ECONOMIST IMPACT

Rethinking plastics in a circular economy

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Contents

About Economist Impact

Economist Impact combines the rigour of a think-tank with the creativity of a media brand to engage a globally influential audience. We believe that evidence-based insights can open debate, broaden perspectives and catalyse progress. The services offered by Economist Impact previously existed within The Economist Group as separate entities, including EIU Thought Leadership, EIU Public Policy, EIU Health Policy, Economist Events, EBrandConnect and SignalNoise.

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About this research

Rethinking plastics in a circular economy is an Economist Impact report, sponsored by Dow. In this report, Economist Impact examines the distinguishing characteristics of a range of plastic recycling technologies and presents the results of an in-depth assessment informed by an advisory board and desk research. The report further explores the policy framework necessary to implement and scale up these emerging technologies.

The findings are based on an extensive literature review, an advisory board meeting and an expert interview programme conducted by Economist Impact between April and August 2021. The advisory board members and interviewees are listed below.

Technologies assessment methodology

This plastic recycling technologies assessment evaluates the performance of ten mechanical, chemical and biological technologies across 16 indicators grouped into five categories:

- **Applicability:** Technologies were assessed based on the number of types of plastic they can process, their ability to process multi-material or mixed waste streams, and the level of sorting and decontamination required prior to recycling.
- **Quality of output:** Technologies were assessed based on whether the recycled output is typically of similar or higher quality (upcycled) or lower quality (downcycled) than the input, and whether the output is considered food-grade, i.e. suitable for food-contact packaging.
- **Efficiency & sustainability:** Technologies were assessed based on process temperatures and whether the process can be considered 'open loop' (where the recycled output cannot be used to produce the original product and is used for other purposes) or 'closed loop' (where the recycled output can be used to produce the original product).
- **Integration:** Technologies were assessed on the ease of integration with downstream processes and the range of applications for which the output would be useful.
- **Reach & scalability:** Technologies were assessed based on their maturity, the number and total capacity of operational and planned facilities using the technology, and the highest capacity of operational or planned facilities.

The ten technologies featured in our assessment were selected from a long list in consultation with a panel of experts. For each indicator, the technology was assigned a score from 1 to 5, where 1 represents a weak attribute and 5 represents a strong attribute. Scoring guidelines were developed based on the range of performance across the ten technologies for each indicator.

Scoring guidelines

Applicability

- Range of plastics processed: The higher the number of plastic types the technology can process, the higher the score.
- Processing multi-material plastics: The more effective the technology is at processing multi-layer and multi-material plastics, the higher the score.
- Processing mixed waste streams: The more effective the technology is at processing mixed waste streams (which refers not just to waste streams with different types of plastics but also to other waste materials such as food, wood, paper and clothing, among others), the higher the score.
- Level of sorting and decontamination: The lower the extent of sorting and decontamination of the waste required prior to recycling, the higher the score.

Quality of output

- Upcycled vs downcycled: The higher the quality of the output, the higher the score.
- Food-grade: The more suitable the recycled output is for food-contact packaging, the higher the score.

Efficiency & sustainability

- Process temperatures: The lower the temperature necessary for the process, the higher the score.
- Closed loop vs open loop: The easier it is to produce the original product from the recycled output, the higher the score. Although open loop processes can also produce higher-value output, in the context of this study processes that can help close the loop on production of a specific product are given a higher score.

Integration

- Ease of downstream integration: The easier it is to integrate the process or recycled output with the next step in the plastics value chain, the higher the score.
- Application across sectors: The wider the range of cases in which the recycled output can be used, the higher the score.

Reach & scalability

- Technology maturity: The more mature the technology, the higher the score. Laboratory-scale technologies were assigned the lowest score, followed by those with pilot or demonstration facilities, followed by early-stage commercial installations. Those with many commercial installations were assigned the highest score.
- Number of operational facilities: The higher the number of facilities in operation, the higher the score.
- Total operational capacity: The higher the total capacity of all operational facilities, the higher the score.
- Number of planned facilities: The higher the number of facilities planned (i.e. those announced or under construction), the higher the score.
- Total planned capacity: The higher the total capacity of all planned facilities, the higher the score.
- Operation on a large scale: The higher the capacity of the largest facility in operation or planned, the higher the score.

A more descriptive assessment of each technology and the rationale for the scores are available for download on our website: https://ocean.economist.com/rethinking-plastics/.

Advisory board members

Our thanks are due to the following people, in alphabetical order, for their time and insights:

Claudia Amos—Technical director for circularity, resource efficiency and waste, Anthesis Group

Paul Davidson—Challenge director: Smart Sustainable Plastic Packaging, UK Research and Innovation

Ioanna Dimitriou—Assistant professor in chemical engineering, University of Nottingham

George Huber—Professor of chemical engineering and director of the Center for Upcycling of Waste Plastics, University of Wisconsin-Madison

Colin Kerr—Home, beauty and personal care packaging director, Unilever

David McNamara—Chief technology officer, Plastic Energy

Akash Singh—Investment director, Circulate Capital

Ed Socci—Director, R&D packaging, PepsiCo

Karine Tessier—Vice president, research and development, Loop Industries

Interviewees

Our thanks are due to the following people, in alphabetical order, for their time and insights:

Joshua Baca—Vice president, plastics division, American Chemistry Council

Tanya Barden—CEO, Australian Food and Grocery Council

Suhas Dixit—Founder and CEO, Agile Process Chemicals

Rob Kaplan—Founder and CEO, Circulate Capital

Colin Kerr—Home, beauty and personal care packaging director, Unilever

Rachel Meidl—Fellow in energy and environment, Rice University's Baker Institute for Public Policy

Michael Norton—Environment programme director, European Academies Science Advisory Council

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Executive summary

In the world of plastic, the covid-19 pandemic has been a stark reminder of people's dependency on this versatile material as well as the ongoing failure of efforts to address a worldwide crisis of plastic waste. Globally, only 14-18% of plastic is recycled, while the rest is incinerated or landfilled, and some ultimately leaks into the environment, including waterways and the ocean. Rising concerns over plastic's contribution to environmental pollution and climate change are driving governments and business leaders to rethink the plastics value chain, including strengthening recycling.

A wave of advanced recycling innovations has the potential to transform recycling practices, offering some important advantages over established mechanical recycling technologies. Below we present the results of Economist Impact's assessment of plastic recycling technologies, in which we draw comparisons between advanced recycling technologies and existing mechanical recycling approaches. To implement and scale up these innovations, we explore policies and industry initiatives that promise to strengthen the overall recycled plastic value chain.

The key findings of this report are:

- **Emerging methods of advanced recycling can process flexible packaging and multi-material plastics, which are some of the most prolific forms of plastic waste found in the ocean.** In our assessment, technologies such as pyrolysis, hydrothermal recycling and gasification obtained the highest scores for processing multi-material plastics, as well as for their ability to process mixed waste streams, neither of which is possible with existing mechanical technologies.

- **Advanced recycling technologies can produce higher-quality and higher-value outputs than mechanical recycling approaches.** These methods can revert plastic waste back into molecules, which can then be refined into a mix of high-value uses, including new plastics suitable for food contact applications or (and only if no other use in the chemical value chain is possible) into fuels.

- **Advanced recycling technologies face a challenging path to commercialisation.** Many of these technologies are unproven at large scale: non-catalytic thermal pyrolysis and gasification are used in early commercial installations, some chemolysis technologies are being tested in demonstration facilities, and others, such as plasma pyrolysis and enzymatic hydrolysis, show promise but remain at the laboratory stage. Beyond technical maturity, the policy pathways to implementing and scaling up these facilities are either lacking or inadequate. An essential legislative amendment being introduced in some states in the US is the reclassification of advanced recycling under manufacturing rather than solid waste management.

- **Mechanical recycling remains the first port of call for the plastics recycling industry and is expected to co-exist and complement advanced recycling approaches.** Mechanically reprocessing plastic is simpler and requires fewer steps and less complex equipment than many emerging chemical recycling approaches. As such, even as advanced recycling technologies mature, mechanical recycling will continue to be the primary path for some types of plastic materials.

- **To prime demand for recycled materials, policymakers can adopt recycled content targets and reassess food-contact regulations.** A staggered rollout of targets—that is, more aggressive targets for plastics that are widely recycled, such as PET, PP and HDPE (see Figure 1 for definitions of plastic types) and a slower rollout for variants that are harder to recycle—will give recyclers time to scale up. To meet these targets, there needs to be a wider acceptance of the mass-balance approach, which helps brands achieve verifiable levels of recycled content in plastic materials. In addition, policymakers must consider whether or not food-contact regulations as they are applied today to mechanical recycling output are applicable to output from chemical or biological recycling approaches.

- **To increase the supply of recyclate, policymakers can enforce bans on exporting waste and landfilling, introduce extended producer responsibility (EPR) programmes and promote deposit return schemes.** Limits or bans on exporting waste and landfilling can divert waste to local recycling facilities. **Eco-modulated EPR schemes** can incentivise producers and brand owners to invest in waste collection and make better packaging material choices. To lift waste collection rates at the consumer level, deposit return schemes have proven to be effective. Well-designed labels can help consumers to better identify which materials to recycle (and how), which can in turn improve the economics of sorting by waste processors.

- **EPR can be a useful funding mechanism for waste collection and to subsidise recycling operations but may not be adequate for financing advanced recycling facilities.** Only once demand for recycled content is secured and supply of plastic waste is streamlined will the industry see an influx of investment. In the interim, greater knowledge of advanced technologies among development finance institutions could help spark investment, especially in emerging markets. Plastic producers and other petrochemical companies could also drive further investment in chemical recycling. These players are more familiar with operating large-scale chemical facilities, and the recycled output could serve as feedstock for their processes.

- **Stakeholder collaboration can play a catalytic role by establishing a clear roadmap to implement emerging recycling technologies.** Pilot projects can demonstrate how a new era of collaboration across the plastic value chain can help the industry evolve through this coming-of-age process. The lessons learnt from these projects promise to help establish industry best practices and guide future standards.

Introduction

Plastic is ubiquitous—it is used in products from disposable face masks to cutting-edge aviation composites—and as such is more vital to modern life than ever. Its wide range of uses stems from essential properties: plastic is lightweight, ductile, relatively low-cost and durable. Compared with metal car parts, for example, plastic substitutes often need less energy to make and weigh less, so can improve fuel efficiency. "Some forms of plastic that are lightweight are actually much better from an environmental perspective," says Tanya Barden, chief executive of the Australian Food and Grocery Council. Plastic packaging also enables food preservation: wrapping a cucumber in just 1.5g of plastic film can extend its shelf life from three to 14 days, allowing food waste to be reduced.[1] Yet our ability to properly manage waste generated from plastic's many forms lags far behind the growth in consumption.

With the health of the ocean and climate in the balance, there is a dire need to rethink the world's approach to plastic. "It would be a big mistake if plastic was just demonised," says Ms Barden. "If you can capture and recycle those materials, you can keep them in the economy. They are a problem when they leak out into the environment."

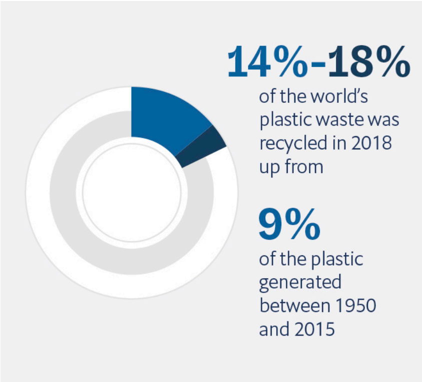
To close the loop requires transformative improvements to the fractured value chain of the plastic industry: from manufacturing and packaging design, to waste collection and sorting, to recycling.

[1] https://earth.org/why-we-cant-quit-plastic-waste/.

The plastic pollution problem

The covid-19 pandemic has highlighted the world's conflicted relationship with plastic. It is estimated that in the first year of the pandemic 3.5m tonnes of masks were landfilled worldwide.[2] During 2020 orders for online shopping and takeout food, which often use plastic packaging, rose by 78% in the US alone.[3] Consumer behaviours in Europe shifted along similar lines.[4] But little of this tsunami of pandemic-related plastic is likely to be recycled.

The crisis in plastic recycling pre-dates the pandemic. An estimate from 2018 reveals that only around 14-18% of plastic was recycled annually.[5] The rate has roughly doubled in recent years: another study from 2017 estimates that about 9% of the plastic generated between 1950 and 2015 was recycled and that plastic recycling grew by 0.7% annually between 1990 and 2014.[6] But still, one-third of overall plastic packaging produced leaks into the environment, while over half is landfilled or incinerated.[7] With global plastics production on track to double over the next 20 years,[8] a business-as-usual path suggests that the deluge of plastic into the environment could grow by as much as that (or more). Plastic waste leaking into the ocean is on track to nearly triple, from 11m tonnes in 2016 to 29m tonnes by 2040. At this rate, the stock of accumulated ocean plastic could quadruple, reaching over 600m tonnes.[9]



As plastic demand has grown in recent years, key links in global plastic waste collection and processing have strained or snapped. China, long the willing buyer of much of the world's plastic waste, closed its doors to imports of most plastic waste in 2018.[10, 11] Malaysia, Thailand and Vietnam are among a growing list of former importers that have followed suit.[12]

The upshot is that because of the lack of buyers plastic waste has piled up in sorting centres in many developed markets and is ultimately diverted to landfills or to incineration plants with energy recovery. Greater

[2] "C&EN Talks with Joana Correia Prata, Advocate for Plastic Waste Policy", *Chemical & Engineering News*, American Chemical Society, 2021. cen.acs.org/environment/pollution/Single-use-plastics-boomed-during-COVID-19-Joana-Correia-Prata-wants-to-reverse-the-trend/99/i27. Accessed 28 July 2021.

[3] "Reuse Wins", Research Report by Upstream, 16 June 2021. upstreamsolutions.org/blog/reuse-wins-report . Accessed 28 July 2021, page 5. 8.2m metric tonnes converted from 9m US tonnes.

[4] "Impacts of COVID-19 on Single-Use Plastic in Europe's Environment", European Environment Agency, 2021. www.eea.europa.eu/publications/impacts-of-covid-19-on. Accessed 13 Aug. 2021.

[5] OECD, Improving Plastics Management: Trends, policy responses and the role of international co-operation and trade, 2021. https://www.oecd.org/environment/waste/policy-highlights-improving-plastics-management.pdf

[6] The study estimates that 9% of the plastic generated between 1950 and 2015 was recycled. See Geyer, Roland et al., "Production, Use, and Fate of All Plastics Ever Made", *Science Advances*, vol. 3, no. 7, July 2017, p. e1700782. www.science.org/doi/10.1126/sciadv.1700782. Accessed 19 September 2021.

[7] Ellen Macarthur Foundation, "Extended Producer Responsibility", 2021. https://plastics.ellenmacarthurfoundation.org/epr#Position-paper, page 5.

[8] Lebreton, Laurent and Anthony Andrady, "Future Scenarios of Global Plastic Waste Generation and Disposal", *Palgrave Communications*, vol. 5, no. 1, 29 January 2019. www.nature.com/articles/s41599-018-0212-7, 10.1057/s41599-018-0212-7. Accessed 4 August 2021.

[9] The Pew Charitable Trust and SYSTEMIQ, "Breaking the plastic wave", 2020.

[10] Brooks, Amy L. et al., "The Chinese Import Ban and Its Impact on Global Plastic Waste Trade", *Science Advances*, vol. 4, no. 6, June 2018, p. eaat0131. advances.sciencemag.org/content/4/6/eaat0131, 10.1126/sciadv.aat0131. Accessed 4 August 2021.

[11] https://e360.yale.edu/features/piling-up-how-chinas-ban-on-importing-waste-has-stalled-global-recycling

[12] O'Neill, Kate, "As More Developing Countries Reject Plastic Waste Exports, Wealthy Nations Seek Solutions at Home". The Conversation, 5 June 2019. theconversation.com/as-more-developing-countries-reject-plastic-waste-exports-wealthy-nations-seek-solutions-at-home-117163. Accessed 13 August 2021.

pressure on landfills increases the risk of leakage into the environment, and more incineration increases carbon dioxide emissions. This build-up of waste is thus driving local, regional and national governments to rethink their approach to plastic waste management.

Policymakers are exploring a range of options, including banning exports of plastic waste as well as increasing local recycling capacities to accelerate domestic recycling. Rising pressure to create a circular economy and reduce greenhouse gas emissions are adding momentum to such efforts.

Shifting from linear to circular value chains

For most of its history the plastics industry has operated in a linear fashion, where products are made, used and disposed of, with little recycling or reuse afterwards. The need of the hour is to turn this fragmented, linear approach into an integrated, circular value chain. "We see [today's approach] as a system failure," says Michael Norton, environmental programme director at the European Academies Science Advisory Council (EASAC) and co-author of a 2020 EU report on plastics.[13] "The overall objectives, rewards and incentives for a more circular approach to plastics just aren't there."

Central to this shift is the scope of recycling technologies themselves. Limitations in widely used mechanical recycling technologies have meant that only a handful of plastic materials can be economically recycled today and that recycled plastics are all too often used in products of lower quality and thus lower value. A new crop of technologies—spanning chemical and biological approaches—is allowing business and government leaders to reimagine what is possible in the realm of plastic recycling.

In this report, we present the results of Economist Impact's plastic recycling technologies assessment, in which we explore advanced recycling technologies in depth, drawing comparisons with existing mechanical approaches.[14] This review is followed by an overview of select policy pathways that promise to help scale up these technologies—including options that will help to prime demand for recycled content, secure supply of plastic waste, establish advanced recycling facilities and incentivise investment.

[13] "Packaging Plastics in the Circular Economy." EASAC - *Science Advice for the Benefit of Europe*, 3 November 2020, easac.eu/publications/details/packaging-plastics-in-the-circular-economy/ . Accessed 4 August 2021.

[14] A quantitative assessment of ten recycling technologies is available on our website https://ocean.economist.com/rethinking-plastics/.

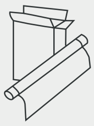
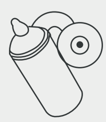
Chapter 1: Plastic recycling technologies

Mechanical recycling sits at the heart of today's plastic recycling industry. It is a mature technology, whose economics and methods are well understood. Yet it is limited in its ability to recycle a variety of plastics commonly used in consumer packaging, such as flexible and multi-layer, or multi-material, formulations, and there are restrictions in its use for food packaging and other regulated applications.

A new generation of advanced recycling methods can process many of these hard-to-recycle variations, whose output is suitable for producing food-contact material. These emerging technologies will be essential to help shift the plastics industry towards circularity. "Advanced recycling has the potential to be an important enabler to help unlock broader access to the use of recycled plastic of the right quality, as it can be a complementary

Figure 1: Commonly used plastics in consumer products

Plastic Resin Identification Codes

1 PETE	2 HDPE	3 PVC	4 LDPE	5 PP	6 PS	7 OTHER
Polyethylene Terephthalate	**High-Density Polyethylene**	**Polyvinyl Chloride**	**Low-Density Polyethylene**	**Polypropylene**	**Polystyrene**	**Other**
Common products: soda & water bottles; cups, jars, trays, clamshells	Common products: milk jugs, detergent & shampoo bottles, flower pots, grocery bags	Common products: cleaning supply jugs, pool liners, twine, sheeting, automotive product bottles, sheeting	Common products: bread bags, paper towels & tissue overwrap, squeeze bottles, trash bags, six-pack rings	Common products: yogurt tubs, cups, juice bottles, straws, hangers, sand & shipping bags	Common products: to-go containers & flatware, hot cups, razors, CD cases, shipping cushion, cartons, trays	Common types & products: polycarbonate, nylon, ABS, acrylic, PLA; bottles, safety headlight lenses
Recycled products: clothing, carpet, clamshells, soda & water bottles	Recycled products: detergent bottles, flower pots, crates, pipe, decking	Recycled products: pipe, wall siding, binders, carpet backing, flooring	Recycled products: trash bags, plastic lumber, furniture, shipping envelopes, compost bins	Recycled products: paint cans, speed bumps, auto parts, food containers, hangers, plant pots, razor handles	Recycled products: picture frames, crown molding, rulers, flower pots, hangers, toys, tape dispensers	Recycled products: electronic housings, auto parts
						

Source: https://mediaroom.wm.com/recycle-more-or-recycle-better/

Figure 2: Established and emerging plastic recycling technologies

Category	Technology	Description
Mechanical	Melt filtration and extrusion	Plastic waste is melted to filter out impurities, after which it is passed through an extruder to finally produce plastic pellets.
Mechanical	Flake to preform	A direct method of making preforms by flaking, decontaminating, melting, filtering and then feeding the melt into the injection moulding machine, skipping the pelletisation stage.
Mechanical	Purification/ Dissolution	Plastic is dissolved in a solvent and then purified to separate the polymer from additives and contaminants, with the polymers then selectively crystallised.
Chemical	Chemolysis	Use of a chemical agent such as methanol, glycol or just water to break down plastic material into its monomers.
Chemical	Non-catalytic thermal pyrolysis	Thermal decomposition of waste in the absence of oxygen to produce a plastic oil.
Chemical	Catalytic pyrolysis	Thermal decomposition of waste in the absence of oxygen but in the presence of a catalyst to enhance yield, operating window and other performance metrics.
Chemical	Plasma pyrolysis	A process integrating conventional pyrolysis with thermochemical properties of plasma to transform plastic waste into synthesis gas very quickly.
Chemical	Hydrothermal recycling	Uses water at elevated pressures and temperatures to cut longer-chain hydrocarbon bonds in plastics to produce oils and chemicals that can be reprocessed to make virgin monomers and then into plastics.
Chemical	Gasification	A process which takes place in a gasifier, generally in a high-temperature or high-pressure vessel, where controlled or limited oxygen and/or steam are in direct contact with the feed material to produce synthesis gas that can be chemically converted into monomers.
Biological	Enzymatic hydrolysis	An enzyme found in rubbish-dwelling bacteria (which live on a diet of plastic bottles) is combined with another enzyme (PETase) to speed up the breakdown of plastic into its building blocks (monomers).

Source: Economist Impact.

solution in areas where we cannot use mechanically recycled plastic, such as in food grade applications," says Colin Kerr, packaging director at Unilever.

Key considerations for mechanical recycling

Mechanical recycling remains the first port of call for the plastics recycling industry. Mechanically reprocessing plastic is simpler and requires fewer steps and less complex equipment than many emerging chemical recycling approaches. As such, mechanical recycling is commercially viable even on a smaller scale. And as advanced recycling technologies mature, mechanical recycling will still continue to be a primary path for some plastic products, including laundry bottles and agricultural films.

In recent years the process of melt filtration and extrusion has been most widely adopted to recycle PET plastic waste, such as water or soda bottles. After sorting and decontamination, PET waste is melted and passed through an extruder to produce pellets, which are subsequently melted and reshaped into new products.

Another mechanical approach, known as flake to preform, allows recyclers to mould plastic into new products directly after melting, skipping the pelletisation stage. For this approach to be effective, however, waste input must be especially consistent—for instance, bottles from a specific brand or manufacturer. This guarantees that the quality of the output is higher than that of the conventional melt filtration approach, because it is produced from a single waste stream and skips a second round of melting.

In both approaches, each time the material is recycled, there is degradation in the quality of the output. In our assessment, melt filtration and extrusion received the lowest score on "quality of output", while flake-to-preform received only a slightly higher score (as the waste is sorted extensively). As a result of the degradation, there are limitations on the number of times plastic can be recycled, and some waste products cannot be recycled into their original application. As such, for certain products, this approach cannot be considered "circular" but rather an "open loop" process.[15]

In addition, mechanical approaches are unable to process mixed or multi-material waste streams and as such require a high level of sorting and decontamination to create streams with only a single type of plastic. But perhaps most importantly, current food-safety regulations restrict the use of mechanically recycled plastic in the production of food packaging.

Advancing beyond mechanical recycling

Advanced recycling technologies hold great promise, including the increased use of the recyclate in food packaging, creating the equivalence of new plastic during recycling, and the ability to process hard-to-recycle plastics such as thin film and multi-material plastics often used in packaging.

The output quality of chemical recycling processes is a key virtue. Across all chemical

[15] 'Open loop' is a process in which the recycled output cannot be used to produce the original product and is used for other purposes. 'Closed loop' is a process in which the recycled output can be used to produce the original product.

and biological processes, the outputs are widely considered to be of higher value and quality than those obtained from mechanical approaches.

Among the chemical and biological approaches covered in our assessment, chemolysis and enzymatic hydrolysis—which can only process PET plastic waste—produce monomers (i.e. molecules of plastic) that can easily be used as feedstock for the production of new plastic materials. For different types of pyrolysis, hydrothermal and gasification technologies, the output comprises a mix of liquid hydrocarbons (oils) and gases. Currently, these outputs are often used for purposes other than plastic production, such as fuel production. But the oils and gases extracted from these recycling processes can be cleaned and processed into virgin-like polymers, which makes them suitable for food-grade packaging.

This kind of molecular recycling also minimises the degradation common in mechanical processes, so that recycled plastics can be reused repeatedly at the same quality level rather than being downcycled. As such, the chemical recycling technologies featured in our assessment receive higher scores than mechanical technologies for quality of output, surpassed only by enzymatic hydrolysis (where the output has the same properties as virgin PET).

Technologies that can process multi-material plastics are also of great interest, as about 70% of the plastic waste found in the ocean is flexible packaging and multi-material plastics.[16] These include chemical recycling methods such as pyrolysis (different types) and hydrothermal and gasification technologies.

Hydrothermal and gasification technologies are also effective at processing mixed waste streams—that is, different types of waste jumbled together, including plastics, paper and wood, among others (excluding metals and glass).[17] In our assessment, hydrothermal and gasification technologies receive higher scores on this indicator as they can process mixed waste streams more effectively than pyrolysis technologies. The ability to handle heterogeneous materials and waste streams suggests that, over the long term, these technologies could potentially lower the cost and effort required today to segregate waste at source (i.e. in our homes, at work or in public) or at later stages at waste management facilities (although they are unlikely to eliminate the need for sorting altogether, given that there are limits to the types of waste they can process).

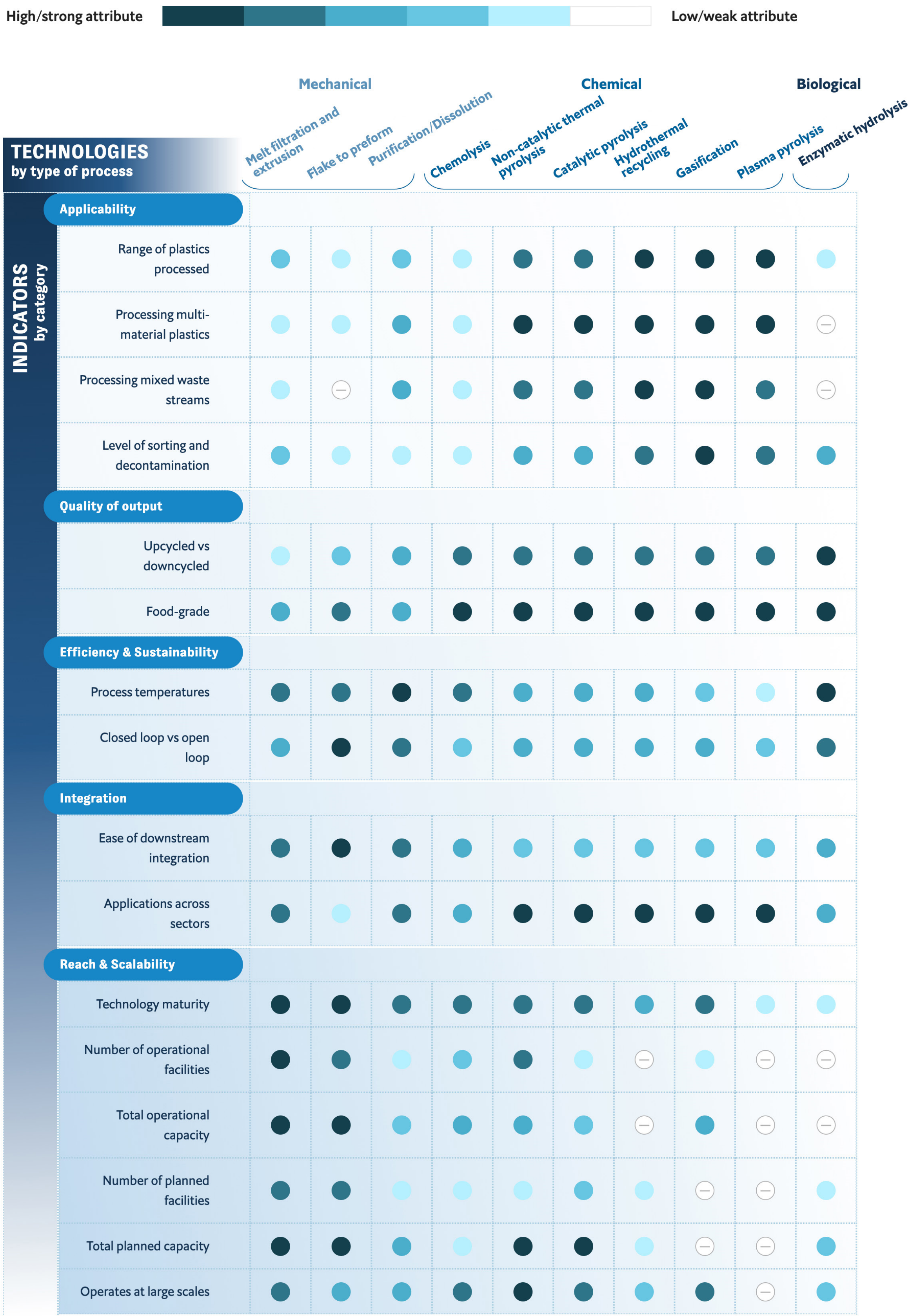
Impediments to scaling up advanced technologies

Despite these advantages, the rollout of advanced recycling technologies has only just begun. Facilitating wider implementation will require the recycling industry to navigate multiple challenges, ranging from technical immaturity and uneven policy to raising finance and collaborating with wider groups of stakeholders. We will explore a selection of these factors in the next chapter.

[16] The Pew Charitable Trusts and SYSTEMIQ, Breaking the Plastic Wave: A Comprehensive Assessment of Pathways Towards Stopping Ocean Plastic Pollution, 2020. https://www.pewtrusts.org/-/media/assets/2020/10/breakingtheplasticwave_mainreport.pdf

[17] https://netl.doe.gov/research/coal/energy-systems/gasification/gasifipedia/waste

Figure 3: Plastic recycling technologies assessment



Source: Economist Impact.

For details on the assessment methodology and scoring guidelines, please see the "About this research" section.

Many of these technologies are at the early stages of their development. Chemolysis and some types of pyrolysis technologies, for example, are currently used only at demonstration facilities; enzymatic hydrolysis and plasma pyrolysis are still at the laboratory stage. There are only operational commercial facilities using some types of non-catalytic thermal pyrolysis and gasification, and one hydrothermal facility is under construction.[18]

Crucially, chemical recycling processes are complex, relatively energy-intensive and can lead to high carbon dioxide emissions unless powered by renewable energy sources (which, according to the experts we interviewed, seems unlikely at this stage). In our assessment, plasma pyrolysis receives the lowest score as it requires the highest process temperatures (ranging from 1,800°C to 10,000°C),[19] followed by gasification (about 1,200°C) and then pyrolysis and hydrothermal recycling (ranging from 300°C to 700°C).

In addition, the chemical reactions essential for these processes present complex safety hazards. The relevant facilities demand careful engineering and construction as well as advanced safety protocols when operational, and thus demand higher investment compared with mechanical recycling. The oil or gas yield of some of these processes can vary, as residues and side streams (including impurities) from inbound plastic waste must be managed carefully.

Furthermore, some of the recycled output will need additional preparation before it can be used to produce new plastic materials. "You cannot just take plastic oil [after pyrolysis] and start feeding it into a cracker," says Suhas Dixit, founder and chief executive of APChemi, a Mumbai-based firm which has constructed over 30 conventional thermal pyrolysis recycling plants globally. Some further clean-up is required, which can lead to bottlenecks. From that perspective, our assessment assigns a higher score for chemolysis compared with pyrolysis and gasification because the outputs of the latter technologies require more preparation prior to plastic production. However, given the complexity of operating advanced plastic recycling compared with mechanical recycling, it is likely that the former will be commercially viable only on a large scale.

As these emerging solutions evolve from development to commercialisation, their chances of success depend on the overall health of the wider value chain of plastic recycling. In the absence of a steady supply of plastic waste coming from upstream and sustained demand for recycled content downstream, advanced plastic recycling cannot thrive. In the next chapter, we will explore a variety of policy options that can strengthen the wider value chain.

[18] At the time of writing, in August 2021.

[19] Plasma pyrolysis powered by electricity from renewable sources of energy could be more energy-efficient. As the technology is still at laboratory scale, further research is required to better assess this.

Chapter 2: Policy pathways

A sequence of events—from China's import ban on unsorted plastic waste to the increased use of single-use plastics during the covid-19 pandemic—has fanned climate anxieties. Growing public concern over plastic pollution has spurred policymakers to launch a range of initiatives, including upgrading the plastics recycling system. This involves engaging industries along the plastics value chain to commit to and invest in recycling plastic.

But much of what might be called first-generation plastics recycling policy is proving ill-suited to recent technical and market shifts. Indeed, for technologies ready for use on a commercial scale—particularly some types of pyrolysis, hydrothermal technologies and gasification—the right policy framework is critical to enable faster, wider implementation. A robust set of policies will help to expand the market for recycled content and streamline the supply of plastic waste. Only when these are ensured is the industry more likely to see an influx of investment.

Addressing the trilemma of demand, supply and finance will require a great deal of collaboration among governments and business leaders across the value chain. Indeed, the need for better co-ordination is a thread that runs through many of the policy initiatives we explore in this chapter.

Priming demand for recycled plastic

For new advanced plastic recycling methods to flourish, recyclers and their financiers must be confident that the markets will be there to buy their recycled plastics. Thus, cultivating stronger demand for recycled plastics may be a good priority to start with, because it can act as an animating force: justifying new recycling capacity, attracting investment and catalysing further innovation. Here, we explore key policy measures to prime demand, focusing on recycled content targets and food safety standards.

Setting content targets

Minimum recycled content targets are a potent device to establish stable, long-term demand for recycled plastics. These can be voluntary (established by brands and other plastics consumers) or mandatory (enforced by regulators).

In the private sector, some global brands have set out voluntary targets. Unilever, a multinational producer of foods, household supplies and other consumer goods, is aiming to boost the use of recycled plastic material in its packaging to at least 25% by 2025, from current rates of 15%.[20]

Mandatory targets are multiplying too. Under the EU's 2019 Single Use Plastic Directive, PET beverage bottles must be made of at least 25% recycled content by 2025, and all beverage containers must achieve 30% recycled content by 2030.[21]

Other economies are moving in the same direction. Australian rules call for 20% plastic content by 2025.[22] In the US, California became the first state to mandate a target: 15% post-consumer recycled resin by 2022, rising to 25% by 2025 and 50% by 2030.[23] In July 2021 the American Chemistry Council (ACC), an industry group of plastics producers, called on Congress to pass a standard at the federal level requiring that all plastic packaging include at least 30% recycled content by 2030.[24]

But rolling out quotas can be a delicate balancing act, as they can outpace the availability of recycled content. In the US, for example, if enacted today, ACC's proposed 30% national standard would require 5.9bn kg of recycled plastic annually, a level not currently available.[25] Smart policies must therefore recognise the limits of today's recycling capacity while spurring investments in waste infrastructure and policies to increase recycling.

Solutions include varying rollout periods by plastic type, to give suppliers of recycled content time to scale up, and setting thresholds with rising fees to help induce more of the market to comply over time. For instance, quotas for PET, PP and HDPE—the most highly recycled plastics today—can be more aggressive sooner than those for plastics which are harder to recycle.

Yet even in more established markets such mandates can miss the mark of nurturing local recycling capacity. The EU's recycled content minimum has spiked demand—and prices—for recycled PET in Asia. "Most of the recyclers we talk to in Indonesia export their PET material to Europe," says Rob Kaplan, founder and CEO of Circulate Capital, a Singapore-based investment management firm dedicated to the development of a circular economy to combat plastic pollution.[26] Mr Kaplan points out that this is a questionable outcome if the EU's policy goal is to incentivise new recycling capacity at home.

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[20] 15%. https://www.unilever.com/planet-and-society/waste-free-world/rethinking-plastic-packaging/

[21] "Europe's Drive to Slash Plastic Waste Moves into High Gear", Yale E360, June 8 2021, e360.yale.edu/features/europes-drive-to-slash-plastic-waste-moves-into-high-gear. Accessed 13 August 2021.

[22] Department of Agriculture, Water and the Environment, 2021. www.environment.gov.au/protection/waste/plastics-and-packaging/national-plastics-plan/recycling. Accessed 14 August 2021.

[23] "CA to Require Minimum Recycled Content in Plastic Bottles | PackagingLaw.com", 15 October 2020. www.packaginglaw.com/news/ca-require-minimum-recycled-content-plastic-bottles. Accessed 13 August 2021.

[24] Staub, Colin, "ACC Calls for 30% Recycled Content Mandate in Packaging," Plastics Recycling Update, 14 July 2021. resource-recycling.com/plastics/2021/07/14/acc-calls-for-30-recycled-content-mandate-in-packaging/. Accessed 14 August 2021.

[25] "Plastic Makers Outline 5 Actions Congress Can Take to Advance Circular Economy, End Plastic Waste". Americanchemistry.com, 2020, www.americanchemistry.com/Media/PressReleasesTranscripts/ACC-news-releases/Plastic-Makers-Outline-5-Actions-Congress-Can-Take-To-Advance-Circular-Economy-End-Plastic-Waste.html. Accessed 14 August 2021.

[26] Circulate Capital's founding investors include Dow, the sponsor of this report, along with Chanel, Chevron Phillips Chemical, Coca-Cola, Danone, PepsiCo, Procter & Gamble and Unilever.

Another challenge the industry faces is raising the percentage of recycled content in production. The technical realities of blending recycled plastic into complex production systems can vary significantly based on the recycling process—i.e. mechanical vs chemical. In recent years plastic makers have increasingly coalesced around a **"mass-balance approach"** to introduce and account for how recycled material (drawn from either mechanical and/or chemical processing) is blended into new plastic.[27] See **Box 1** for views on the need for a wider adoption of the mass-balance approach.

Applicability of food safety standards

Existing food safety rules in many areas treat recycled plastic cautiously. For instance, the US Food and Drug Administration has expressed concerns that contaminants from post-consumer recycled plastics may appear in food-contact packaging.[28] These concerns, however, are largely based on risks associated with the mechanical recycling of plastic recyclates, in which impurities could survive the journey through sorting, grinding and reheating and make their way back into food packaging.

Advanced recycling can largely eliminate such risks by delivering virgin-grade material that is molecularly identical to fossil-based polymers (i.e. it has the same characteristics and purity levels) and so would just be subject to the well-known and existing specifications already in place for virgin material. As such, food safety regulations or restrictions that apply to the output of mechanically recycled plastic may not apply to chemically recycled plastic.

Securing supply of plastic waste

The plastics industry finds itself at an imbalance, whereby demand for recycled content is beginning to surge but sources of supply remain limited. "Global supply for recycled plastic content is not sufficient to meet existing levels of demand," says Ms Barden.

Efforts to stimulate demand for recycled plastic further, as discussed in the previous section, should be matched with efforts to broaden supply. In this section we explore supply-side initiatives, including a ban on exporting plastic waste or landfilling, policies to incentivise better collection and sorting of plastic waste, and measures to boost collection rates at the consumer level. Together, these policies promise to help increase not only the flow of post-consumer plastic but also its consistency and quality.

Creating local recycling pathways

Some developing countries, such as Indonesia, continue to import plastic waste from more developed nations, thereby

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[27] The Ellen Macarthur Foundation, "Enabling A Circular Economy For Chemicals With The Mass Balance Approach". https://www.ellenmacarthurfoundation.org/assets/downloads/Mass-Balance-White-Paper-2020.pdf

[28] Center for Food Safety and Applied Nutrition, "Recycled Plastics in Food Packaging," US Food and Drug Administration, 2020. www.fda.gov/food/packaging-food-contact-substances-fcs/recycled-plastics-food-packaging. Accessed 10 September 2021.

Box 1: Mass-balance approach to recycled plastic production

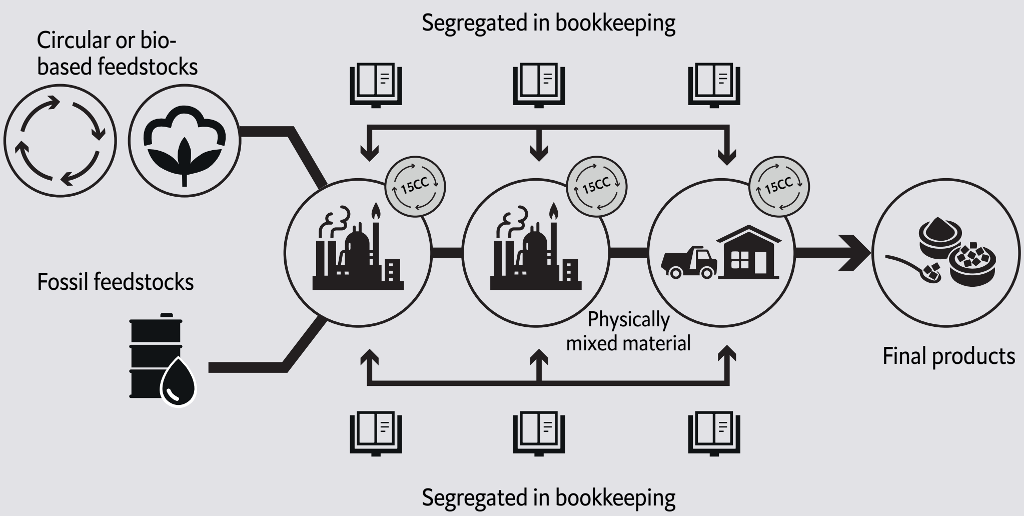
Consider a food company which wants to buy plastic containers made with 30% recycled feedstock. One might guess that the chemical plant would simply produce a discrete batch of plastic by mixing seven parts virgin resin with three parts recycled plastic. Yet petrochemical plants do not work in that way. Rather, their immense scale and continuous production flows make it impossible to physically separate a discrete batch of recycled material at the end of the production line.

Via a mass-balance approach, producers can mix the necessary amount of recycled feedstock into production flows. Standardised accounting methods, which are being refined for a circular plastic economy, let the producer and the buyer validate key attributes, such as the volume of recycled content used relative to the output, along with their sustainability characteristics.

The mass-balance approach has been successfully implemented in other industries, including sustainable forestry, renewable electricity, fair trade coffee and organic cotton.[29] A wider acceptance of the approach could benefit both mechanical and chemical plastics recycling.

For the latter, a recent report from the Ellen Macarthur Foundation concludes that the mass-balance approach can make it easier to blend recycled feedstock into extant chemical production networks and accelerate the move towards a circular economy.[30] Chemical recycling approaches produce virgin-like hydrocarbon molecules from plastic waste that can more easily be integrated with existing petrochemical facilities for plastic production.

Figure 4: Mass-balance approach accounting process



Source: International Sustainability and Carbon Certification.

[29] Ibid.

[30] Ibid., page 25.

often overwhelming already weak waste-management systems. This has been the primary source of ocean plastic pollution. Preventing such exports to emerging economies which lack the infrastructure is thus a top priority. In developed countries, policymakers hope to boost local recycling capacity utilisation and incentivise investment in additional infrastructure by introducing bans on exporting waste to low-cost outlets.

In 2021 global rules came into effect reflecting a decision by 187 countries to significantly limit global trade in plastic scrap and waste. Passed in 2019 in the wake of China's curtailment of plastic waste imports, the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes was designed to address the improper disposal of plastic waste and reduce its leakage into landfills and the environment. The treaty sets controls for crossborder shipments of most plastic scrap and waste, permitting shipment only with the prior written consent of the importing country and any transit nations.[31]

At the national and regional level, policymakers are developing complementary policies to limit exports of plastic waste and spur the growth of domestic recycling capacity. Australia, for instance, has implemented limits on the export of unprocessed plastic waste.[32] The rule, effective from July 2021, only permits exports of plastics "sorted into single resin or polymer type" or "processed with other materials into processed engineered fuel". At the same time, regulators offered public funding to help upgrade domestic sorting and processing capacity, a step towards building more advanced recycling capacity once supplies are stable. Such export bans have the added benefit of reducing the carbon footprint of recycled content, so long as waste is reprocessed closer to its origins.

Momentum is building in Europe too. In January 2021 an EU-wide ban came into force prohibiting the shipment of unsorted plastic waste to countries outside the region. Some EU lawmakers are pushing to go further by curtailing the export of all plastic waste with the aim of facilitating intra-EU recycling capacity and shifting towards a circular economy.[33] This regional approach is especially beneficial for smaller countries that are unable to scale up advanced recycling technologies.

In addition to banning the export of plastic, the EU's scientific advisory body, the EASAC, has also endorsed a zero-plastic-waste-to-landfill policy.[34] Already 11 European nations landfill less than 10% of their plastic waste.[35] EU rules mandate that member nations reduce overall waste landfilled to 10% or less by 2035.[36] Combined, these limits on plastics exports and landfilling force municipalities to

[31] "New International Requirements for the Export and Import of Plastic Recyclables and Waste | US EPA". 28 August 2020. www.epa.gov/hwgenerators/new-international-requirements-export-and-import-plastic-recyclables-and-waste. Accessed 10 September 2021.

[32] "Australia: Bill Banning Export of Unprocessed Waste Enacted", The Library of Congress, 11 January 2021. www.loc.gov/item/global-legal-monitor/2021-01-11/australia-bill-banning-export-of-unprocessed-waste-enacted/ . Accessed 16 August 2021.

[33] Taylor, Kira, "Stop Exporting Plastic Waste out of Europe, EU Lawmakers Say". www.euractiv.com, EURACTIV.com, 20 April 2021. www.euractiv.com/section/circular-materials/news/stop-exporting-plastic-waste-out-of-europe-eu-lawmakers-say/ Accessed 10 September 2021.

[34] "Packaging Plastics in the Circular Economy". EASAC - Science Advice for the Benefit of Europe, 3 November 2020, easac.eu/publications/details/packaging-plastics-in-the-circular-economy/. PDF, page 3. Accessed 13 August 2021.

[35] "Zero Plastics to Landfill", Plasticseurope.org. www.plasticseurope.org/en/focus-areas/circular-economy/zero-plastics-landfill . Accessed 10 September 2021.

[36] "Diversion of Waste from Landfill in Europe", European Environment Agency, 2021. www.eea.europa.eu/data-and-maps/indicators/diversion-from-landfill-1/assessment . Accessed 10 September 2021.

better manage their waste and could increase intra-EU recycling capacity utilisation.

Extending producers' responsibility

When considering ways to alleviate supply constraints for plastic recycling, extended producer responsibility (EPR) regimes can help in two ways. First, by holding packaging producers, importers and brand owners responsible for a product even after consumer use, EPR incentivises them to invest in post-consumer waste collection, sorting and recycling. Organisations such as Ocean Conservancy and the Ellen Macarthur Foundation have determined that EPR schemes are effective ways to increase investment in waste management.[37, 38] Second, by having brands bear the costs of post-consumer product management, they are incentivised to make better material choices at the outset, as explained below.

Box 2: EPR defined

According to the OECD, extended producer responsibility is "an environmental policy approach in which a producer's responsibility for a product is extended to the post-consumer stage of a product's life cycle". As for packaging, this means that whoever introduces packaging or packaged goods into a country's market remains responsible for that material after use.

Sources: OECD;[39] Ellen Macarthur Foundation.[40]

From less than ten nations in 2000, hundreds of countries, provinces and regions have passed or are in the process of preparing EPR laws today.[41, 42] In 2021 a tax of €800/ tonne on non-recycled plastic waste came into effect in EU member states,[43] part of a wider recycling policy that obliges EU nations to establish EPR schemes by 2025, with specific targets for plastic recycling of 55% by 2030, from around 25% in 2021.[44]

However, the devil is in the detail. "EPR is one of the most promising tools, but also one of the most misapplied," says EASAC's Professor Norton. "It's ostensibly applied by each member state, but in some member states it's basically a blanket, small amount. It's not differentiated between different resins or different applications." To establish a rigorous hierarchy of packaging options, fee structures need to be informed by sophisticated life cycle assessments (LCAs), which map out a product's comprehensive impact on carbon,

[37] Ocean Conservancy, Plastics Policy Playbook: Strategies for a Plastic-free Ocean, 2019. https://oceanconservancy.org/wp-content/uploads/2019/10/Plastics-Policy-Playbook-10.17.19.pdf

[38] Ellen MacArthur Foundation, "Extended Producer Responsibility: A necessary part of the solution to packaging waste and pollution", 2021. https://emf.thirdlight.com/link/cp8djae8ittk-xo55up/@/#id=0

[39] OECD, Extended Producer Responsibility: updated guidance on efficient waste management (2016), definition and policy rationale. https://www.oecd.org/environment/waste/extended-producer-responsibility-9789264256385-en.htm

[40] Ellen Macarthur Foundation, "Extended Producer Responsibility", 2021. https://plastics.ellenmacarthurfoundation.org/epr#Position-paper

[41] Environmental Performance Index 2018, page 7.

[42] Ellen MacArthur Foundation, "Extended Producer Responsibility: A Necessary Part of the Solution to Packaging Waste and Pollution". https://plastics.ellenmacarthurfoundation.org/epr. Accessed 31 July 2021, page 19 for the data and map image.

[43] Packaging Europe, "Unpacking the EU Plastic Packaging Levy", 22 March 2021. https://packagingeurope.com/unpacking-the-eu-plastic-packaging-levy/. Accessed 31 July 2021.

[44] "Packaging Waste", Environment. ec.europa.eu/environment/topics/waste-and-recycling/packaging-waste_en#ecl-inpage-507. Accessed 31 July 2021.

energy, water and other resources from creation to the end of its life.

Guided by a framework of eco-modulation (see Box 3), EPR schemes can be developed to reward choices of materials that are easily recyclable and escalate penalties for difficult-to-recycle materials. For example, the makers of a sports drink would face higher fees to package their drink-mix powder in a hard-to-recycle pouch made of layered metal and thin plastic than if they opted for a slightly heavier but more reliably recyclable HDPE container. The regime's use of pricing signals rather than blunt mandates could be more effective in steering packaging design decisions towards more recyclable options, thereby increasing their supply. Europe calls for eco-modulation as part of the EU's 2025 EPR regime, mentioned above.

What constitutes a "recyclable" material will need ongoing vigilance, given the evolution in material science and recycling technologies. For instance, emerging chemical recycling approaches can process multi-material packaging that is today considered too costly to recycle.

Boosting collection of plastic waste

To improve collection rates of plastic waste in the early stages of the value chain, regulators and the industry are looking at a mix of policies to lift collection volumes and encourage consumer participation, including financial incentives and digital labels.

Deposit return schemes (DRS)—small, refundable deposits on each container—are among the oldest and most effective tactics to move the needle on waste capture rates. Establishing or raising the bounty on containers has repeatedly been shown to lift collection rates.

Germany, which introduced DRS in 2002, is considered a model for the wider EU adoption of the scheme. Today, only 1-3% of non-reusable bottles are not returned in the country.[45] In 2016 Lithuania instituted a new scheme with a container deposit of €0.10 on glass, plastic and metal beverage containers. By the end of 2017 the return rate for PET bottles had nearly tripled to 92%, from 34%. By raising financial incentives, the rollout of DRS can also deliver an important secondary benefit: increasing the public's awareness of and engagement in pre-sorting and recycling.[46]

[45] https://www.theguardian.com/world/2018/mar/30/has-germany-hit-the-jackpot-of-recycling-the-jurys-still-out

[46] Hazlegreaves, Steph, "Recycling: Lithuania Deposit System Exceeds All Expectations", Open Access Government, 24 April 2018. www.openaccessgovernment.org/recycling-lithuania-deposit-system-exceeds-all-expectations/45003/. Accessed 1 August 2021.

In addition to financial cues, better consumer education and clearer labelling are both considered important tactics to lift collection rates. Giving consumers and recyclers access to more and clearer information about materials can help them discern which can be recycled.

A new generation of digital labels shows promise. QR codes can hold more information and can be scanned more reliably, including by smartphones. In Europe, more than 130 companies and organisations from across the packaging value chain are collaborating on HolyGrail 2.0, a digital watermark for plastics and other packaging.

Combined with the latest sorting technologies powered by artificial intelligence, these digital labels could boost the quality and consistency of waste streams significantly. "Technology and innovation can help develop solutions to the barriers to recycling, for example, helping to improve the ability of waste materials to be cleanly separated at the recycling stage," says Unilever's Mr Kerr."

For advanced and mechanical recyclers alike, this could mean more reliable sorting and higher market prices if their output is of higher quality. Dependable tracking could help establish a more reliable chain of custody—particularly for EPR implementation—and boost trust in the marketplace that claims about recycled content are valid.[47] From the consumer perspective, these digital codes could minimise the need to sort materials at home.

Box 3: How Italy makes eco-modulation work

Italy has emerged as a leading practitioner of well-designed eco-modulated EPR. Fees scale sharply: some of the most readily recycled materials are €150/tonne, while unrecyclable materials are nearly four times as costly, at €546/tonne.[48] For multi-material and composite packaging fees can be adjusted to reflect the ease—or difficulty—of separating and recycling layers. Penalties can be applied to additives or design elements that disrupt sorting, such as opacifiers, labels, glues and lids.[49]

Introduced in 1997, Italy's CONAI-COREPLA system is notable for its culture of constructive collaboration between plastic producers, the packaging industry and regulators. The regime includes the consideration not just of technical recyclability but also of the availability of local capacity to produce and use the recycled material. The scheme thus works to encourage improvements in local recycling infrastructure.

Rules for implementation

In parallel, policymakers must ensure that the legislative agenda enables advanced recycling facilities to set up and operate as intended. Amendments to existing legislation regarding the classification of these facilities may be necessary.

Across the US, in the states of Virginia, Arkansas and New Jersey, lawmakers have implemented or are developing appropriate legislation reclassifying advanced recycling as a manufacturing process rather than a solid waste management facility.[50, 51, 52] The EU's

[47] "Decoding the New 'Uniform Framework for Extended Producers Responsibility' under Plastic Waste Management Rules", Recykal Blog, 4 May 2021. blog.recykal.com/decoding-the-new-epr-framework/. Accessed 7 August 2021.

[48] *Packaging plastics in the circular economy*, European Academies Science Advisory Council, 2020-11-03. https://easac.eu/publications/details/packaging-plastics-in-the-circular-economy/, page 4.

[49] Ibid, page 19.

[50] virginiamercury.com/2021/01/25/lawmakers-are-considering-adding-advanced-recycling-to-state-code-so-what-exactly-is-it/

[51] americanchemistry.com/Media/PressReleasesTranscripts/ACC-news-releases/Arkansas-Is-13th-State-to-Pass-Advanced-Recycling-Legislation-to-Help-End-Plastic-Waste.html

[52] resource-recycling.com/plastics/2021/06/30/new-jersey-lawmakers-advance-recycled-content-mandate/

plastic strategy also acknowledges the need to develop advanced recycling facilities, and while work is ongoing, there is little detail available on the changes to legislation that might enable wider implementation.[53]

Financing plastic recycling

"Many, many billions of dollars are needed to build the infrastructure required to prevent plastic pollution and enable a circular economy, [including] the collection, sorting, processing and manufacturing in every country around the world," says Mr Kaplan, who founded Circulate Capital in Singapore to help fund the plastic recycling industry in Asia.

The scale of the finance challenge is enormous. As a back-of-the-envelope estimate, to achieve targets of recycling 50% of global

Box 4: A case study in collaboration to boost plastic recycling

In the past, thin flexible plastics—the sort often used to wrap a chocolate bar—have been among the toughest to recycle. Very light and often composed of mixed materials, such wrappers are typically too costly and too low-value to process. But in recent years chemical recycling methods have emerged that can process the material. How, then, do you quickly establish a group of allies to set up a whole new recycling value chain?

"When I talk to business leaders—from big brands to small local recycling companies—they're all struggling to deal with this alone," says Tanya Barden, chief executive of the Australian Food and Grocery Council. "There is a massive need for collaboration across the value chain."

Enter KitKat. Nestlé's crunchy chocolate-covered wafer biscuit sits at the centre of a pilot undertaken by a consortium of companies in Australia to recycle flexible films and blend them into new wrappers made with 30% recycled content.

The effort brings together a coalition on the key steps of the new value chain, starting with material collection (REDcycle and CurbCycle), sorting (iQ Renew), chemical recycling (Licella, which has developed hydrothermal liquefaction technology able to process plastic films into plastic oils), refining (Viva Energy Australia), packaging materials makers (LyondellBasell, Taghleef Industries and Amcor), and last but not least, an end buyer (KitKat confectioner Nestlé).[54]

The lessons learnt from the trial will be informative as the industry works to develop an EPR scheme for hard-to-recycle plastics, such as soft packaging, says Ms Barden.

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[53] https://ec.europa.eu/environment/strategy/plastics-strategy_en#ecl-inpage-356

[54] Tavares Kennedy, Helena, "Gimme a Piece of That! Licella, Nestlé, Others Have Sweet News on Plastic Waste to Plastic Resource", *Biofuelsdigest.com*, 2021. www.biofuelsdigest.com/bdigest/2021/03/21/gimme-a-piece-of-that-licella-nestle-others-have-sweet-news-on-plastic-waste-to-plastic-resource/. Accessed 6 August 2021.

plastic by 2030, the industry would require about 230m tonnes of recycling capacity (if the demand for plastics follows its current trajectory, an estimated 460m tonnes of plastic is expected to be generated in 2030).[55] Much of that capacity is needed in Asia, Africa, Latin America and other emerging markets, where investment is limited but plastic is proliferating."It can be 100 times more difficult to raise funds for advanced plastic recycling in Asia," says Mr Dixit of APChemi.

Yet if the growth in plastic consumption is in Asia, current demand for recycled materials is centred in the US and Europe among the big global brands such as Unilever, P&G, Danone, Coke and Pepsi, says Mr Kaplan. There is an opportunity then for Asian countries to expand advanced recycling capacity to process large volumes of plastic waste and serve demand in North American or European markets.

Uncharted waters

Compared with mechanical technologies, advanced recycling technologies are expected to operate on a much larger scale, are more complex and must adhere to stringent safety standards. As a result, the initial capital outlay as well as the operational costs can be significantly higher. For technologies that are largely unproven, it is unsurprising then that investors are slow to enter.

There are as yet no dominant solutions to make financing advanced plastic recycling facilities more attractive. Some experts point to EPR schemes as a promising source of financing to expand recycling capacity,[56] but past EPR schemes have fallen short. "There is a difference between funding and financing that is drastically misunderstood in a lot of these conversations," says Mr Kaplan.

"Investors finance projects or companies and expect a return," he adds. "EPR is a funding mechanism that brings cash into the system, but it doesn't expect a return." EPR regimes may be better suited to fund waste collection and sorting and potentially even subsidise recycling operations, but to date they have had only a marginal impact on financing new facilities.

For this reason, it is crucial for policymakers to create an enabling environment for advanced plastic recycling facilities (through policies for priming demand and streamlining supply) and allow market forces to drive private-sector investment into this sector. So as long as landfills or incineration are the cheaper path, recyclers will struggle to compete.

[55] McKinsey, How plastics waste recycling could transform the chemical industry, 2018. https://www.mckinsey.com/industries/chemicals/our-insights/how-plastics-waste-recycling-could-transform-the-chemical-industry

[56] Institute for European Environmental Policy, "How to implement EPR for plastics packaging and recycling", 2019-08.pdf

Closing the gap

To date, advanced recycling has been too nascent to attract the attention of big institutional investors, says Mr Kaplan. The recycling industry suffers from a "missing middle": intermediaries who can bundle opportunities into packages better tailored to the needs of large investors, such as pension funds, sovereign investment funds and other institutional investors.

Even development finance institutions (DFIs), the typical first movers for funding in emerging markets, have been reluctant, according to Mr Kaplan. "[DFIs such as the World Bank and Asian Development Bank] don't understand this space yet," he says.

DFIs have only recently started to assess recycling projects as part of their portfolio to drive sustainable finance, but even this investment has been directed to traditional mechanical approaches. In November 2020 the International Finance Corporation (IFC) arranged a landmark US$300m loan package for Indorama Ventures, the world's largest PET producer, to boost its flake-to-preform recycling capacity to 750,000 tonnes per year by 2025. The capital will fund facility upgrades in Brazil, India, Indonesia, the Philippines and Thailand.[57] Similar investments for advanced recycling will be the starting point for wider implementation.

In addition, plastic producers and other petrochemical companies may be well suited to expand current operations vertically into recycling. Output from recycled chemical processes—such as plastic oil from pyrolysis or synthesis gas[58] from gasification—can serve as feedstock for their facilities. "These industry players will also be far more familiar with the engineering, safety and operational challenges of large-scale chemical processes," says Joshua Baca, vice president of the plastics division at the American Chemistry Council. Members of PlasticsEurope, an association of plastic manufacturers on the continent, are planning to invest up to €7.2bn by 2030.[59]

Tax credits and exemptions for advanced recycling facilities could also improve the economics of the investment. In 2019 the state of Virginia implemented an income tax credit and an exemption from the state sales tax for equipment used in advanced recycling facilities.[60]

Ultimately, the knowledge of plastic recycling will deepen among investors as industry trends follow a pattern seen with other climate opportunities. Mr Kaplan notes that just a decade ago a lot of big investors did not understand how to invest in solar or wind either. "Now they do." Capital has a way of finding growth opportunities, after all.

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[57] "New Blue Loan to Help Indorama Ventures Recycle 50 Billion PET Bottles a Year by 2025", Indorama Ventures Public Company Limited, 2020. www.indorama-ventures.com/en/updates/other-release/1647/new-blue-loan-to-help-indorama-ventures-recycle-50-billion-pet-bottles-a-year-by-2025. Accessed 14 August 2021.

[58] A combination of hydrogen, carbon monoxide and often carbon dioxide used to produce ammonia or methanol.

[59] https://www.bioplasticsmagazine.com/en/news/meldungen/20210527-European-plastics-manufacturers-plan-7.2-billion-Euros-of-investment-in-chemical-re-cycling.php

[60] https://www.deq.virginia.gov/land-waste/recycling/tax-incentive-programs

Conclusion

A fundamental industry shift is catalysing a wave of technological innovation in plastic recycling. Advanced recycling methods are worthy of special attention because, vital as mechanical recycling methods will remain, they face limits. On the road to a circular plastics economy a new generation of chemical recycling technology will be essential to handle increasing volumes of plastic waste.

Economist Impact's assessment of plastic recycling technologies shows that non-catalytic and catalytic pyrolysis, gasification and hydrothermal technologies hold the greatest promise. They are at a stage of early commercial installation, with a few already operating on a commercial scale, and there are plans for further expansion. Their ability to produce recycled content that can be used in food packaging, process multi-material plastics that are currently hard to recycle and potentially recycle plastics infinitely make them particularly appealing for further exploration.

Additional technical analysis will be required to assess the environmental attributes of these technologies and their output. There is currently little information available on resource efficiency of advanced technologies, including water and energy usage. These elements will inform the life-cycle analysis of recycled materials and ultimately determine how widely they are used. As recyclers scale up from demonstration to commercial-scale facilities, greater information-sharing, particularly on challenges faced, can benefit the industry as a whole, enabling all players to accelerate their transition to a more sustainable, circular model.

This may be possible as industry players are recognising that no one can lead this change alone. Their success, and that of the wider value chain, will depend on co-operation. "To make all of this work in a true global sense requires collaboration across the entire value chain," says Mr Baca of the American Chemistry Council. "It is really critical that there is a role for the resin producers, the converters, the brands, retailers, NGO community, and recyclers—both mechanical and advanced. It entails more than just one piece of the value chain to succeed over the long term."

In this report we have outlined the policy and industry tactics that will be crucial to implement and scale up these technologies. These include policies to prime demand (recycled content targets and food-contact regulations) and enrich supply (limits on exports, eco-modulated EPR programmes and deposit return schemes). In the absence of confirmed buyers for the industry's outputs and a secure supply of plastic waste for feedstock, investment will remain tentative: virgin plastic is cheap, while recycling remains relatively costly.

Our research programme underscores the industry's potential for fundamental change. A new generation of industry players is emerging for the 21st century, excited about a different era of plastics innovation and how to become truly sustainable. Mr Kerr from Unilever reaffirms this commitment: "Across the industry, there's a groundswell of enthusiasm and desire to create new solutions to these challenges." Indeed, in the 20th century the plastics industry delivered truly world-changing inventions, pioneered by generations of innovators inspired by the potential of new chemistry. This century should be no different.

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