labelling for recycling.
  - Leveraging 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.

  - Harmonize and simplify recycling labelling and help educate consumers on what and how to recycle. To be effective, this step will require competitors to collaborate and agree on industry-wide standards.

In the face of rising consumer pressure and policy action, some businesses are already showing that they can commit to plastic reduction targets and successfully deploy alternative delivery models.[229] Businesses should look to adopt more granular decision-making tools when choosing the appropriate material for a particular application and country, using tools that analyse not only GHG emissions, but also the other environmental and health impacts of a particular material choice. It is vital that they carefully consider what packaging material is the right choice for a particular product and region, whether there are alternative delivery mechanisms better suited to the product application, the collection/recycling rate and risk of leakage to the environment, and how the business model can incentivize collection, reuse, and recycling. With more careful assessments of delivery mechanisms and materials on a case-by-case basis, businesses, with the support of policy measures, could play the deciding role in reducing plastic entering the environment.

Waste management (collectors, sorters, and recyclers)

Under the System Change Scenario, demand for recycled content is expected to grow by 2.7 times (see Chapter 2, System Interventions 3-6), 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:

- Scale up and improve collection to reduce plastic pollution and secure feedstock for recycling by:
  - Working with the public sector to rapidly improve efficiency and convenience in collection, scale up at-source waste separation, and improve the logistics and economic viability of waste collection in difficult-to-reach areas.
  - Developing and integrating new matchmaking tools among waste producer, (formal and informal) collector, recycler, and end user, creating targeted secondary markets for recycled materials and incentivizing more demand-driven collection.
  - Employing new business models to drive up collection rates, including new models for aggregation and decentralized management of waste. Forward-looking companies are already piloting business models that incentivize consumers to collect and separate at source by providing them with a share of the value of the collected product.
- Facilitate source separation in collection systems by:
  - Using incentives and improved standards aimed at decreasing contamination and maximizing recycling yields.
  - Collaborating with producers/retailers to create standardized labelling in line with local recycling capabilities to maximize consumer participation.
  - Integrating waste workers in waste collection (particularly in low middle-income and low-income countries).
- Reduce the risk of direct discarding of plastic waste into waterways by:
  - Combining existing technological innovation and regulatory oversight to reduce deliberate dumping.
  - Using new developments in telemetry to allow tracking of waste collection vehicles.
- Scale up and expand recycling systems by:
  - Adapting their practices to accommodate and capitalize on the massive material shifts in the supply chain.
  - Expanding their separate organic waste treatment capacity and ensuring that it accepts compostable packaging, as well as building paper recycling capacities that accept coated paper.
  - Expanding infrastructure capacity to enable the recycling of waste locally or regionally.
- Improve efficiencies in the new waste system through technological improvements by:
  - Improving sorting and separation technologies that reduce losses and create a higher-quality, safer output.
  - Developing and scaling up chemical conversion technologies to meet the growing demand for recycled content in food-grade applications.
  - Advancing certification and regulation of recycled content.
- Scale up and improve wastewater management in households and textile production and road runoff treatment:
  - Establishing mandatory treatment protocols for textile production wastewater to tackle microplastic removal and safe disposal.
  - Expanding connection of households to wastewater treatment systems.
  - Expanding and improving road runoff systems to safely capture and dispose of microplastic released from tyre wear.

Paper and compostable material manufacturers

In the System Change Scenario, we estimate that paper, coated paper and compostable materials could meet 17 per cent (or 71 million metric tons) of the plastic utility demand by 2040. This scenario offers a significant opportunity for manufacturers to:

- **Capitalize on growing business opportunities** by developing alternative formats and materials that can meet the requirements of the plastic they would be replacing. Innovations in product design and material need to be thoroughly studied and tested so that the introduction of any new product or material to the market works in circular systems and does not generate new environmental and health problems. These new materials must meet national certifications according to the end-of-life processing technologies that exist in the country, and labelling should be clear for the consumer.

- **Improve resource efficiency and paper recycling capacity** to meet the growing demand in this sector. It is important that the materials are sustainably sourced, and—where possible and safe—sourced exclusively from recycled content or, in the case of compostable materials, waste by-products. Suppliers need to work with certifiers and roll out recycled input wherever possible to prevent material substitutes for packaging becoming a driver of deforestation or land use change.

The role of investors and financial institutions

Investors should seek out opportunities in the new plastic economy and urgently address 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.

As shown in Figure 44, we estimate that the total investment requirements from 2021 to 2040 under the System Change Scenario are about half those required under BAU, but the portfolio of investments is completely different. Although it may appear that investments under BAU (primarily virgin plastic production and conversion plants) are less risky, as they are directed at mature technologies, supportive policies, and established markets, analysis in this report shows that the risks may be significantly higher than is currently understood by financial markets as policies, technologies, brand owners, and consumer behaviour all continue to shift towards a new, more circular plastics economy. But it is important to acknowledge that many of the new investments required under the System Change Scenario—mainly, alternative materials and new delivery models—have risks associated with them, namely market, technology, and regulatory risks.

Investment into the new value chain could come with many co-benefits, including cost savings for governments and consumers, health improvements, GHG emission cuts, and increased job creation relative to BAU. So why is attracting finance for this space often challenging? One reason is the paucity of investable projects and perceived poor risk/return profiles. Investors can seek to overcome this challenge by:

- **Focusing on developing a robust investment pipeline**
Arguably there is sufficient capital to fund proven technologies and business models (at least in the high-income economies). 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 startups 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 should help scale innovation.

- **Developing 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 (by development agencies, donors, climate funds, or philanthropy) to mitigate investor risk or to develop pipelines through project preparation facilities and technical assistance grants.

- **Analysing the commercial feasibility of various business models**
A thorough review of credit profile, new technologies, and commercial market potential would help demonstrate the attractiveness of the solutions proposed under the System Change Scenario compared with traditional products and infrastructure.

- **Incorporating "plastic risk" in financial and environmental, social, and governance (ESG) assessments**
As we have shown in this report, the valuation of current plastic assets does not account for the fact that the expected industry growth is not aligned with the clean ocean agenda, commitment to a 1.5°C world, emerging societal and consumer trends, or changing government policies—all of which may have significant implications for financial performance. It is time for analysts and investors to account for these sector-specific developments—or "plastic risks"—in their company valuations. Investment banks, sustainability indices, and credit/ESG rating agencies could all play a role here. For example, there are already examples of credit ratings being punitive towards plastic packaging companies on the basis of increasing demand for recycled over virgin material and possible clean-up costs.[230] A longer-term and more holistic approach to risk and impact trade-offs could be used, ensuring that plastic risk is not replaced by other risks, such as emissions and land use change.

As highlighted in the previous section, investments in the System Change Scenario need to cover formal new delivery models, substitute materials, collection and sorting, recycling (mechanical and chemical), incineration, and landfilling. These different types of plastic assets are all at various stages of development (e.g., R&D or growth stage)—and each requires different forms of financing (e.g., venture capital, growth equity, corporate debt, project finance or grant support). The table below provides an overview and examples of the different types of investors and sources of funding with roles to play.

Table 11: Various types of investors and sources of funding

Type		Description
Public	Government funding	National or subnational/municipal (through public budgets)
	Donor capital	Through ministries or development agencies (through official development assistance)
	Development banks	Typically provide commercial rate lending or equity finance (multilateral or bilateral)
	Climate facilities	Typically provide grants and technical assistance (often in the form of trust funds managed by development banks)
Private	Philanthropy	Typically for grants and technical assistance or other form of catalytic capital (programme-related investment and mission-related investment)
	Impact private equity/blended funds	For various stages of development (seed, venture capital, growth, etc.). Can incorporate blending of public/philanthropic capital to mitigate risk
	Commercial finance	Providing debt/bilateral lending, corporate finance advice
	Institutional investors	Representing pension funds, insurers, or sovereign wealth funds (typically public security only or large infrastructure)

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 and citizen science. In the context of plastic pollution, different factions of civil society are occupying all of these roles and, in particular, helping direct the focus of governments and corporations towards upstream action. Civil society will be vital in achieving each of the eight system interventions documented in this report and facilitating the transition to a System Change Scenario, including through the following actions:

- **Research and monitoring**
  Academic scientists and citizen science programmes are essential for building the evidence base for policy and corporate action through assessment of the distribution, scale, and impacts of plastic production and pollution. Research and monitoring should be harmonized across countries and regions to better identify trends, leakage routes to the ocean, and the impacts of plastic use and pollution on biodiversity and health. Microplastics, contaminants, and maritime sources are all areas that should be prioritized for further research.

- **Incubation and acceleration of 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 System Change Scenario 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.

- **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 would help build even stronger, more informed consumer engagement on a practical level and support the shifts necessary to transition to the System Change Scenario.

- **Grass-roots community action**
  Flagship zero-waste communities and cities have not only directly reduced the production of plastic waste and leakage to the environment, but 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 transition to a low-plastic future is impossible without civil society; it is the key to both embracing deep reductions in plastic use and supporting governments and businesses in achieving a circular economy.

The role of consumers

The changes modelled under the System Change Scenario entail significant changes to consumer habits and behaviour. The scenario shift towards less single-use plastic, 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. For example, policies should be in place to drive reductions in avoidable plastic across the board and ensure full and easy access to low-waste products, business models and waste services, rather than placing the burden on consumer choice.

Incentive structures are likely to be crucial drivers if the required behaviour changes are to reach mass scale. These incentives could include "pay-as-you-throw" measures, deposit-return schemes, regulatory changes to make behaviour such as waste separation mandatory, or changes in product pricing structures (e.g., plastic bag charges and single-use packaging fees, taxation, or subsidies) so that lower-waste and more circular solutions are also cheaper for customers. To make the transitions faster and smoother, businesses and governments should work together to ensure that new systems are designed with usability, convenience, and affordability in mind.

Consumer demand has played and should continue to play a catalytic role in accelerating the change. For example, consumers expressing preferences for more sustainable products or services helps 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 crisis. There are already strong signs of high consumer demand for products with less plastic packaging,[231] more recycled content,[232] and sustainably branded products,[233] which could translate into more buying choices.

Education, incentives, and clear labelling will be key to delivering the outcomes modelled in the system interventions, both so that consumers are guided more often to do the right thing in terms of their purchasing and recycling behaviours, and so that consumer pressure—alongside advocacy from civil society groups—continues to catalyse change by businesses and policymakers.

Regional priorities: applying different solutions for different geographies

Our model results suggest, unsurprisingly, that different archetypes require different solution sets. This finding stems from the fundamentally different context and jumping-off points that different regions of the world are starting with, specifically, different waste composition, policy regimes, labour and capital costs, infrastructure, population demographics, and consumer behaviour.

For the purpose of this section, we have grouped the eight geographic archetypes into three groups and have identified the priority system interventions that each of them should implement if they are to achieve the outcomes modelled in the System Change Scenario. Figure 47 highlights the most urgently needed interventions in each group of archetypes, based on our model.

High-income countries

The most relevant system interventions for high-income countries include:

- **Deal with microplastic pollution**
  In high-income countries, microplastics are the leading driver of leakage; therefore, microplastic emissions should be a top priority when looking for solutions.
- **Lead innovation and policy on reducing and substituting plastic and minimizing microplastic emissions**
- **Increase separation at source and recycling**
- **Reduce exports to the middle-/low-income countries and deal with plastic waste locally (or regionally)**
- **Address maritime sources of leakage**

Upper middle-income countries

The most relevant system interventions for upper middle-income (UMI) countries include:

- **Significantly reduce and substitute plastic**
  We estimate that UMI countries have the potential to cut 30 per cent of their plastic consumption by 2040 (relative to BAU) by reducing avoidable plastics and shifting to reuse and other new delivery models (detailed in System Intervention 1) and to substitute 17 per cent of their plastic consumption (relative to BAU) with paper, compostable materials, or other substitutes (detailed in System Intervention 2).
- **Expand collection**
  Expand collection in urban areas from 85 per cent to 95 per cent by 2040 and in rural areas from 45 per cent to 50 per cent (detailed in System Intervention 4).
- **Invest in sorting and recycling infrastructure**
  Grow mechanical recycling output by 2.5 times (from 10 million metric tons per year to 25 million metric tons per year) by 2040 (detailed in System Intervention 5), which will require significantly increasing the share of separation at source and collection for recycling. A growth in plastic-to-plastic chemical conversion from trivial amounts today to 4.3 million metric tons per year by 2040 would facilitate the processing of residual low-value plastic waste that has not been eliminated or substituted (detailed in System Intervention 6).
- **Restrict plastic waste imports**
  Reduce plastic waste imports by 70 per cent by 2030 and 90 per cent by 2040 to ensure that local infrastructure is used to handle local waste.

Figure 47: Priority interventions for different geographic archetypes

By 2040, virgin plastic demand could fall by 11 per cent relative to 2016 in the System Change Scenario

	1 High-income economy	2 Upper-middle income	3 Lower-middle income	4 Low-income economy
U Urban areas	Archetype 1U	2U	3U	4U
R Rural areas	1R	2R	3R	4R

Top solutions for high-income countries:

- Address microplastic leakage
- Lead innovation and policy on reduce and substitute
- Increase separation at source and recycling
- Reduce export to low-income countries
- Address maritime sources of leakage

Top solutions for urban archetypes in middle-/low-income countries:

- Invest in formal collection
- Invest in sorting and recycling infrastructure
- Significant reduce and substitute
- Design for recycling: Increase share of high-value plastic
- Reduce post-collection leakage
- Ban plastic waste imports

Top solutions for rural archetypes in middle-/low-income countries:

- Heavily invest in collection
- Support informal sector by designing more value into material
- Significant reduce and substitute
- Reduce post-collection leakage

Today, 95 per cent of plastic demand is fulfilled by virgin plastic. By 2040, we expect the demand for virgin plastic to reduce by 11 per cent relative to 2016 due to the significant reduction by Reduce and Substitute as well as an increase in recycled feedstock. This includes only plastic in municipal solid waste.

Lower middle-income countries

The most relevant system interventions for lower middle-income (LMI) countries include:

- **Significantly reduce and substitute plastic**
  The scale of waste infrastructure is insufficient to deal with the large volumes of waste, and this problem is expected to become worse as plastic waste continues to grow faster than the ability to expand waste infrastructure. Reducing the amount of waste in the system and, where appropriate, substituting plastic with other materials that are easier to deal with is essential. We estimate that 30 per cent of plastic can be reduced and 17 per cent can be substituted in LMI countries by 2040, compared with BAU

- **Invest in formal collection**
  Collection rates in this archetype are relatively low, and raising them is a critical component in addressing plastic pollution. According to the World Bank, average collection rates in urban areas are 71 per cent and in rural areas 33 per cent. Following a similar path that high-income countries have followed during their development can yield collection rates of 90 per cent and 50 per cent in urban and rural areas, respectively, by 2040.

- **Invest in sorting and recycling infrastructure**
  Today, almost the entire recycling industry relies on the informal sector and there is very little separation at source. Under the System Change Scenario, with significant investment in sorting and recycling infrastructure, we estimate that mechanical recycling can grow its recycled output from 8.9 million metric tons per year in 2016 to 17.6 million metric tons per year by 2040. In addition, a new plastic-to-plastic chemical conversion industry could be scaled to produce 3.4 million metric tons per year of recyclate by 2040.

- **Reduce post-collection leakage**
  According to World Bank data, only 4 per cent of collected plastic in this income group is managed in a way that it does not leak. Increasing this share to 50 per cent by 2040, largely by replacing dumpsites with managed landfills, can reduce vast amounts of plastic leakage to the ocean.

- **Restrict plastic waste imports**
  By limiting plastic waste imports from other regions, LMI countries can ensure that their waste infrastructure is directed towards handling local waste.

Low-income countries

The most relevant system interventions for low-income (LI) countries to achieve a System Change Scenario include:

- **Massively expand collection**
  Our System Change Scenario model estimates that collection in LI countries could grow in urban areas from 48 per cent to 90 per cent and in rural areas from 26 per cent to 50 per cent by 2040.

- **Support the informal sector by choosing materials that have higher inherent value**
  The majority of plastic in LI countries has very low inherent value and is hard to recycle. By shifting to materials with higher inherent value, the large informal sector can be supported to help reduce ocean plastic pollution.

- **Significantly reduce and substitute plastic**
  As in other archetypes, plastic waste in LI by 2040 will significantly outpace local waste management infrastructure. Our analysis shows that it is possible to reduce 30 per cent of plastic by 2040 (relative to BAU) and to substitute 17 per cent of plastic by 2040 (relative to BAU). Details can be found in System Interventions 1 and 2.

- **Reduce post-collection leakage**
  According to World Bank data, only 3 per cent of collected plastic in this income group is managed in a way that it does not leak. Increasing this share to 50 per cent by 2040, largely by replacing dumpsites with managed landfills, is essential to reducing leakage.

The cost of waiting: delaying implementation of the system interventions from 2020 to 2025 would add 80 million metric tons more plastic to the ocean

All elements modelled under the System Change Scenario exist, or are already under development, today and now need to be scaled up quickly. An implementation delay of five years—even if then carried out at the same level of ambition and effectiveness—could result in an additional ocean plastic stock of ~80 million metric tons. Moreover, delays in implementing the system interventions could have knock-on effects for the rest of the plastic system, knocking the world off its critical path towards—ultimately—near-zero leakage. The next few years are crucial for implementing an ambitious set of "no regret" actions, so that key measurable milestones can be met by 2025. Only by achieving key milestones in the short term can the groundwork be laid for implementing the further solutions required in 2030-2040.

It is not the lack of technical solutions that is preventing us from addressing the ocean plastic pollution crisis, but rather inadequate regulatory frameworks, business models, and funding mechanisms. Achieving the level of ambition laid out in the System Change Scenario requires triggering key changes in 2020-2022, through regulatory frameworks, new business models, massive infrastructure investments and funding mechanisms, and innovation.

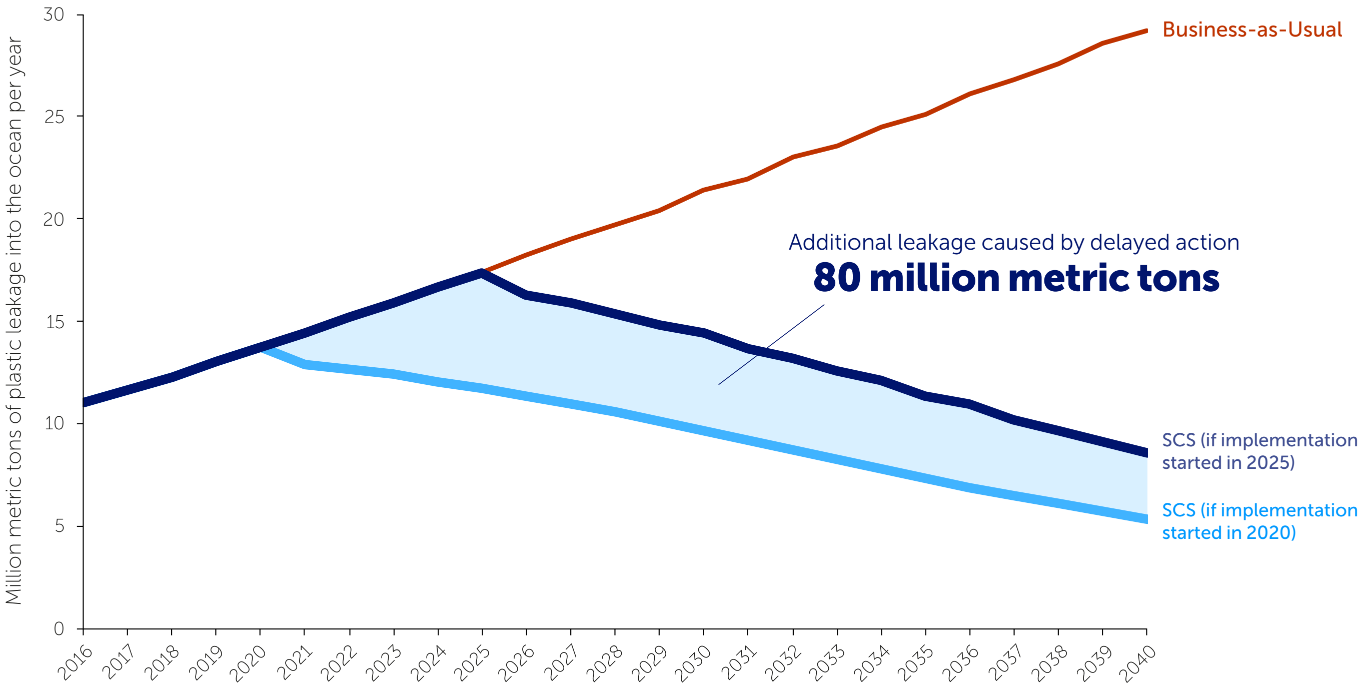
To be on track to achieve about an 80 per cent reduced leakage by 2040, key milestones for the next five years should be established and monitored for attainment. Potential milestones for 2025, identified in the System Change Scenario, are presented in Table 12.

There is a logical staging, or order of actions, that should be achieved before other intervention solutions can be implemented. Catalysing this scale of change requires pursuing "no regrets" actions in the next two years, which we call Horizon 1 (see Figure 49). These measures include stopping the production of avoidable plastic, educating or incentivizing consumers about reuse, improving labelling, and testing innovations such as new delivery models. This period is also critical for sending clear policy and market demand signals that will determine the future direction of travel, such as voluntary or regulatory commitments on reducing plastic, increased collection coverage, 100 per cent recyclable packaging, and minimum recycled content goals. Now is also the time to set up large-scale funding and investment initiatives, ready to scale up new delivery models, waste collection services, recycling infrastructure, and innovations such as new packaging materials and tyres that produce less microplastics.

Assertive action in "no regrets" Horizon 1 will set the stage for Horizon 2, to "catalyse" changes by 2025, including large-scale financing and implementation of current solutions, and scaling of innovative alternatives. By 2030, the "breakthrough" Horizon 3 could then be reached, in which all incentives in the system are aligned towards radically reduced leakage, and the next phase of innovative solutions is being rolled out.

Figure 48: Implications of delaying the implementation of the System Change Scenario for plastic leakage to the ocean

Delaying the implementation of the System Change Scenario by 5 years may increase plastic pollution in the ocean by ~80 million metric tons



Red and light blue lines are modelled scenarios: Business-as-Usual and System Change Scenario, respectively. Dark blue line is a simple illustration of the possible impact of five years' delayed action, if: Business-as-Usual leakage is realized between 2021 and 2025; in 2026, the absolute mass of leakage reduced from BAU is the same as System Change Scenario reductions in 2021; 2027 leakage reduction is the same as System Change Scenario reductions in 2022, etc. The cumulative impact of this illustration of delayed implementation is shaded light blue and sums to a cumulative ~80 million metric tons of additional leakage between 2021 and 2040 as compared with the System Change Scenario.

Table 12: Milestones reached in the System Change Scenario by 2025

Intervention	Proposed milestone for 2025
Reduce and substitute	**10 per cent reductions and substitutions achieved**, capping plastic waste generated at 259 million metric tons per year globally (i.e., 91 million metric tons in HI and 168 million metric tons in LI/LMI/UMI) before decreasing by 2040. In particular, by 2025 flexible plastic waste should be capped near 102 million metric tons globally to ensure that the reductions represent a genuine decrease in the number of items rather than "light-weighting" from a more recyclable rigid to lighter, less recyclable, and higher-leakage flexible packaging.
Design for recycling	Switch **25 per cent of multimaterial sachets/multilayer plastics** and 2.5 per cent of household goods to monomaterials by 2025.
Collect and sort	**Collection service roll-out in middle-/low-income countries increased to 69 per cent,** compared with today's 63 per cent, including through the integration of waste pickers into the municipal waste management systems.
Mechanical recycling	**Growth of recycled content to at least 30 per cent** in plastic products.
Chemical conversion	**Chemical conversion capacity grows 2.4 times** to reach the scale required by plastic-to-plastic chemical conversion, contingent on reductions in associated GHG emissions.
Microplastics	**10 per cent reduction of average kilometres driven per capita in passenger cars.** **10 per cent reduction of tyre loss rate** for passenger cars by switching to more durable tyres. **Pellet losses reduction of 15 per cent by minimizing losses from plastic handling facilities** through measures such as installing improved machinery and drain filters.

Figure 49: Three time horizons, illustrating the actions that could be taken in stages to achieve the System Change Scenario

1 2020-2022: Horizon 1 *"No Regrets"*	2 2025: Horizon 2 *"Catalyse"*	3 2030: Horizon 3 *"Breakthrough"*
• **Eliminate overpackaging and avoidable plastic** use, e.g., product bans, voluntary corporate commitments. • Curb further expansion of **virgin plastic production.** • Enable **consumer behaviour change** through improved labelling, economic incentives, and customer communications. • **Test delivery innovations**, e.g., reuse-refill and new delivery models. • **Design current packaging and products for recycling** and introduce standards, Extended Producer Responsibility, and minimum recycled content commitments. • Invest in **collection infrastructure** and establish policy incentives, e.g., deposit-return schemes, statutory targets. • **Commit to financing** the transition, signalling a business opportunity for innovators. • Implement measures to address **microplastic sources**, e.g., bans on microplastic ingredients, mandatory supply chain standards to eliminate pellet loss.	• **Ensure convergence and collaboration** among government and industry leaders to overcome paralysis on differing visions. • Rapidly scale up **system innovations** including new delivery models (reuse-refill), reverse logistics, incentives for packaging recovery. • **Innovate to find new or improved materials and technology** to increase value after use or expand frontiers of compostable and bio-benign materials. • **Secure large-scale investment for waste and recycling systems** to catalyse improvements and ramp up implementation. • **Increase statutory targets** to drive continued progress (e.g., collection, reuse, recycling, recycled content targets). • **Streamline** polymer types and product designs to facilitate reuse and recycling. • Innovate in **textile** and **tyre design.**	• **Expand system innovations globally** (e.g., reuse, new delivery models, bio-benign substitutes, measures to minimize microplastic emissions). • **Achieve a value-driven system** for recovery and recycling of packaging and use of plastic waste as feedstock-based on enhanced material value and policy innovation. • **Align commercial benefits** for companies that navigate the circular economy opportunity with new business models based on reuse. • **Provide packaging as a service** based on reuse, with innovative financing and material leasing models.

If early milestones are not met, knock-on and snowball effects for other parts of the system could occur due to co-dependency effects. Examples of co-dependencies between interventions include:

- Delaying making plastic reductions and substitutions until 2025 places extra annual burden onto waste infrastructure to 2040. This could mean businesses and consumers become accustomed to higher plastic use rather than leapfrogging towards a lower-waste world, with increased effort required to bring production and consumption back down, and greater risk of stranded assets. It also means that there is more mass to be collected, redesigned for recycling, and processed each year after that.
- Delaying design for recycling measures would create more losses from mechanical recycling by 2040, with an associated drop in recycling profitability in 2040 per metric ton collected. This outcome, in turn, decreases the financial incentives behind both informal and formal sector collection for recycling and could slow the pace of building recycling capacity.
- Delays to expanding collection means additional uncollected waste annually to 2040, which is not available as feedstock for recycling plants and which either leaks to the environment or is burned illegally, driving up GHG emissions and other toxins.

There are also hard limits on how fast change can happen, for policy, scaling new infrastructure, and consumer behaviour. Examples of time lag effects include:

- Pioneer countries and regions adopting and testing new policies today so that late adopter countries can follow suit.
- Implementation timelines, between passing a policy and entering into force, or investing in infrastructure, and that infrastructure coming online.
- Lags between when new products become available and when they replace the stock of plastic currently in use, such as selling more reusable and recyclable packaging, more durable tyres, or clothing with lower microplastic shedding rates.

- Early-stage reuse and new delivery models that need piloting and refinement now so that the best models emerge by 2025, then have time to reach the mass market.
- Limits to how fast consumer paradigms can be shifted from first adopters to mass uptake in how we use packaging, consume and shop, and segregate waste.
- Improving technologies today—for better-performing substitute materials, more recyclable plastic products, improved sorting, etc.—to avoid retrofitting and stranded assets and so that new sustainable supply chains can be built.
- The "lock-in" effect means the longer that society continues on the BAU path, the harder it is to implement disruptive innovations.

These time factors highlight both the urgency, and the opportunity, of acting early to scale all system interventions, and avoid delays, higher costs, and increased ocean plastic pollution later.

Conclusion

"Breaking the Plastic Wave" is not about fighting plastic, it is about fighting plastic pollution. And yet we must recognize that although the scale-up of recycling and waste management is critically needed in many parts of the world and is the cornerstone of a circular economy, these efforts alone will not be enough to avoid plastic pollution within budgetary and political constraints at the current levels of plastic production—let alone the expected growth. Even if it were possible, the associated GHG emissions from plastics in 2040, 1.6 GtCO_2e, would nearly double compared with 2016, and could account for 15 per cent of the forecast allowable emissions budget under the IPCC's Representative Carbon Pathway 2.6, a climate change scenario resulting in 1.5°C warming by 2100. Reduction—through elimination, reuse, and new delivery models—and appropriate substitution are essential to achieving a system change and stopping plastic leakage into the ocean.

This report outlines a feasible way to radically reduce the amount of plastic entering the ocean. The mounting challenge of plastic pollution threatens the health of our ocean, upon which so many lives and livelihoods depend. And like the response required to tackle any global threat, effectively stopping plastic from leaking into the ocean requires vast coordination, increased resources, and close collaboration among governments and industry, as well as the ongoing vigilance and engagement of citizens and communities.

Achieving the ambitious changes envisioned under the System Change Scenario would require governments to incentivize more sustainable business models based on the reuse of materials, and realign incentives that currently give virgin plastic feedstock an advantage over recycled secondary materials. They would also need to enact ambitious policy measures across the plastics value chain to foster innovation. Industry would need to remove avoidable, single-use and hard-to-recycle plastic from the market, invest in material and business model innovation, and join with governments to help finance waste collection and sorting. Public-private collaborations would be required to set standards on materials, formats, reuse, and recyclability. And the management of this progress would be critical.

Unless the plastics value chain is transformed in the next two decades, the compounding risks for marine species and ecosystems, our climate, our economy, and our communities will become unmanageable. But alongside these risks are unique opportunities for governments, businesses, and innovators ready to lead the transition to a more sustainable world, with circular business models and new sustainable materials.

Breaking the wave of ocean plastic pollution is a challenge that respects no boundary: It affects communities, businesses, and ecosystems in both the high-income and middle-/low-income geographies. Businesses, governments, investors, and civil society should aspire to a shared near-zero leakage vision and commit to ambitious, concrete steps towards achieving this critical objective.

Unless the plastics value chain is transformed in the next two decades, the compounding risks for marine species and ecosystems, our climate, our economy, and our communities will become unmanageable. But alongside these risks are unique opportunities for governments, businesses, and innovators ready to lead the transition to a more sustainable world, with circular business models and new sustainable materials.

Appendix A

Key assumptions and data sources

Fishing boats moored by a shore.
Vijak/Adobe Stock

Appendix A: key assumptions and data sources

This appendix describes the most important assumptions and data sources used for the purpose of building the Business-as-Usual (BAU), Current Commitments, and System Change scenarios. For full details of all assumptions, data sources, and methodology, please see the technical appendix. All assumptions and methodologies in this project have been peer-reviewed.

Population and waste generation

The total mass of macroplastic waste generated for each archetype is estimated using World Bank data of waste generated by country in 2016,[234] United Nations population data by archetype, and projected growth rates of plastic generation from Material Economics' analysis.[235] The results are summarized in Table A.1.

Table A.1: Estimated annual total macroplastic waste generation projections and calculated compound annual growth rates (CAGR) by archetype from 2016 to 2040

Archetype		Total annual plastic waste generated (million metric tons)			Calculated CAGR
		2016	2030	2040	
Urban	High-income (HI)	72.8	90.3	104.2	1.51%
	Upper middle-income (UMI)	53.3	104.7	143.7	4.22%
	Lower middle-income (LMI)	25.5	48.8	70.6	4.33%
	Low-income (LI)	3.8	10.1	17.2	6.58%
Rural	HI	17.0	17.3	16.7	-0.07%
	UMI	19.2	23.6	25.0	1.11%
	LMI	19.4	27.6	31.4	2.04%
	LI	4.2	8.1	10.9	4.18%
Global		215.0	330.4	419.7	2.83%

Table A.2: Waste composition by plastic categories by income group

Plastic category	Income group	
	HI	UMI/LMI/LI
Rigid monomaterial	53%	33%
Flexible monomaterial	24%	45%
Lower middle-income (LMI)	23%	22%

The proportion of municipal solid waste allocated to each plastic category was done by analysing available full data sets on waste composition from representative countries in the high-income archetype and combined middle-income and low-income archetypes, due to scarcity of data (see technical appendix Section 8). The results are shown in Table A.2. We assumed that the trajectory observed from 2014 to 2019 for these proportions would continue to 2040: an annual decrease in the share of rigid monomaterials of -0.22 per cent and an annual increase in the share of flexibles of 0.11 per cent across all archetypes.[236]

Table A.3: Estimated populations living in proximity to rivers or coastal waters

Archetype	Proportion of population living in proximity to water	
	<1 km	>1 km
HI-urban	43.5%	56.5%
HI-rural	41.1%	58.9%
UMI-urban	43.6%	56.4%
UMI-rural	40.9%	59.1%
LMI-urban	46.2%	53.8%
LMI-rural	42.0%	58.0%
LI-urban	40.2%	59.8%
LI-rural	36.4%	63.6%

We assumed that waste generated near coastal waters and rivers has a greater likelihood of reaching water and therefore proportioned the population living within 1 km of a river or coastal water using GIS modelling, as shown in Table A.3, and assigned transfer ratios of mismanaged waste to the ocean accordingly (see "Transfer to waterways" section below and technical appendix Section 14).

Business-as-Usual: Mass

Collection

Collection rates for each archetype are taken from the World Bank.[237] The amount of plastic waste collected is projected to increase over time, as total plastic waste generation increases. We assumed that the proportion of government budgets spent on waste management would remain constant. Consequently, we assume gross domestic product (GDP) growth is a proxy for the average annual growth of government budgets, and therefore an estimate for growth in waste management spending. The expansion in the volume of collected plastic waste is therefore constrained by global GDP growth at an average of 3 per cent per year.[238]

The number of waste pickers in each income group is estimated based on Linzner and Lange, 2013.[240] We assume that the informal sector will grow at the same rate as the overall population, such that their relative proportion remains the same as in 2016.

Table A.4: Baseline conditions of plastic waste collection rates by archetype for base year 2016[239]

Archetype	HI urban	HI rural	UMI urban	UMI rural	LMI urban	LMI rural	LI urban	LI rural
Plastic collection rates	99%	96%	85%	45%	71%	33%	48%	26%

Table A.5: Estimated proportion of waste pickers in 2016

Income group	Urban population (millions)	Proportion of waste pickers in urban population	Number of waste pickers (millions)
HI	962	0.005%	0.05
UMI	1,693	0.33%	5.6
LMI	1,196	0.41%	4.9
LI	207	0.41%	0.85
Total	**4,058**		**11.4**

Managed waste

The share of managed waste in each archetype is based on World Bank data.[241] Similar to collection rates, the growth of waste management infrastructure is constrained not to exceed GDP growth averaged at 3 per cent per year. Moreover, to estimate the amount of mismanaged waste in urban and rural areas, we assume it to be proportional to the amount of uncollected waste in urban and rural areas. The resulting proportions of managed waste in each archetype are shown in Table A.6. We assume that these proportions remain constant to 2040 under BAU.

Mechanical recycling

In the BAU Scenario, all recycling between 2016 and 2040 is assumed to be mechanical recycling, and only of monomaterials. We assume that recycling rates will increase over time in HI countries (driven by regulation) and that all recycling in UMI, LMI and LI countries is enabled, in some way or another, by the informal sector.

Chemical conversion

We model pyrolysis-based chemical conversion in urban areas of HI, UMI and LMI countries only. We assume that all feedstock for this technology is flexible plastic (both monomaterials and multimaterials). To approximate the total mass input for the BAU Scenario, we quantify the current total installed capacity and project this forward to 2040 using a compound annual growth rate (CAGR) of 2 per cent, which has been observed between 2014 and 2019. Moreover, because plastic-to-plastic chemical conversion technologies are all currently virtually at pilot scale, we assume that no commercial development of plastic-to-plastic chemical conversion will occur under the BAU Scenario.

Disposal

The share of managed waste directed to landfill versus incineration is based on existing trends in each archetype, as shown in Table A.7.

Import and export of plastic waste

The increase in global trade is assumed to match the growth rate in plastic waste generation in high-income countries because these countries represent a large share of the plastic waste export market. We base our analysis on total plastic waste mass data obtained from the United Nations Comtrade database for 2018[250] after the significant disruptions to trade in plastic waste following the Chinese import ban in January 2018.

Open burning

The percentage of collected plastic waste that is burned openly in dumpsites and the rate of uncollected plastic waste that is burned openly in residential settings is based on general municipal solid waste data reported by Wiedinmyer *et al*., 2014, for middle income and low income countries.[251] Because of a lack of data, high-income countries are assumed to have the same rates. As a result, the open burning of collected plastic waste in dumpsites is assumed at 13 per cent and the open burning of uncollected waste in residential areas is assumed at 60 per cent, globally.

Transfer to waterways

The precise transfer rates of plastic waste in each route are not well understood. Table A.8 shows the rates assumed based on expert panel consensus, informed by published research and survey data, where such data exist.[252] The highest uncertainty band of 50 per cent is assigned to this parameter due to the lack of empirical data. Transfer rates are distinguished by distance to water.

Table A.6: Proportion of managed plastic waste (as share of disposal) reported by Kaza et al., 2018[242]

Archetype	HI urban	HI rural	UMI urban	UMI rural	LMI urban	LMI rural	LI urban	LI rural
Managed plastic waste, 2016	96%	94%	53%	28%	4%	2%	3%	2%

Table A.7: Disposal rates by income group (as per cent of managed waste)

	2016		BAU 2040	
	Engineered landfill	**Incineration with energy recovery**	**Engineered landfill**	**Incineration with energy recovery**
HI[a,d]	65%	35%	30%	70%
UMI[b,d]	85%	15%	58%	42%
LMI[c,d]	100%	0%	100%	0%
LI[c,d]	100%	0%	100%	0%

Sources: a = World Bank, 2018;[243] b = Fernandez, 2020;[244] Hu et al., 2015;[245] Hu et al., 2018;[246] Chinese Statistical Service;[247] and Ji et al., 2016;[248] c = Kumar et al., 2019;[249] d = expert panel consensus

Table A.8: Estimated transfer rates of mismanaged waste

Pathway	System map arrow	Denominator	Rigid		Flexible		Multi	
			<1km	>1 km	<1km	>1 km	<1km	>1 km
Direct to water (resident)	Arrow Q3	Q: Uncollected	20%	0.1%	20%	0.1%	20%	0.1%
Leakage to water from terrestrial dumping	Arrow T1	T: Diffuse terrestrial dumping	10%	3%	35%	8%	35%	8%
Direct to water (collection vehicle)	Arrow R1	R: Post-collection mismanaged	5%	5%	5%	5%	5%	5%
Dumpsite leakage to water	Arrow V3	V: Dumpsites/unsanitary landfills	1%	0.5%	8%	3%	8%	3%

Business-as-Usual: Costs

Both operating and capital expenditures are assumed to improve at a fixed rate for every doubling of capacity, which varies based on activity. All cost data and estimates are reported in 2016 US$.

Collection and sorting costs

The collection and sorting costs are prorated for plastics such that the costs within the modelled system account for only the costs attributable to plastic waste and are therefore higher than the collection and sorting of other waste streams, such as organic waste. Allocation is done to reflect the relatively higher volume-to-weight ratio that plastic occupies in a collection truck.

Table A.9: Cost of collection (allocated to plastics) (US$ per metric ton)

Income group	Average cost for all waste[253]	Weighted average—urban			Weighted average—rural		
		Operating expenditure	Capital expenditure	Total	Operating expenditure	Capital expenditure	Total
HI	145	149	64	213	202	86	288
UMI	75	81	35	115	109	47	156
LMI	53	56	24	81	76	33	109
LI	35	38	16	54	51	22	73

Sources: Kaza et al., 2018;[254] Hogg, 2002[255]

Table A.10: Estimated formal sorting costs (US$ per metric ton)[256]

Income archetype	Operating expenditure	Capital expenditure	Total
HI	156	52	208
UMI	117	39	156
LMI	88	29	117
LI	66	22	88

Recycling costs

Both capital and operating expenditures for closed-loop and open-loop mechanical recycling plants are based on the experience and knowledge of our expert panel and confirmed through interviews. Similar to mechanical recycling, costs for plastic-to-fuel and plastic-to-plastic chemical conversion plants are based on consultation with chemical conversion companies. These are nascent technologies with limited cost data available.

Sale prices

The sale prices for different recyclates are based on a composition of high-value plastics (PET, HDPE, and PP) as shown in Table A.12. We assume that these prices remain constant to 2040.

Table A.11: Closed- and open-loop mechanical recycling costs (US$ per metric ton of input)

	Operating expenditure			Capital expenditure		
Income group	Closed-loop mechanical recycling	Open-loop mechanical recycling	Chemical conversion	Closed-loop mechanical recycling	Open-loop mechanical recycling	Chemical conversion
HI	596	410	246	160	120	101
UMI	452	307	172	140	90	77
LMI	300	200	158	115	75	77
LI	300	200	N/A	115	75	N/A

Sources: Based on expert panel consensus; Deloitte, 2015;[257] proprietary data by expert panel member Jill Boughton

Table A.12: Recyclate sale price by archetype (US$ per metric ton of output)

Income group	Mechanical recycling		Chemical conversion [c]	
	Closed loop [a, b]	Open loop	Plastic-to-plastic	Plastic-to-fuel
HI	1,218	810	648	637
UMI	1,157	770	645	637
LMI	1,096	729	645	637
LI	1,096	729	645	637

Sources: a = Plastics Information Europe, 2019;[258] b = Based on expert panel consensus per proprietary data shared by panel member Ed Kosior; c = Based on expert panel consensus per proprietary data shared by panel member Jill Boughton

Disposal costs

Total landfills costs are calculated based on World Bank data and Eunomia data, as shown in Table A.13. The split between operating and capital expenditures is done through expert panel consensus. The costs reflect the capital expenditures and annualized operating expenditures of engineered landfills. Incineration costs are based on expert panel consensus based on data from actual plants. The costs reflect the same operating, safety, and environment standards across all archetypes.

Incineration revenues account for the sale price of the energy generated, as shown in Table A.14. We assume these prices remain constant to 2040.

Table A.13: Disposal costs by income group (US$ per metric ton of input)

Income group	Engineered landfills		Incineration	
	Operating expenditure	Capital expenditure	Operating expenditure	Capital expenditure
HI	7.5	22.5	63	27
UMI	7.5	22.5	28	21
LMI	5.0	15.0	26	21
LI	5.0	15.0	26	21

Sources: Based on World Bank, 2018;[259] Eunomia, 2002;[260] and expert panel consensus per proprietary data shared by panel member Jill Boughton

Table A.14: Incineration sale prices by income group (US$ per metric ton of input)

Income group	Revenue
HI	44
UMI	34
LMI	35
LI	35

Source: Based on World Bank, 2018,[261] and expert panel consensus per proprietary data shared by panel member Jill Boughton

Current Commitments Scenario: Mass

The Current Commitments Scenario accounts for the impact of major government policies as well as the reduction committed by industry through the New Plastics Economy Global Commitments.[262] This scenario includes all commitments made between Jan. 1, 2016, and June 30, 2019.

Government bans and levies

This element quantifies the anticipated reduction in plastic due to government bans/levies that have been passed into legislation. Where countries introduced bans on specific items (e.g., plastic bags), we estimate that it will lead to 100 per cent elimination of that item. The European Union single-use plastics directive[263] is analysed separately to determine its plastic reduction impact.

New Plastics Economy Global Commitments

The New Plastics Economy Global Commitments are evaluated to quantify the potential plastic reduction of its signatories resulting from the commitments in three ways:

1. ***Increase in recycled content.***
2. ***Reduction in plastic resulting from the commitment to "take action to eliminate problematic or unnecessary plastic packaging by 2025."***
3. ***Innovation where 100 per cent of plastic packaging is reusable, recyclable, or compostable by 2025.***

Costs and sale prices for this scenario were assumed to be the same as for the BAU Scenario.

System Change Scenario: Mass

Reduce and Substitute interventions

The methodology used for Reduce and Substitute is described under System Intervention 1 and System Intervention 2 (for details, see technical appendix Section 15).

Collection and sorting

Table A.15 shows the target collection rates for each archetype under the System Change Scenario. These rates are determined based on our expert panel consensus of what ambitious but realistic targets for each archetype would be, and while comparing to what best-in-class countries have achieved in each archetype.

The formal sorting losses are modelled to halve from 20 per cent in 2016 to 10 per cent in 2040. This is due to an increase in the proportion of plastic that is technically recyclable as enabled by improvements in design for recycling, sorting at source, labelling for recycling, and recycling technology. For the informal sector, the sorting losses are assumed to be less than the formal sector because waste pickers generally "cherry pick" the most valuable recyclable plastic waste at source. A loss rate of 5 per cent across all plastic categories is modelled, which is assumed to remain stable over time.

Table A.15: 2040 targets of plastic waste collection rates by archetype under System Change Scenario

Archetype	HI urban	HI rural	UMI urban	UMI rural	LMI urban	LMI rural	LI urban	LI rural
Collection rate for plastic waste	100%	100%	95%	50%	95%	50%	95%	50%

Recycling

The share of rigid plastics going to closed-loop mechanical recycling is assumed to increase by 2040 as regulatory requirements for recycled content increase and as recycled technologies improve, as shown in Table A.16.

In the System Change Scenario, we assume that there will be a growth in chemical conversion capacity, both plastic-to-fuel and plastic-to-plastic. We base the maximum foreseen growth rate for chemical conversion on the compounded annual growth rate (CAGR) of ethanol production in Brazil between 1975 and 1995, a time in which the Brazilian government assertively drove the development of ethanol production and incentivized it accordingly.[264] We consider the historical ethanol production trajectory in Brazil to be a good proxy because of the similar capex-intensive nature as well as interest by public and private sectors to develop the industry. The Brazilian ethanol CAGR of 16.5 per cent is used to project the maximum capacity growth of chemical conversion (for both plastic-to-fuel and plastic-to-plastic). In addition, the maximum mass flowing to chemical conversion is constrained to a maximum of 50 per cent of all collected flexible monomaterial and multilayer/multimaterial plastic waste in any given year. We further assume that plastic-to-plastic chemical conversion begins in 2030, and that a 50:50 split with plastic-to-fuel is achieved by 2040.

Post-collection mismanaged plastic waste

Table A.17 shows the target rate of managed plastic waste as a proportion of all plastic waste for each archetype under the System Change Scenario. This rate is based on expert panel consensus of what is achievable in an ambitious scenario.

Table A.16: Target outcome of formal and informal sorting processes for rigid monomaterial plastics (as per cent of plastic waste entering sorting) under System Change Scenario

a. Formal:

Income group	2016			2040—after intervention		
	Going to closed loop	Going to open loop	Lost in sorting process	Going to closed loop	Going to open loop	Lost in sorting process
HI	53%	27%	20%	65%	25%	10%
UMI	10%	70%	20%	20%	70%	10%
LMI	5%	75%	20%	20%	70%	10%
LI	0%	80%	20%	0%	90%	10%

b. Informal:

Income group	2016			2040—after intervention		
	Going to closed loop	Going to open loop	Lost in sorting process	Going to closed loop	Going to open loop	Lost in sorting process
HI	70%	25%	5%	80%	15%	5%
UMI	25%	70%	5%	35%	60%	5%
LMI	25%	70%	5%	35%	60%	5%
LI	25%	70%	5%	35%	60%	5%

Table A.17: Target proportion of managed waste in 2040 under System Change Scenario

Archetype	HI urban	HI rural	UMI urban	UMI rural	LMI urban	LMI rural	LI urban	LI rural
Managed plastic waste; 2040 (as per cent of disposal)	100%	100%	90%	75%	50%	50%	50%	50%

System Change Scenario: Costs

End-of-life costs

The end-of-life costs per metric ton of plastic substituted include the collection, disposal, and recycling/composting costs of substitute material. These costs are multiplied by an average weighted factor increase of replacing a plastic packaging unit with a substitute package (1.5 for paper or coated paper[265] and 1.3 for compostable materials).[266] This method is based on two key assumptions. First, it assumes that 100 per cent of substitutes are collected, disposed of, or recycled as managed waste, which is conservative to ensure that end-of-life costs are not underestimated. Second, it assumes that cost per metric ton and per cent by waste treatment type remain at 2016 levels to 2040.

Recycling prices

In the System Change and Recycling scenarios, we model an increase in recyclate prices, driven primarily by an increased demand for recycled content as well as a higher quality of recyclates due to design for recycling.

Table A.18 Closed-loop sale prices by income group (US$ per metric ton of output) assumed under System Change Scenario

Income group	Closed loop		Open loop	
	2016	2040—after intervention	2016	2040—after intervention
HI	1,218	1,350	810	1,000
UMI	1,157	1,283	770	950
LMI	1,096	1,215	729	900
LI	1,096	1,215	729	900

Source: 2040 price assumptions and rationale based on expert panel consensus per proprietary data shared by panel member Ed Kosior

Appendix B

System maps

Simon Clayton/Pexels

APPENDIX B

Figure B.1: Global macroplastic system map

The macroplastic system map depicts the five major components of the global plastic system: production and consumption; collection and sorting; recycling; disposal; and mismanaged. The boxes labelled with letters (A to W) represent mass aggregation points in the model, and the arrows represent mass flows. Boxes outlined in solid lines represent places where plastic mass leaves the system, including where it leaks into the ocean (see Box W). The boxes to the left of Box A reflect plastic demand. See Appendix A and the technical appendix for details on the modelling methodology and parameters used.

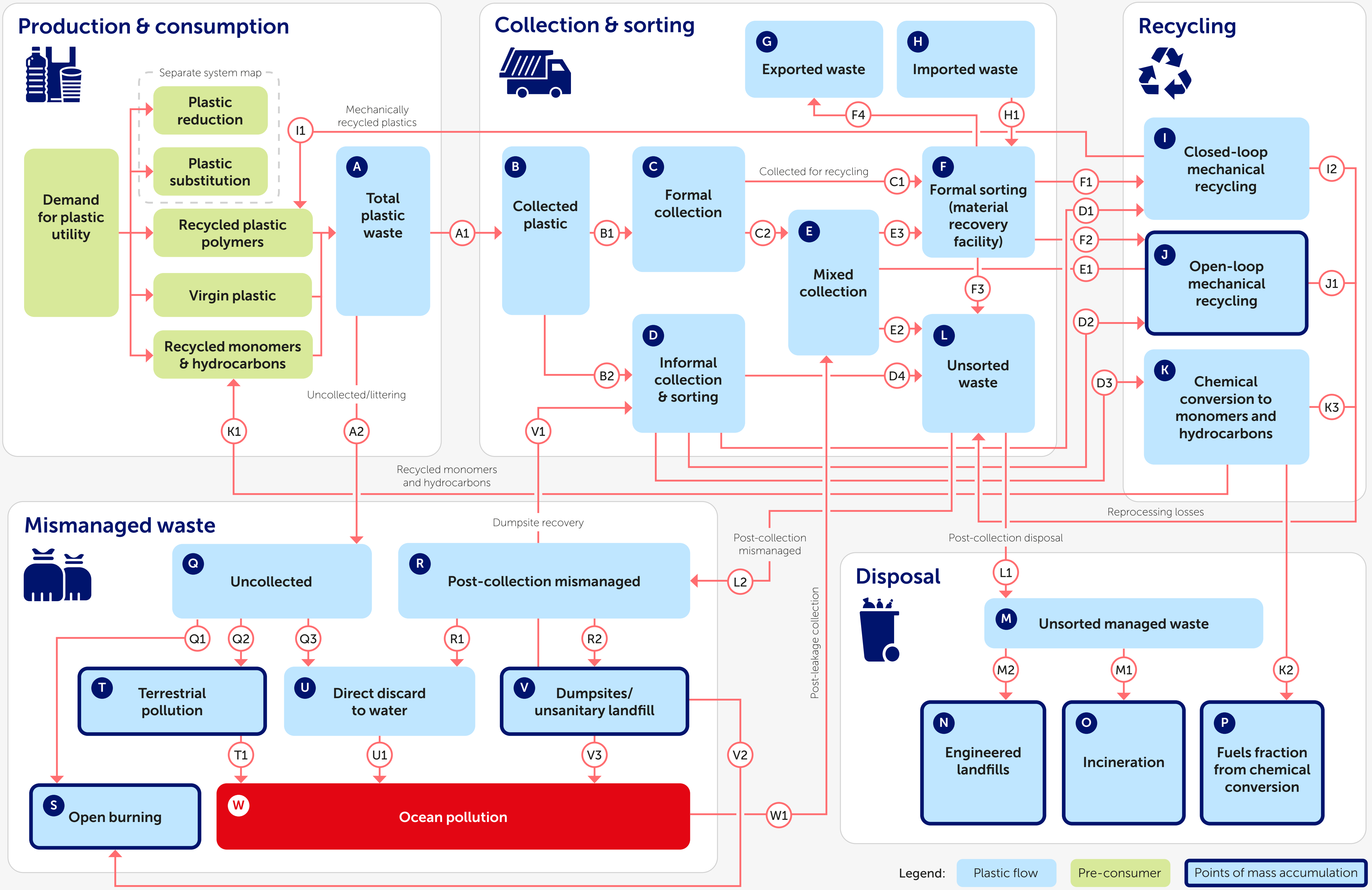


Figure B.2: Detailed view of the subsystem map of the Reduction and Substitution boxes

Box 0 and the Plastic Reduction and Plastic Substitution boxes in Figure B.1 are detailed in this subsystem map. The numbered boxes depict the flows of utility demand and supply (green boxes), plastic mass demand and supply (blue boxes), and substitute material mass (pink boxes; not modelled). Business-as-Usual (BAU) demand for plastic mass that accumulates in the system is estimated in Boxes 0.5 and 0.7 such that utility in boxes 0.5, 0.7, and 0.8 adds up to the sum of Box 0. Arrow 0.6 is a dotted arrow because it represents a partial flow as only multiuse packaging for nonfood applications was modelled as plastic. The three Reduce levers are depicted in Boxes 0.1, 0.2, and 0.3. See Appendix A and the technical appendix for details on the modelling methodology and parameters used.

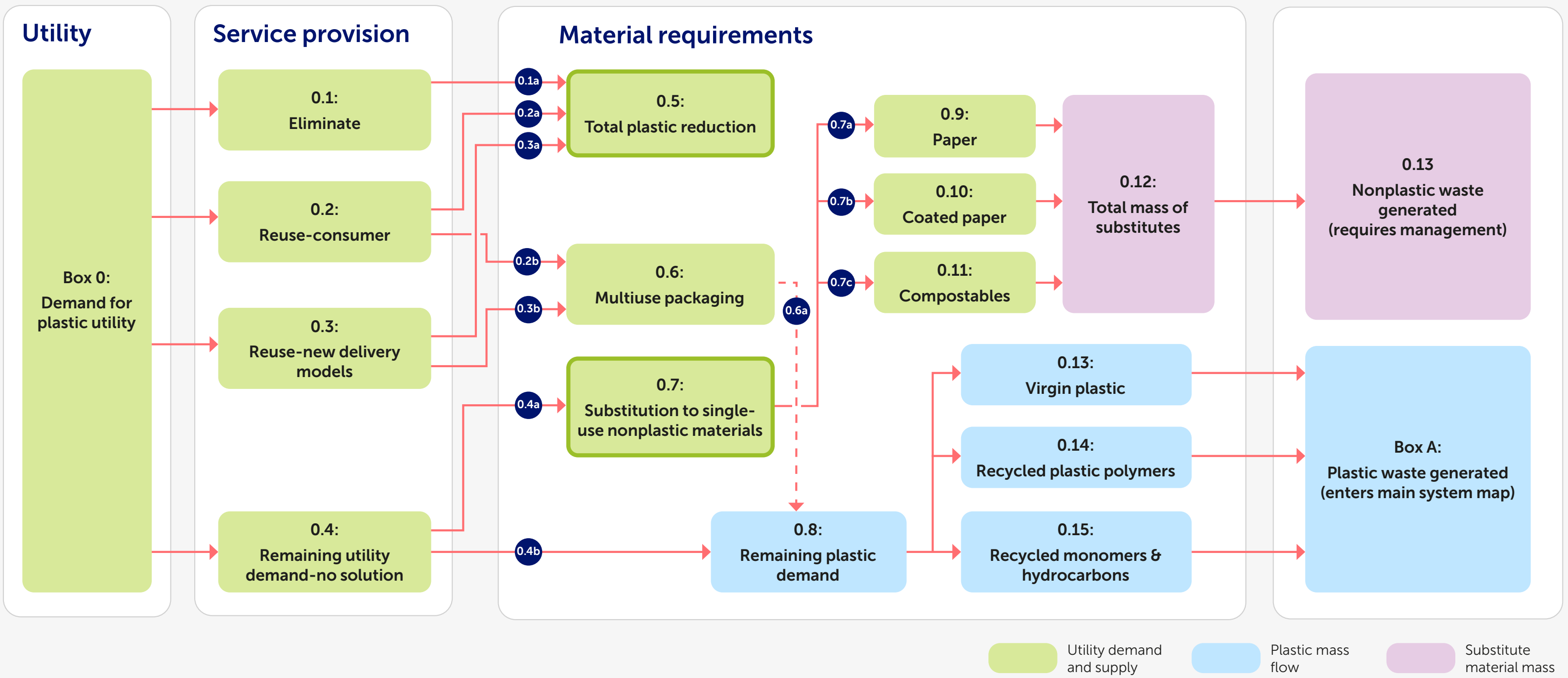
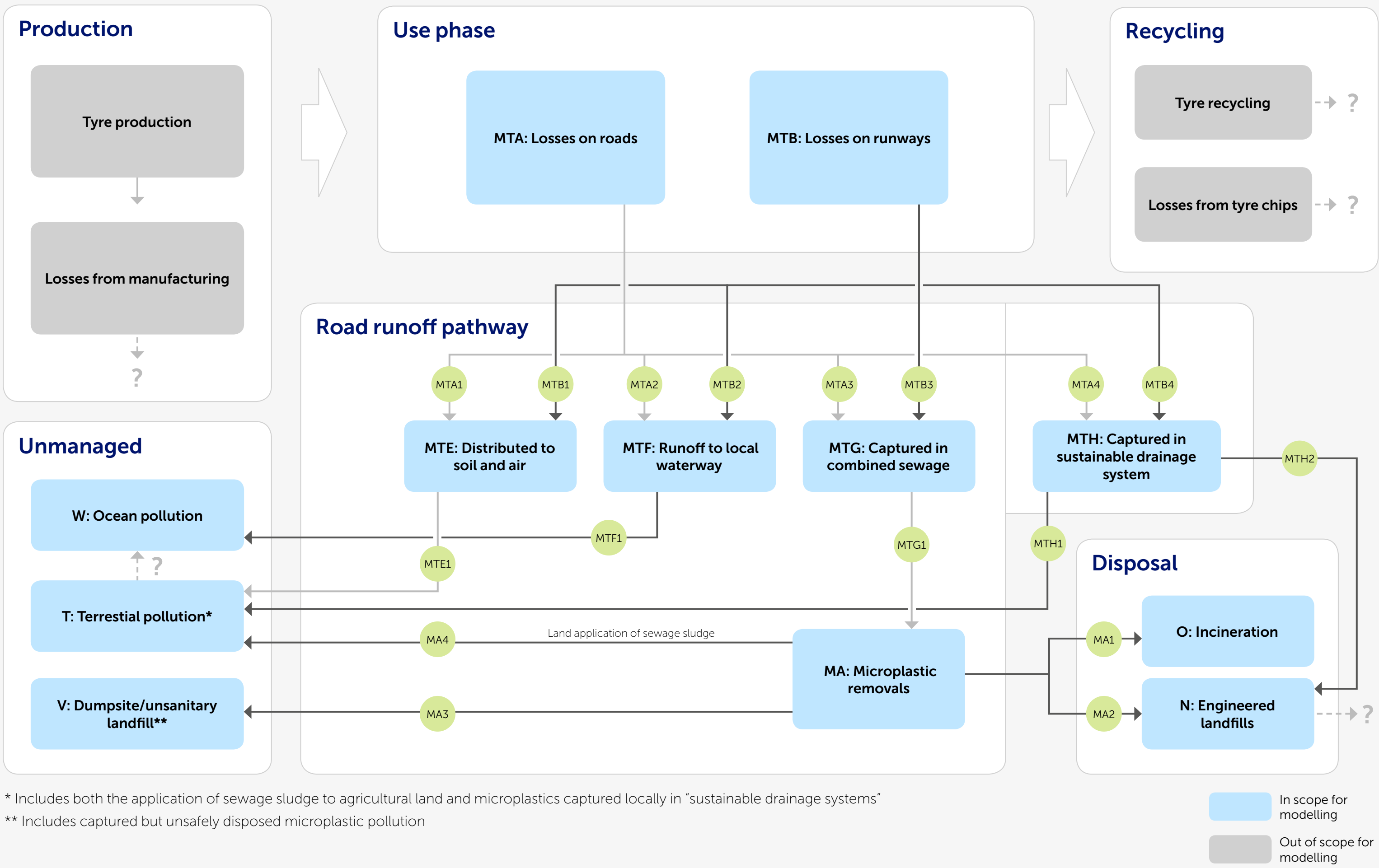


Figure B.3: Tyre wear particles system map

Microplastics generated from tyre-wear particles (TWP) are microsize particles with a spectrum of airborne (>10µm) to coarse fraction (>1mm) released through mechanical abrasion of tyres, with chemical composition depending on rubber type. The major pathways are depicted in this system map, but because of a lack of data, only the blue boxes and the associated arrows are modelled. The grey boxes are outside the scope of this study. Box MTA, "Losses on roads," represents TWP generated by vehicles on urban and rural roads and motorways. Box MTB, "Losses on runways," represents TWP generated by airplanes during takeoffs and landings. Box MTE, "Distributed to soil and air," represents TWP distributed directly or via air to near road/runway soils. Box MTF, "Runoff to local waterway," represents TWP distributed directly to near road/runway waterways. Box MTG, "Captured in combined sewage," represents TWP distributed and removed by combined wastewater treatment plants. Box MTH, "Captured in sustainable drainage system," represents TWP distributed to near roads/runways, sumps, and filter systems. Box T, "Terrestrial pollution," includes both the application of sewage sludge to agricultural land and microplastics captured locally in sustainable drainage systems that are not safely disposed. Box V, "Dumpsite/unsanitary landfill," represents captured but unsafely disposed microplastics. See Appendix A and the technical appendix for details on the modelling methodology and parameters used.

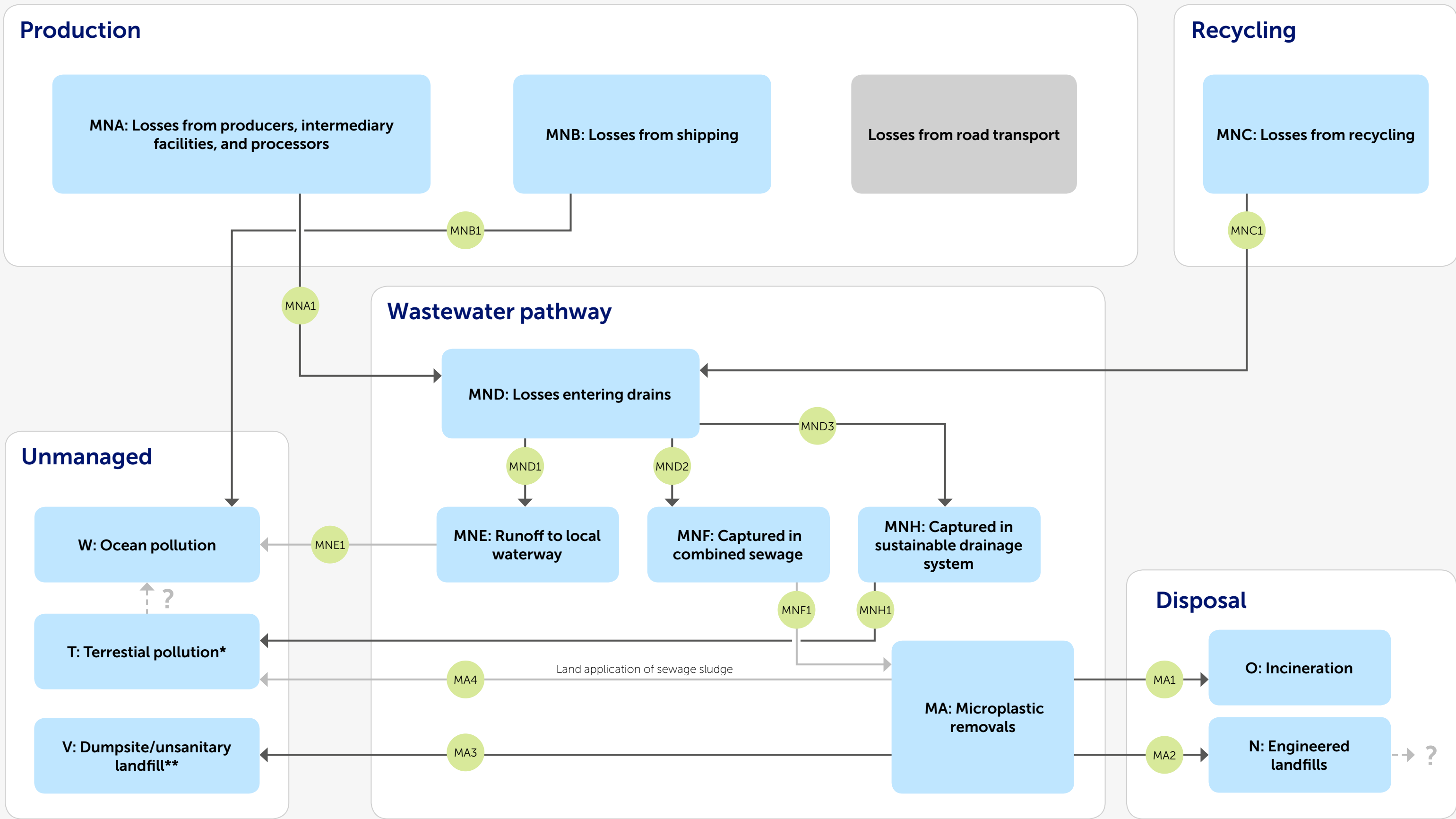


* Includes both the application of sewage sludge to agricultural land and microplastics captured locally in "sustainable drainage systems"

** Includes captured but unsafely disposed microplastic pollution

Figure B.4: Plastic pellets system map

Microplastics generated from plastic pellets are microsize (µ5mm) granules usually in the shape of a cylinder or a disk, produced as a raw material (also from plastic recycling) used in the manufacture of plastic products. Because of a lack of data, blue boxes represent the masses and flows that are included in our analysis, while grey boxes are outside the scope of this study. Box MNA, "Losses from producers, intermediary facilities and processors," represents pellet loss across the plastic supply chain. Box MNB, "Losses from shipping," includes pellet loss during sea transport (loss of containers). Box MNC, "Losses from recycling," includes pellet loss during the plastic recycling process. Box MND, "Losses entering drains," represents lost pellets distributed to indoor and outdoor drains. Box MNE, "Runoff to local waterways," represents pellets distributed directly to the sea. Box MNF, "Captured in combined sewage treatment," represents pellets distributed and removed by combined wastewater treatment plants. Box T, "Terrestial pollution," includes both the application of sewage sludge to agricultural land and microplastics captured locally in sustainable drainage systems. Box V, "Dumpsite/unsanitary landfill," includes captured but unsafely disposed microplastics. See Appendix A and the technical appendix for details on the modelling methodology and parameters used.



* Includes both the application of sewage sludge to agricultural land and microplastics captured locally in "sustainable drainage systems"

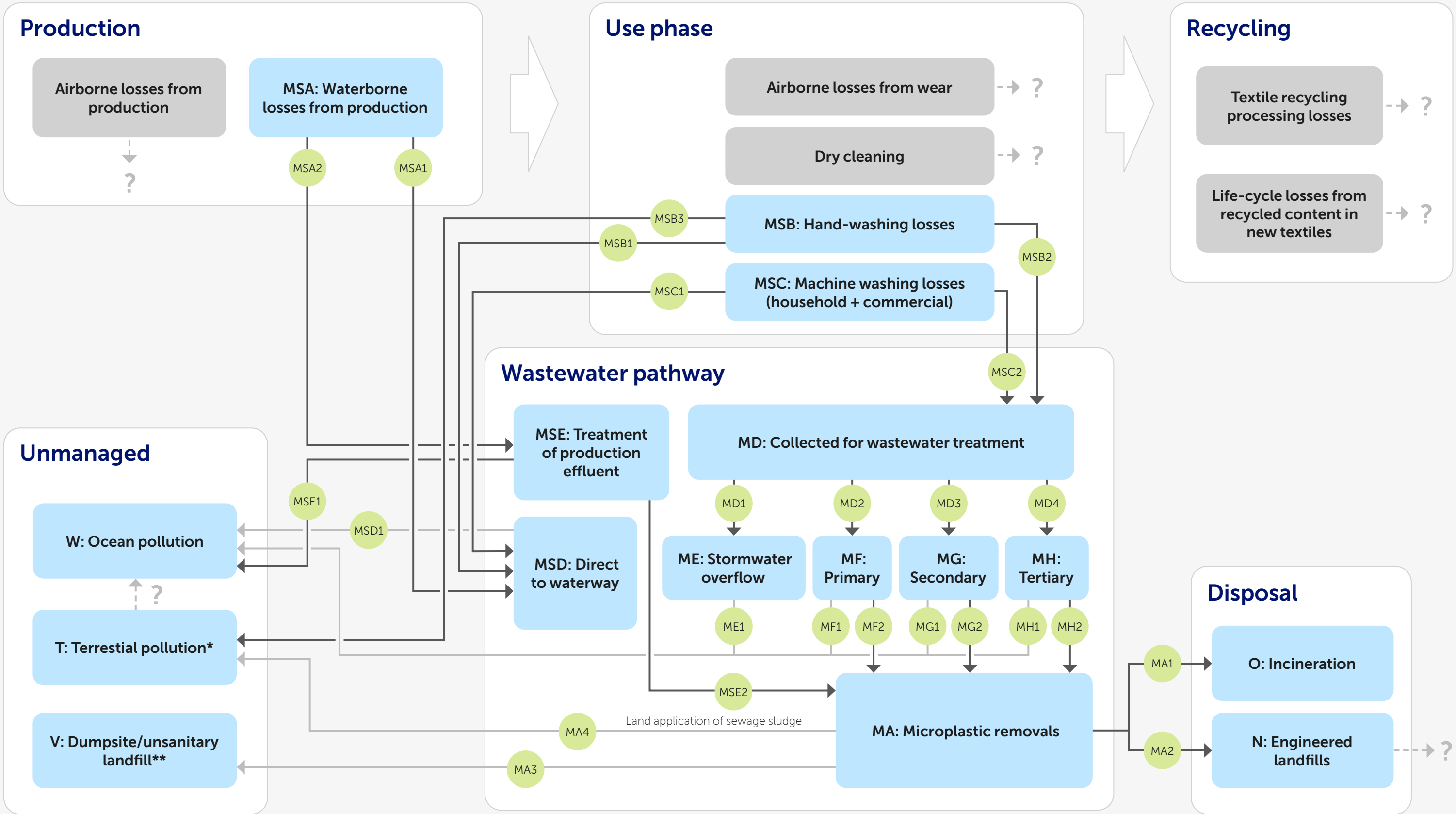
** Includes captured but unsafely disposed microplastic pollution

In scope for modelling

Out of scope for modelling

Figure B.5: Synthetic textiles system map

Microplastics generated from synthetic textiles are microsize textile fragments (>1mm) released via shedding to air, water, or wastewater during production or use. Because of a lack of data, blue boxes represent the masses and flows included in our analysis, while grey boxes are outside the scope of this study. Box MSA, "Waterborne losses from production," represents microfibres released during textile production. Box MSB, "Hand-washing losses," represents microfibres released during hand-washing of clothes within households. Box MSC, "Machine washing losses (households + commercial)," represents microfibres released during household machine washing of clothes or commercial laundromats. Box MSD, "Direct to waterway," represents microfibres distributed directly to waterways via hand-washing in rivers or wastewater without treatment. Box MSE, "Treatment of production effluent," represents microfibres distributed to wastewater treatments of textile producers. Box MD, "Collected for wastewater treatment," represents microfibres distributed to wastewater treatment facilities. Box MSD, "Stormwater overflow," represents microfibres released from wastewater treatment facilities via overflows. Boxes MF, MG, and MH "1ary," "2ary," and "3ary," represent different stages of wastewater treatment: primary, secondary, and tertiary, respectively. Box T, "Terrestrial pollution," includes both the application of sewage sludge to agricultural land and microplastics captured locally in sustainable drainage systems. Box V, "Dumpsite/unsanitary landfill," includes captured but unsafely disposed microplastics. See Appendix A and the technical appendix for details on the modelling methodology and parameters used.



* Includes both the application of sewage sludge to agricultural land and microplastics captured locally in "sustainable drainage systems"

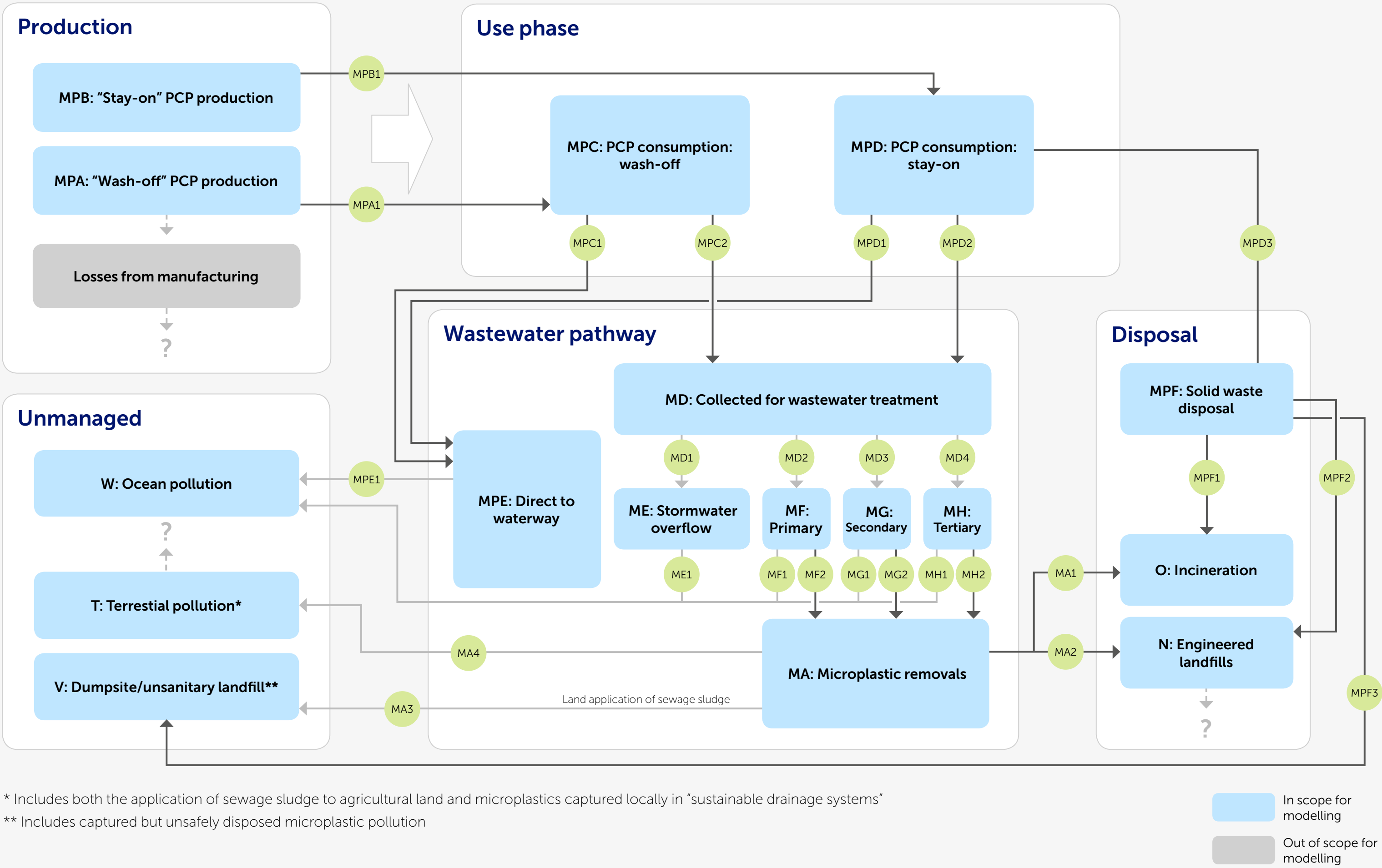
** Includes captured but unsafely disposed microplastic pollution

In scope for modelling

Out of scope for modelling

Figure B.6: Personal care products (PCP) system map

Microplastics generated from personal care products (PCP) are microplastic ingredients added to PCPs intentionally by producers for a range of functions. Because of a lack of data, blue boxes represent the masses and flows included in our analysis, while grey boxes are outside the scope of this study. Box MPA, "'Wash-off' PCP production," represents wash-off PCPs (e.g., shampoos) production rate. Box MPB, "'Stay-on' PCP production," represents stay-on PCPs (e.g., makeup) production rate. Box MPC, "PCP consumption: wash-off," represents wash-off PCP usage by consumers. Box MPD, "PCP consumption: stay-on," represents stay-on PCP usage by consumers. Box MPE, "Direct to waterway," represents microplastic ingredients from PCPs directly released to waterways via untreated wastewaters. Box MPF, "Solid waste disposal," represents microplastic ingredients in stay-on PCPs, removed by absorbent materials and disposed to solid waste. Box MD, "Collected for wastewater treatment," represents microfibres distributed to wastewater treatment facilities. Box ME, "Stormwater overflow," represents microfibres released from wastewater treatment facilities via overflows. Boxes MF, MG, and MH "1ary," "2ary," and "3ary," represent different stages of wastewater treatment: primary, secondary and tertiary, respectively. Box T, "Terrestrial pollution," includes both the application of sewage sludge to agricultural land and microplastics captured locally in sustainable drainage systems. Box V, "Dumpsite/unsanitary landfill," includes captured but unsafely disposed microplastics. See Appendix A and the technical appendix for details on the modelling methodology and parameters used.



* Includes both the application of sewage sludge to agricultural land and microplastics captured locally in "sustainable drainage systems"
** Includes captured but unsafely disposed microplastic pollution

Glossary

Additives
Plastic is usually made from polymer mixed with a complex blend of materials known as additives. These additives, which include flame retardants, plasticizers, pigments, fillers, and stabilizers, are used to improve the different properties of the plastic or to reduce its cost.[267]

Business-as-Usual (BAU) Scenario
See definition under "Scenarios."

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

Bio-benign (materials)
A material harmless to natural systems in case it unintentionally escapes collection and recovery systems.

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

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

Chemical conversion
Process that breaks down polymers into individual monomers or other hydrocarbon products that can then serve as building blocks or feedstock to produce polymers again.[268]

Circular economy
A circular economy is one that is restorative and regenerative by design. It looks beyond the take-make-waste extractive industrial model, and aims to redefine growth, focusing on positive society-wide benefits.[269] It is based on three principles: design out waste and pollution; keep products and materials in use; and regenerate natural systems.

Closed-loop recycling
Closed-loop recycling is the recycling of plastic into any new application that will eventually be found in municipal solid waste, essentially replacing virgin feedstock in "Box A" of the system map (i.e., plastic bottle, pen, etc.)

Collect and Dispose Scenario
See definition under "Scenarios."

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

Current Commitments Scenario
See definition under "Scenarios."

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

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

Dumpsites
Places where collected waste has been deposited in a central location and where the waste is not controlled through daily, intermediate or final cover, thus leaving the top layer free to escape into the natural environment through wind and surface water.

Economic costs
Techno-economic costs of a process or technology. Includes operating and capital expenditures (opex and capex) where relevant, but does not include taxes, subsidies or externalities. All government and private-sector costs cited as outputs of scenarios are reported in US$ and are calculated as present value using a 3.5 per cent discount rate.

End-of-Life (EOL)
End-of-life is a generalized term to describe the part of the life cycle following the use phase.

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 that is the principal input for an industrial production process.[270]

Flexible monomaterial plastics
See definition under "Plastic categories."

Formal waste sector
Antonym of "informal waste sector."

Geographic archetype
Geographic archetypes are parts of the world with similar characteristics when it comes to plastic waste. The archetypes are divided into four groups depending on country income, according to World Bank definitions: high-income (HI) economies; upper middle-income (UMI) economies; lower middle-income (LMI) economies; and low-income (LI) economies. The rural and urban settings for each of the four income groups are also analysed separately to create the eight geographic archetypes.

Incineration
Destruction and transformation of material to energy by combustion.

Informal waste sector
Individuals or enterprises who are involved in private-sector recycling and waste management activities that are not sponsored, financed, recognized, supported, organized or acknowledged by the formal solid waste authorities.

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.[271]

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]).

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.

Maritime sources
All plastics that enter the environment from seagoing vessels (including from fishing activities).

Mechanical recycling
Operations that collect after-use plastics via mechanical processes (grinding, washing, separating, drying, regranulating, compounding) without significantly changing the chemical structure of the material.[272]

Microfibres
Microsize fragments (>1mm) released via textiles shedding to air, water or wastewater during production or use.

Microplastics—primary and secondary
Primary microplastics are those originally produced or directly released into the environment as microsize particles (<5mm size).

Secondary microplastics are microsize fragments originating from the degradation of large plastic waste into smaller plastic fragments once exposed to the marine environment.

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 categorized as unmanaged.

Monomaterials
See definition under “Plastic categories.”.

Multimaterials
See definition under “Plastic categories.”

Multilayer plastics
See definition under “Plastic categories.”

Municipal Solid Waste (MSW)
Includes all residential and commercial waste but excludes industrial waste.

New delivery models
Services and businesses providing utility previously furnished by single-use plastics in new ways, with reduced material demand.

Open burning
Waste that is combusted without emissions cleaning.

Open-loop recycling
Process by which polymers are kept intact, but the degraded quality and/or material properties of the recycled material is used in applications that might otherwise not be using plastic (i.e., benches, asphalt).

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

Pathway
A course of action that combines system interventions across geographic archetypes to achieve a desired system outcome.

Pellets
Microsize (µ5mm) granules usually with a shape of cylinder or a disk, produced as a raw material (also from plastic recycling) and used in the manufacture of plastic products.

Plastic categories
Three plastic material categories that we have modelled as flowing separately through the system map: rigid monomaterial plastics, flexible monomaterial plastics, multilayer plastics and multimaterials.

Rigid monomaterial plastics
An item made from a single plastic polymer that holds its shape, such as a 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, usually packaging, made of plastic and nonplastic materials (such as thin metal foils or cardboard layers) that cannot be easily and mechanically separated.

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 that 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.

Polymers
PET - Polyethylene terephthalate
HDPE - High-density polyethylene
LDPE - Low-density polyethylene
LLDPE - Linear low-density polyethylene
PP - Polypropylene
PVC - Polyvinyl chloride
EPS – Expanded polystyrene
PS - Polystyrene

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

Recyclable
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.[273] Recyclable is used here as a short-hand for "mechanically recyclable."[274] See "mechanical recycling" definition.

Recyclate
Waste material that has been collected or has the potential to be collected for recycling.

Recycling Scenario
See definition under "Scenarios."

Reduce and Substitute Scenario
See definition under "Scenarios."

Resin
A natural or synthetic solid or viscous organic polymer used as the basis of plastic, adhesives, varnishes, or other products.

Rigid plastics
See definition under "Plastic categories."

Rural (vs. Urban)
See definition under "Urban vs. Rural."

Scenarios
For the purpose of our modelling, we have defined six scenarios:

- Business-as-Usual (BAU) Scenario: Defined as "no intervention" scenario; in other words, assumes that the current policy framework, market dynamics, cultural norms, and consumer behaviours do not change.
- Current Commitments Scenario: BAU scenario while incorporating key governmental commitments on reducing plastic waste.
- Collect and Dispose Scenario: Assumes that the majority of efforts focus on ambitiously expanding collection and controlled disposal of waste in middle-/low-income countries.
- Recycling Scenario: Assumes that the majority of efforts focus on ambitiously expanding collection in middle-/low-income countries and recycling of waste globally; includes design for recycling (D4R) levers.
- Reduce and Substitute Scenario: Assumes ambitious reduction and substitution of plastic globally relative to BAU scenario.
- System Change Scenario: Assumes all system interventions are applied concurrently, ambitiously, and immediately; includes the benefits of Collect and Dispose Scenario, Recycling Scenario, and Reduce and Substitute Scenario.

For detailed assumptions on each scenario, see the technical appendix.

Single-use plastic
A product that is made wholly or partly from plastic and that is not conceived, designed or placed on the market to accomplish, within its life span, multiple trips or rotations by being returned to a producer for refill or reused for the same purpose for which it was conceived.

Social welfare
Social welfare measures the overall well-being of people in the economy; it is the summation of all individual welfare in a society, where individual welfare is the sum of satisfactions obtained from the use of goods and services.

Stochastic model
A tool for estimating probability distributions of potential outcomes by allowing for random variation in inputs over time.

System Change Scenario
See definition under "Scenarios."

System map
A visual illustration of the main flows and stocks of the global plastic system. System maps can be found in Appendix B. For the purposes 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 global level, per geographic archetype, and per plastic category.

Tyre dust
Tyre dust consists of microsize particles with a spectrum from airborne (>10μm) to coarse fraction (>1mm) released through mechanical abrasion of tyres, with chemical composition depending on rubber type.

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.

Urban vs. Rural
Our classification of urban versus rural is in alignment with the United Nations Statistics Division, which allows countries to use their own approaches for distinguishing urban and rural areas according to their individual circumstances.[275]

Wedges
Four places in our model where a molecule of plastic can "end up": "Reduce," "Substitute," "Recycle," or "Dispose." The wedges are mutually exclusive, and each includes several sub-wedges. For details, see Chapter 1.

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Ocean swells in Bali, Indonesia.
Ines Álvarez Fdez/Unsplash

Developed by The Pew Charitable Trusts and SYSTEMIQ, "Breaking the Plastic Wave: A Comprehensive Assessment of Pathways Towards Stopping Ocean Plastic Pollution" presents a first-of-its-kind model of the global plastics system. It is an evidence-based roadmap that describes how to radically reduce ocean plastic pollution by 2040 and shows there is a comprehensive, integrated, and economically attractive pathway to greatly reduce plastic waste entering our ocean.

The research supporting this report was co-developed with 17 experts from across the spectrum of professionals looking at the plastic pollution problem, with broad geographical representation. The findings of our analysis were published in the peer-reviewed journal, *Science*.

The aim of this work is to help guide policymakers, industry executives, investors, and civil society leaders through highly contested, often data-poor, and complex terrain.

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