Advanced mechanical recycling:

Enabling true circularity for plastics, now

Table of contents

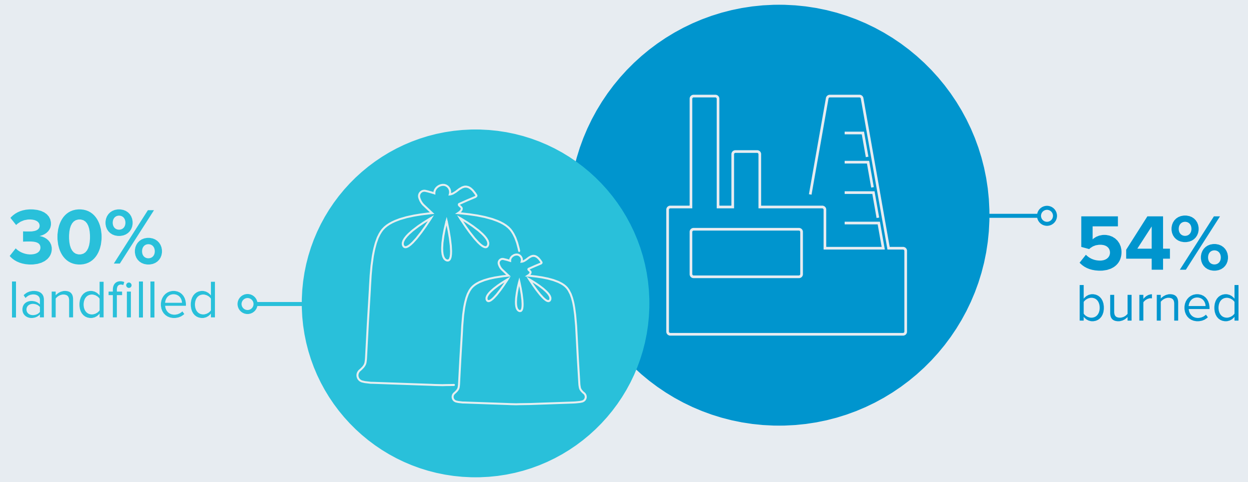
Executive summary

Advanced mechanical recycling (AMR) is revolutionary for the circularity of plastics, with the potential to narrow the sizable gap between the amount of valuable plastic waste that is lost (in the EU alone, 30% is landfilled and 54% is burned[1]) and the ever-growing demand for high-quality recycled content to meet well-legislated recycling and recycled content targets.

Combining existing technologies, AMR is able to deliver specific polymer and color-based recycled content from an abundance of waste to meet the quality standards for a variety of demanding applications, and the increasing quantity requirements. With the fulfillment of those quality and quantity demands, investment into new infrastructure is justified. Once the capacity to sort and recycle is increased due to those investments, so will the amount of material that is sorted and recycled, and eventually used in new products, packaging, and non-packaging products.

AMR makes it possible to create virgin-like recycled plastic pellets from source separated waste streams (achieving closed-loop recycling for PET) as well as from mixed waste streams. Until recently, plastics recovered from mixed waste were seen by many in the recycling industry as contaminated, and of poor quality. However, with the latest developments in sorting, washing lines, decontamination, and extrusion technologies, that narrative has changed.

AMR differs from standard mechanical recycling by including new steps and enhancements to the process: pre-sorting (based on polymer type, colors, and other properties), shredding (into uniform shape and size), hot washing (to remove organics, adhesives, inks, and light contaminants), drying, enhanced flake sorting (using optical sensor technology to remove any unwanted objects and colors), deodorization, enhanced extrusion (to improve overall quality) and super-cleaning.



In 2021, TOMRA, Borealis, and Zimmermann Recycling opened a state-of-the-art demonstration plant for post-consumer plastic waste sorting and AMR[2]. This pioneering plant can process both rigid and flexible plastic from household waste, just scratching the surface of what's possible when key players collaborate across the value chain. AMR processes have also recently helped create the world's first closed-loop system for post-consumer high-impact polystyrene (HIPS) by identifying, sorting, and removing impurities from HIPS found in mixed plastic waste[3].

Undeniably, AMR, coupled with mixed waste sorting, offers municipalities, waste management companies, and incineration plants a breakthrough opportunity to narrow both the quality and quantity gaps along the value chain. First, by ensuring the availability of high-quality recycled plastic, and second, by the ability of this process to produce significantly more plastic recyclate from household waste. In this way, AMR also offers a positive business case for achieving recycled content targets, both from legislative mandates and voluntary brand commitments. Unlike chemical recycling, AMR also offers technical readiness, a crucial factor in target achievement.

This white paper unveils the enormous potential of AMR to recyclers, the plastics industry, policymakers, governments, municipalities, the waste management sector, brands, NGOs, and other stakeholders committed to finding solutions to the waste crisis and accelerating the transition towards a circular economy.

CHAPTER ONE

Ensuring high-quality recyclate with advanced mechanical recycling

The need to expand the amount of plastics recovered, as well as ensure the quality of recyclate that is made available to the market is increasing as recycling and recycled content targets become more widespread. Advanced mechanical recycling (AMR) combines existing technologies in new ways to produce virgin-like recyclates from post-consumer plastic waste and ensure enough high-quality feedstock is available to meet that demand.

This method has been used to achieve closed-loop recycling for PET beverage containers, achieving the highest collection rates through deposit return systems. However, most post-consumer plastics today are processed using standard mechanical recycling, where plastic waste is shredded into flakes, some impurities are removed, and the flakes are then washed in a cold-water treatment.

When flakes are not sorted by polymer type and colors, the product is usually a mixed, darker color with a noticeable odor. Due to its low quality, this recycled plastic is mostly downcycled and used in low-value applications like plastic wood lumber for gardening or non-pressurized pipes, cloth hangers, or flowerpots. From a sustainability perspective, it is advantageous to replace virgin resin with downcycled materials, but demand for low-quality feedstock is limited.

Today, the AMR process has been upgraded to help achieve circularity for polymers beyond PET beverage containers, including HDPE, PE, PP, PS, PE film, PET trays, and LDPE. These upgrades include significant advancements in sorting technology, such as sensors that detect the molecular structure of polymers, and sophisticated color cameras to separate transparent and pigmented plastics.

However, in order to ensure that AMR is feasible and adaptable to various markets, a sufficient and consistent supply of post-consumer plastic waste is needed. This requirement can be fulfilled by tapping into one of the world's most abundant resource streams– mixed waste.

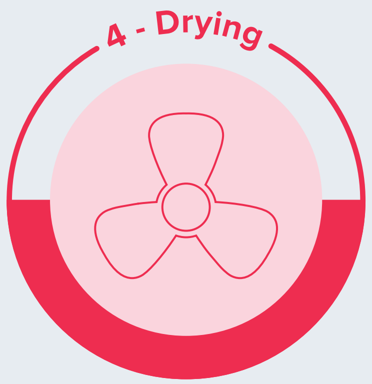
AMR is now able to sort mixed waste by polymer type, colors, and other properties using dedicated pre-sorting, hot washing, enhanced flake sorting, deodorization, enhanced extrusion and super-clean technology. These additional steps ensure that the highest quality recyclate is available to those industries that depend on superior feedstock quality to reduce their $C0_2$ emissions and reach recycling and recycled content targets.

The production of high-quality recyclates derived from mixed waste generally requires the following steps:

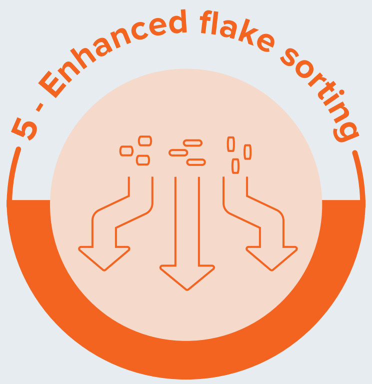
Once plastics have been separated from other material types – whether through mixed waste sorting and/or separate collections - they are pre-sorted based on polymer type, colors and material specific criteria, and the remaining foreign materials are removed.

A shredding machine cuts the pre-sorted plastics into shapes and sizes that are optimal for high-quality recycling. Flakes should not be smaller than 2 mm to ensure that the floatation and centrifugal sorting processes in the hot washing stage are effective. Sensor-based flake sorting technology also requires flake sizes above a 2 mm threshold. Flakes that are too small can lead to product loss, or negatively impact purity levels.

A friction washer with hot water-based solution and detergents removes organics, adhesives, inks, and other contaminants from the flakes. If sleeves and caps made from other polymers remain in the material stream, they will be separated from the targeted material either in a basic sink-float process, mechanical separation, or the flake sorting process. For example, when washing PET and polyolefin (PO) flakes, the PO will float to the surface of the water, making it easy to separate it from PET at the bottom of the tank. To ensure low water consumption, the water is recirculated and treated in a bypass system. The wastewater can contain organic residues or cleaning agents and needs to be processed at a wastewater treatment facility.

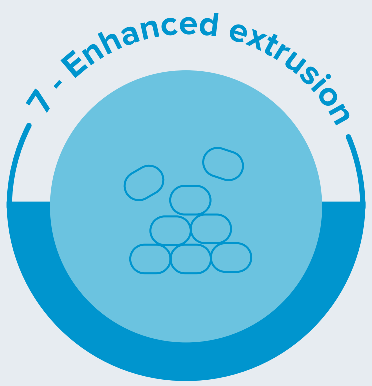


After hot washing, the clean flakes are sent to a mechanical and/or thermal drying process at material specific temperature levels of 90-180°C (180-356°F) until they reach < 1% moisture content. The targeted moisture content is a critical factor in producing recyclates and depends on the specific polymer. The relative humidity, environmental temperatures, and dimension of the flakes can also affect the drying process.



Once dried, the flakes undergo additional mechanical and optical sorting to achieve the highest purity levels possible. The plastic flakes are processed with multiple rounds of sorting based on polymer types and color. This allows producers to create a wide range of color grades, including natural, white, transparent, or specific colors like red, blue, green, etc.

The removal of odor-active compounds is a requirement for high-quality recyclates. It is typical for fragrances used in washing or cleaning detergents to migrate into plastic packaging. Decomposition of organic residue can also create odors in recyclates, unless a deodorization process occurs. Various methods can be applied depending on the type of polymer. By heating the plastic flakes and using vacuum degassing units, a significant odor reduction of recycled plastic is achieved.



The deodorized flakes now enter the extrusion process. Melt flow filtration, and additional degassing during the extrusion process can further reduce odors and improve pellet quality. The extrusion technology varies depending on the polymer type and the desired application.

To help accurately estimate recycling rates, it is recommended that calculation points start as close to the final recycling step as practical (for example, at the enhanced extrusion phase of the process), rather than basing rates on the volumes or weights of material sent to recycling facilities. This way, contamination, pre-treatment losses, and residues are no longer included in the recycling performance numbers.

Until recently, the EU measured the output streams of sorting plants (materials sent for recycling) to calculate an estimated packaging recycling rate. This point of calculation risked an overestimation of materials that were actually recycled. The point of calculation was reset in 2020 to reflect the input of secondary production, which creates incentives to limit losses during pre-treatment and yields more accurate recycling data.

The final step (if needed) is super-cleaning. This process will remove any remaining, unwanted materials in the polymer. Different technologies can be used to remove unwanted materials, if any. The melted plastic, for example, could be placed inside a strong vacuum. In addition, the surface of the melted polymer could be heavily increased in order to ensure that contaminants are removed completely.

Case study: recycled polystyrene yogurt cups

Advanced mechanical recycling (AMR) processes recently helped create the world's first closed-loop system for post-consumer high impact polystyrene (HIPS).[4] As a strategic partner and member of Styrenics Circular Solutions (SCS), the joint industry initiative to advance circularity of styrenic polymers, TOMRA has collaborated with several partners to use AMR technology to identify, sort, and remove impurities from HIPS found in mixed waste. The polystyrene is then processed and extruded into new, high-impact recycled polystyrene (rHIPS).

To challenge the common misconception that high-quality recycled plastic content cannot be produced from mixed waste, sample materials from various collection systems and various countries were tested. Although the sample material came from a combination of source-separated plastic packaging waste and mixed waste, and there was slightly more organic contamination compared to recycling plastics from a separate collection waste stream, foreign materials were hardly present in the polymers from mixed waste, making overall purity the same. AMR processes were found to remove all impurities, resulting in a final product with the same high-quality performance, regardless of the waste collection stream. This case study proves that separate collection is not a prerequisite: AMR can deliver high-quality recyclates from mixed waste streams.

CHAPTER TWO

The complementary roles of mechanical and chemical recycling

In plastic recycling, it is important to understand the complementary roles of mechanical and chemical methods in creating a circular economy. Mechanical recycling shreds plastic waste into flakes, removes impurities, and extrudes, or 'remelts' it into pellets that can be used to make new products. While the molecular structure of the polymer is preserved, each new reprocessing cycle degrades the material (depending on material type), eventually leading to product loss. On the other hand, chemical recycling splits the polymer chains to change and convert waste into chemical building blocks that are used again as raw materials (crude oil, naphtha, or fuels). Chemical recycling processes are energy intensive and still require intensive pre-sorting to deliver usable plastic as feedstock.[5]

Mechanical recycling is prioritized over chemical recycling because it has a smaller ecological footprint than chemical recycling.[6] It involves a much simpler recovery process and uses less energy, making it a more economical solution for the industrial sector and enabling lower pricing of recycled content. Today, mechanical recycling remains the most effective way to recycle plastics and, when technically possible, should always be the preferred method.

> *"The share of plastics that are economically recyclable mechanically could grow from 21 percent in 2016 to 54 percent in 2040."*
>
> Breaking the Plastics Wave
> The Pew Charitable Trusts and Systemiq

Systemiq and The Pew Charitable Trusts recognize the role of mechanical recycling as a solution and call for doubling the capacity to 86 million metric tons per year by 2040.[7] With expansion and investments in collection, sorting, and mechanical recycling, it is estimated that millions of metric tons of plastic could be prevented from reaching waterways and instead turned back into new products, reducing demand for virgin resource extraction and the associated negative environmental impacts.

Investing in mechanical recycling capacity is vital for achieving plastic recycling and recycled content targets. In the EU, mechanical recycling is the only recycling process that can contribute towards the achievement of these legal targets. Currently, recycling targets to which chemical recycling can contribute are debatable, and there are currently no legal initiatives for its contribution to the achievement of targets in the future.

As it stands, the United States does not have the same strong federal mandates driving recycling performance that the EU has in the form of well-legislated recycling and recycled content targets (the EU has targets from the Waste Framework Directive, the Packaging Directive, and the Single-Use Plastics Directive (SUPD). Additionally, there is still an ongoing debate about how to define and classify chemical recycling. The U.S. Environmental Protection Agency (EPA) is currently engaged in a formal rulemaking process to determine how to regulate certain types of chemical recycling.[8] For example, some industry stakeholders would like to reclassify pyrolysis and gasification as manufacturing processes rather than waste management. This could significantly reduce the requirements and regulatory burden (e.g., siting, emissions, etc.) for chemical recycling, putting mechanical recycling at an unfair disadvantage.

Chemical recycling technologies differ in their specifications and require unique input compositions. Pyrolysis, the thermal degradation of plastic waste at different temperatures, limits the amount of certain polymers, such as PVC, PET, and other plastics, to improve the yield to liquid products and reduce the halogen content.[9] Chemical recycling facilities (e.g., pyrolysis, depolymerization, and thermolysis) must typically be designed for very large capacities, like steam crackers[10], in order to justify the high costs of processing feedstock back to plastics.

When recyclability of packaging is incorporated in the design phase, mechanical recycling is highly effective at producing secondary raw materials. Therefore, it is essential that legislation, like eco-modulated extended producer responsibility (EPR) schemes, address plastic packaging and products placed on the market are, whenever possible, designed for mechanical recycling.

As collaboration along the waste-to-material part of value chain continues to evolve, the roles of mechanical and chemical recycling are likely to intersect for processing specific polymers. For plastic products that cannot be recycled with mechanical methods, chemical recycling could be a potential solution if its actual process emissions have a lower carbon footprint than the production of plastic from virgin feedstock.[11] Developing multiple processing pathways could mean that plastics from all waste streams are captured, sorted, and turned into high-quality recycled content. With rigid plastics, mono-material flexibles, and other products processed by mechanical recycling, the remaining materials could be sorted into specific fractions for chemical recycling.

Both mechanical and chemical recycling processes have strengths, limitations, environmental footprints, and specific requirements. What is clear – regardless of the recycling technology – is the need for increasing the capture of post-consumer plastics and quality sorting processes that separate polymer types and colors.

CHAPTER THREE

The hidden value in mixed waste

Ambitious emissions-reduction targets demonstrate the urgent need to step up and act. In response, TOMRA, in partnership with Eunomia, examined which combination of existing waste management systems deliver maximum recycling rates and the most significant reduction in CO_2 emissions.

It was found that the best performing systems are built on mandatory extended producer responsibility (EPR) and combine the elements of deposit return systems (DRS) for beverage containers, separate collections for certain waste fractions, and mixed waste sorting. TOMRA merged these elements to create one holistic system, now known as holistic resource systems (HRS).[12] When supported by strong EPR policies, HRS can increase the extraction of valuable materials – keeping them in circulation, and in the market, for as long as possible.

A crucial element of HRS is mixed waste sorting. Mixed waste streams contain a significant portion of overall plastic waste, even in countries with well-established curbside and drop-off collection systems for plastic packaging. Sorting mixed waste can recover plastics not captured in the dedicated recycling streams that are dependent on the sorting performance of consumers. When processed with the same advanced mechanical recycling (AMR) techniques as source-separated collections, it can produce equal yield quality.

Mixed waste sorting, designed to prevent plastics from being sent to incinerators and landfills, has been in operation at several plants across the EU (i.e., Norway, Netherlands, Poland, Greece, Cyprus, Spain) and the U.S. Depending on local circumstances, infrastructure, and where the benefits outweigh the costs, mixed waste sorting can also target materials such as paper, glass, metals (ferrous and non-ferrous), and organic waste. In most cases, the overall system cost is reduced due to savings on material sales, residual treatment, as well as landfill bans, tipping floor fees, plastic tax, and other financial implications.

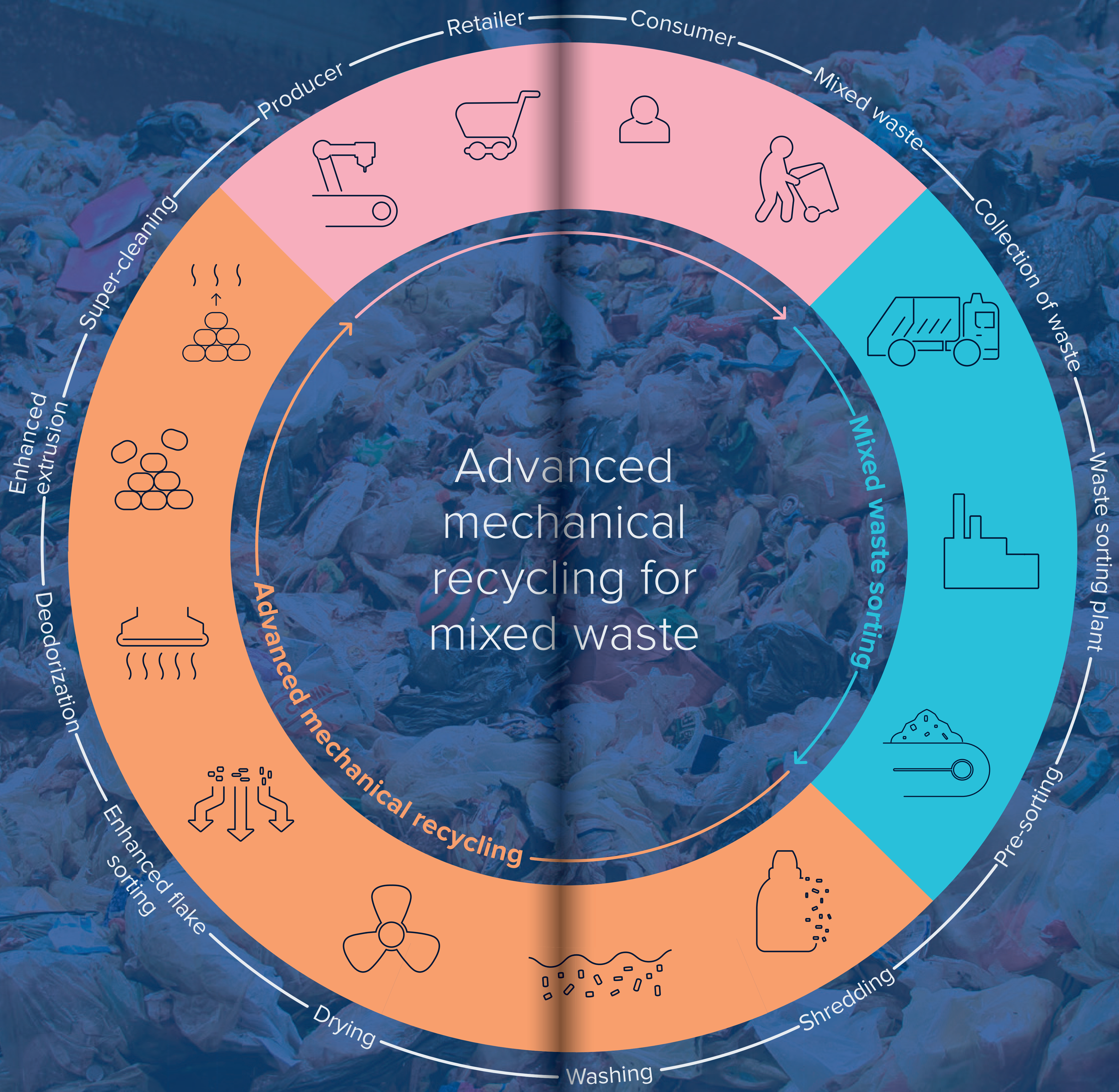
The recovery of plastics with mixed waste sorting is particularly important when considering its greenhouse gas (GHG) benefit – a metric calculated by assigning a CO_2 emission equivalent in terms of net benefit.

> Mixed waste sorting can save 0.73 billion tonnes CO_2e globally each year

The mixed waste sorting process significantly reduces emissions and creates financial opportunities with the sale of secondary raw materials. For incineration plants, with or without energy recovery, the removal of plastics ensures more marketable capacity due to their high caloric value.

Find out more about the recovery and high-quality recycling of plastics destined for landfills and incinerators that mixed waste sorting offers in the white paper: The Ultimate Guide to Mixed Waste Sorting (located in TOMRA's circular economy resource hub). https://circular-economy.tomra.com/resources

*Case study of mixed waste with plastic composition assumed to contain 34% HDPE and 66% PP. The case study examined emissions saved from collecting one tonne HDPE and PP each to determine the GHG benefit of MWS before incineration.


Advanced mechanical recycling for mixed waste
Producer
Retailer
Consumer
Mixed waste
Collection of waste
Waste sorting plant
Pre-sorting
Shredding
Washing
Drying
Enhanced flake sorting
Deodorization
Enhanced extrusion
Super-cleaning
Mixed waste sorting
Advanced mechanical recycling

CHAPTER FOUR

Accelerating plastic recovery to achieve targets

As post-consumer recycled (PCR) content targets become more wide-spread globally, there is a pressing need to expand the amount of plastics recovered and ensure they are processed to meet requirements for demanding applications. The virgin-like quality of PCR recyclates produced through advanced mechanical recycling (AMR) keeps plastics at their highest and best use, a key enabler for closed-loop recycling systems.

There are several key aspects of how quality is achieved through AMR:

Pure polymer types

For recycling, it is important to have a pure polymer type, therefore removing any non-target polymer types, as well as any other contaminants, like metals and paper, is a vital step in the AMR process. In a HDPE bottle stream, for example, PET and PP may still remain in labels, sleeves, and caps – these must be separated to ensure the purification of flakes. The purified flakes are then super-cleaned - a process where flakes are extensively dried to minimize the hydrolytic degradation effects caused by inner moisture in the polymer.

Color separation

AMR goes beyond its standard form with additional steps to separate plastics by color in pre-sorting and flake sorting stages. The enhanced sorting makes it possible to achieve various clean colors, including trans-parent, natural, white, red, green, blue, and more. Producing PCR recyclates with distinct color ranges is particularly desirable for high-value applications. Depending on the color composition of the polymer stream, producing specific color recyclates may only be viable if done at scale to ensure sufficient material for processing. Polypropylene (PP), for example, may be abundant in terms of volume, but only a small fraction of the material stream is red. Thus, producing a clean fraction of red recycled polypropylene (rPP) pellets would require much more input material and processing.

Odorless recyclates

Recycled plastics can retain odors that create substantial quality issues for applications, including packaging, automotive, beauty care, and more. Most odors stem from two fundamental sources: organic contamination (e.g., food residues) and fragrances (e.g., detergents, and body care products). Polyolefins, for example, are particularly prone to residual odors because they are partially absorbed into the polymer matrix. The hot washing process in AMR removes odors related to organic contamination, but not fragrance-based odors. Therefore, additional deodorization technologies are needed before, during or after the extrusion phase to produce odor-free recyclates.

Processability

Advanced mechanical sorting has already processed more than a thousand tons of recyclates to increase the percentage of PCR plastic content that can be incorporated and expand the range of applications. In addition, an important requirement for converters is whether recyclates can be processed with the same parameters and tools as virgin material. For example, if recyclates require even a slightly longer processing time, it could have a significant impact on production costs.

Quality grades

Today, the market for recycled plastic content consists primarily of food and non-food grade materials. However, most consumer-packaged goods applications have specific requirements for recycled content, and thus several organizations are working toward establishing standardized specifications for various grades. The consortium CosPaTox, for example, is working on an official specification for cosmetic grades, which are less stringent than food grade, but still require high standards because they are products that involve skin contact.[13]

The quality of plastic recyclates is categorized into grades:

Food grade
materials that come into direct contact with food (e.g., beverage bottles, yogurt cups, and food trays)

Cosmetic leave-on grade
materials that come into direct contact with products that are intended to stay in prolonged contact with skin, hair, or mucous membranes (e.g., cosmetic and lotion containers)

Cosmetic rinse-off grade
materials that come into direct contact with products that are intended to be removed after application on the skin, hair, or mucous membranes (e.g., shampoo and shower gel containers)

Inert grade
materials that come into direct contact with home care and other products (e.g., laundry detergent and cleaning product containers)

Increasing the uptake of recycled plastic content through well-legislated targets and infrastructure investment are essential to closing the quality and quantity gaps. Regulatory approvals that allow qualified PCR recyclates in contact-sensitive applications are also necessary to achieve circularity. Policymakers can help facilitate the acceptance of PCR recyclates by creating universally accepted standards in production information and compliance testing to ensure quality and safety requirements.

CHAPTER FIVE

Legislation for long-lasting impact

It is clear: ambitious targets and well-designed policies enable systemic change that advances the circular economy. Although efforts such as bans on specific product designs may prove useful, more comprehensive regulatory measures are needed to ensure plastics are recycled into secondary raw materials.

The waste hierarchy is an internationally accepted standard that aims to keep materials at their highest and best use and establishes an order of waste management options from most to least preferred based on ecological and social impact. The TOMRA resource hierarchy expands on this concept by prioritizing methods that employ the least carbon-intensive processes and differentiate between open-loop and closed-loop recycling. It serves as a foundational basis for establishing policies that promote high-quality recycling, enabling post-consumer recycled content that can be used for the same application without downcycling.

Policies to address plastic waste and pollution also need to include targets that directly stimulate the demand for recyclates. Well-legislated post-consumer recycled (PCR) content targets are a powerful tool in advancing circularity, reducing dependency on virgin resources, and addressing challenges to create market certainty and trigger investment in infrastructure. This investment can ensure scalable volumes of high-quality recyclates that meet the necessary health and safety standards for various applications. Like recycling targets, PCR targets should be broad and differentiated to adequately cover different types of polymers and products.

For long-lasting environmental impact, it is important that the scope of plastic policies go beyond PET recycling and food contact materials (FCM). Financial instruments such as a plastic tax and eco-modulation of fees can help to decouple prices of recycled and virgin plastics. This is critical considering that fossil-fuel subsidies create a market distortion for plastics, and a competitive disadvantage for recyclates.

The European Food Safety Authority (EFSA), the Directorate-General for Health and Food Safety (DG SANTE), and the United States Food and Drug Administration (FDA) help to regulate recycling processes and technologies in their respective regions. In the EU, the demand for food-grade rPET has increased, in part, due to the Single-Use Plastic Directive (SUPD),[14] but efforts to simplify the certification and the use of food-grade PCR plastic has yet to be updated in legislation. The FDA continues to voice its concerns about recycled content in FCM and considers the integration of PCR plastics on a case-by-case basis. While many jurisdictions enforce different regulations and standards, TOMRA recommends that policies certify PCR plastics based on the capability to deliver and demonstrate the quality and safety requirements.

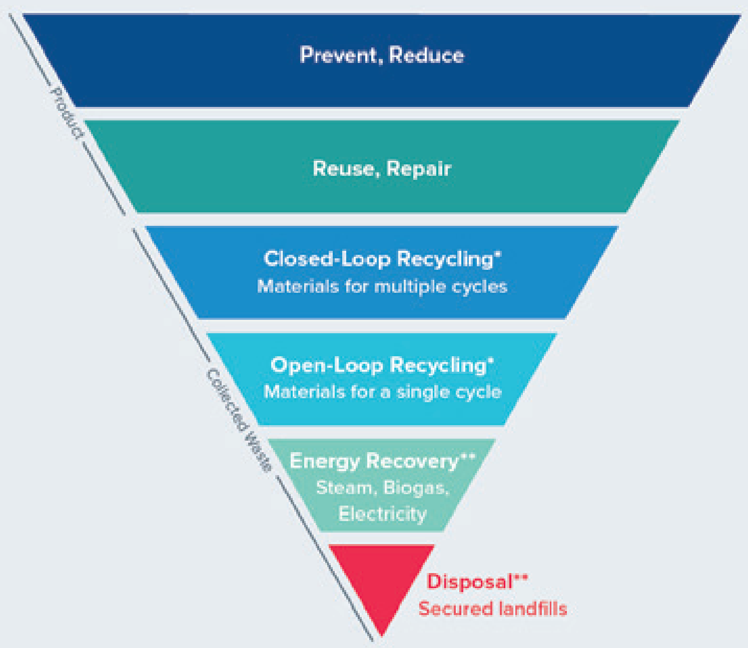
Given the exceptionally large volume of post-consumer plastic waste produced annually, there is an urgent global need for more effective policy solutions. Based on experience and evidence-based practice, well-legislated extended producer responsibility (EPR) schemes for plastic packaging are the only proven way to provide dedicated, ongoing, and sufficient funding at scale while ensuring a level playing field for all industry players.[15]

Establishing high-performing EPR schemes requires in-depth knowledge of the waste management and recycling practices that can feasibly integrate into local contexts and circumstances.[16,17]

By collaborating with established leaders in the waste-to-material part of the value chain, policymakers and stakeholders gain a unique perspective on designing EPR schemes that maximize the circularity of plastics. To learn more about how to design high-performing EPR schemes, read the white paper: EPR Unpacked: A Policy Framework for a Circular Economy (located in TOMRA's circular economy resource hub). https://circular-economy.tomra.com/resources

While the world has seen a pivotal shift in policy recently, namely an increased focus on EPR for packaging and the United Nations Environmental Assembly's (UNEA) endorsement of an historic resolution to end plastic pollution and forge an international legally binding treaty by 2024,[18] it could still be many years before sustainable plastics are realized around the world. The time is now to implement ambitious policy and advanced technological systems.

TOMRA's resource hierarchy



Uncollected Waste

Unacceptable
Open Burning, Dumping, Litter

* *Mechanical recycling preferred*
** *Additional sorting recommended*

CHAPTER SIX

A forward look

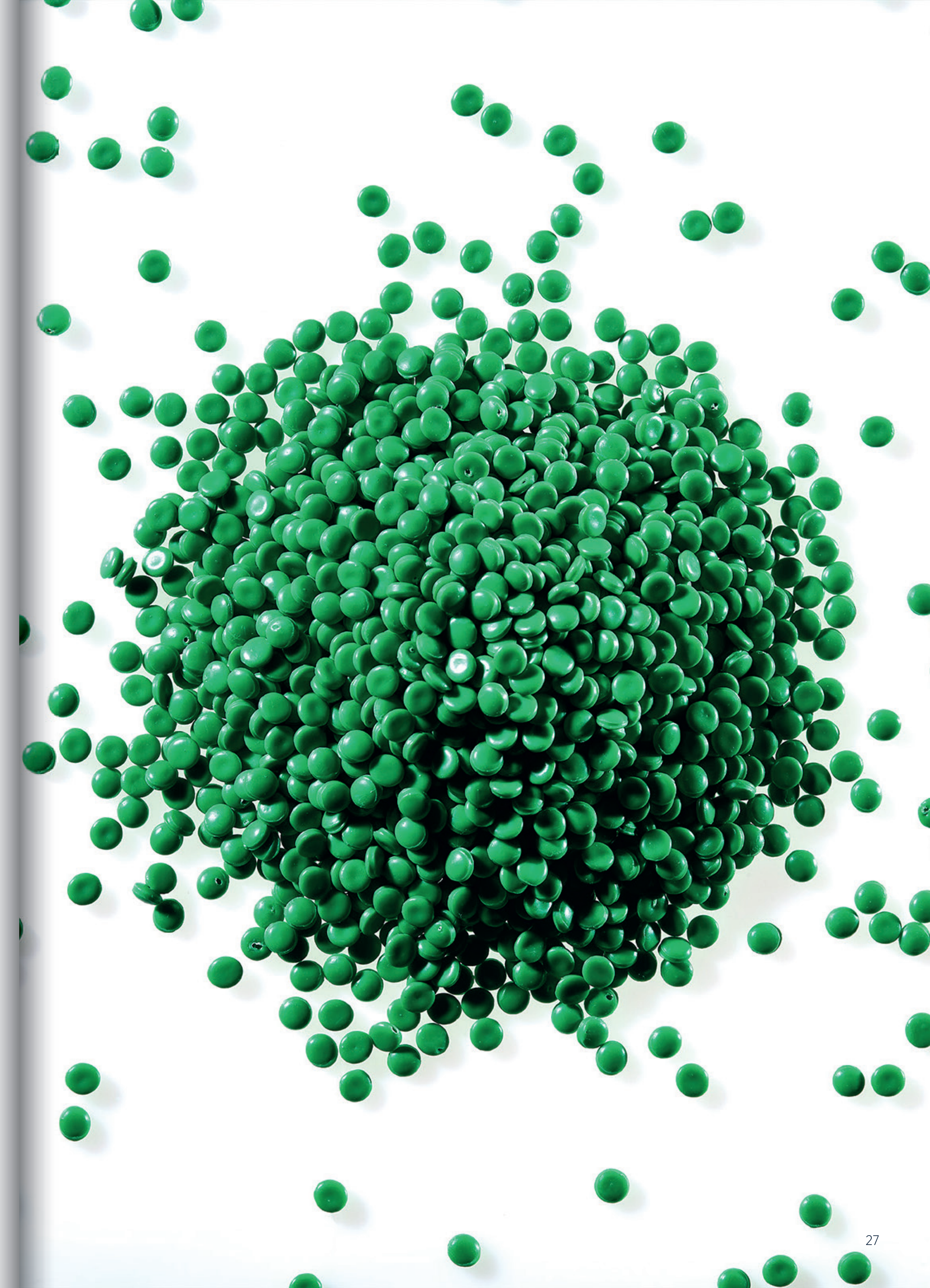
Investment in adequate collection, sorting, and recycling infrastructure is vital to increase the amount of high-quality recyclate on the market that can meet the ever-increasing demand from legislative mandates and brand commitments. To be viable for investment, a significant amount of material input is needed first - with a profitability threshold of around 40 metric kilotons (KT) per annum. For reference, state-of-the-art PET beverage recycling plants are typically designed for 70 KT per annum.

Advanced mechanical recycling (AMR), coupled with mixed waste sorting, can ensure that investment in infrastructure is justified: the former ensures the availability of high-quality recyclate through innovative new steps in the recycling process, while the latter ensures a sufficient and consistent stream of plastic waste to feed into the system.

While the technical readiness of producing post-consumer plastic content from mixed waste is further explored, there are additional, promising possibilities to examine. Achieving food-grade approved recycled polyolefins (such as rPP), for example, remains at the forefront of advancing the circular plastics economy. PP is a highly versatile polymer, widely used in packaging and products such as pots, tubs, and trays (PTT). Together with Nextek's global multi-participant, NEXTLOOPP project, TOMRA has developed solutions to provide 99.9% sorting purity, enabling the first successful full-scale packaging production trial of food-grade compliant rPP.[19]

Globally, flexible packaging is the number one packaging format in household goods,[20] but, while it offers numerous benefits including material reduction and lower transport-related emissions, it is notoriously difficult to mechanically recycle into top quality product. Processes for recycling flexible packaging require additional focus on material handling, mainly sorting and washing treatments.

In terms of separating contact-sensitive plastics (e.g., food vs. cosmetic grades), deep learning-based technologies are being explored for enhanced object recognition and sorting capabilities. The use of physical and digital marking technology remains a hot topic within the industry: it has the potential to create global standards in waste management, but competitive pricing and global regulation could cause bottlenecks.



Top takeaways for stakeholders

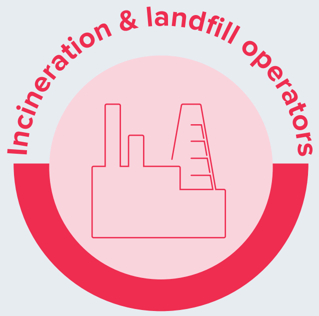
Circular plastics is a complex topic. To address it effectively, key players across the value chain are encouraged to exchange perspectives, learn from each other, and collaborate to co-develop solutions.All stakeholders can do their part in closing the loop on plastics.

Recyclers can prepare for the future by investing in technology that enables high-quality recyclates. With advanced mechanical recycling, they have the opportunity to get ahead of the curve – the demand for recyclates will grow rapidly as more jurisdictions introduce recycled content targets. Securing investments to upgrade will pay off when multiple types of plastics can be recycled from different waste streams, allowing recyclers to sell valuable secondary materials.

To reduce dependency on the extraction of fossil fuels, members of the plastics industry (such as plastics producers and converters) can establish a balanced stake in plastic recycling. While mechanical and chemical recycling are complementary processes in the circular economy, mechanical recycling currently presents the most direct and established pathway for advancing the uptake of recycled plastic content. Collaboration with advanced mechanical recycling plants to enhance recyclates and formulate new products with additives or blends is another option for the plastics industry.

Investors can drive positive change for the environment and their earnings by investing in infrastructure to support the preservation of resources in closed-loop recycling systems worldwide. Sustainable investment in waste collection and recycling infrastructure supports the industrial sector and creates jobs for a thriving green economy. Investors can also improve Environmental, Social, and Governance (ESG) ratings by only investing in waste-to-energy plants that have automated sorting technology to remove plastics and other recyclable materials to reduce emissions and maximize marketable capacity.

Where it makes sense, brands can take all preventative measures to reduce the amount of plastic used in products and packaging. When feasible, all packaging should be designed for recycling and include a portion of recycled content. By boosting the demand for recyclates, brands directly support the development of recycling infrastructure and the future supply of high-quality plastic recyclates. They can let policymakers know that they are serious by supporting well-legislated EPR and ambitious targets in legislation.



Waste management varies widely throughout the world, but there is a universal opportunity to sell secondary raw materials in place of virgin resources. By collaborating with the waste-to-material part of the value chain, these stakeholders can learn more about the opportunity to recover plastics from mixed waste. The recovery of these plastics can help reduce emissions and make room for additional capacity.

Consumers can make a conscious effort regarding the types of packaging and products they use every day. They can try to eliminate single-use plastic items, reuse materials, and recycle packaging. Every purchase influences sustainability trends, so it's important to buy products designed for recycling and made with recycled content where possible. Consumers can choose to compromise on a 'perfect look' or 'unusual colors' to have products and packaging that are made with recycled plastic content and have a lighter environmental footprint.

Policymakers can create framework conditions by applying a holistic approach to managing resources. They can consult with leaders in resource management to learn more about global best practices, finding effective and economically feasible methods for accelerating circularity. They can also gain comprehensive insight into well-designed policies that lead to high-performing deposit return systems (DRS) and extended producer responsibility (EPR) schemes for plastic packaging. Find out more about the design principles and system elements necessary for effectively tackling plastic waste in TOMRA's series of white papers located in TOMRA's circular economy resource hub.
https://circular-economy.tomra.com/resources

Conclusion

The amount of plastic waste produced globally is on track to almost triple by 2060, with less than 20% recycled, and the vast majority littered in nature or disposed of in landfills and incinerators.[21] Advanced mechanical recycling (AMR) is a scalable and economically viable solution that transforms post-consumer plastic waste into ready-for-market, high-quality recycled plastic content. It offers a strong opportunity to achieve recycled content targets and help brands save virgin resources and reach their sustainability commitments.

With a lower ecological footprint than chemical recycling, AMR delivers high-quality recyclate by incorporating the latest technology and innovation into the standard process, including hot washing, enhanced flake sorting, deodorization, enhanced extrusion, and super-cleaning. These steps achieve virgin-like recyclate from both source-separated material as well as from mixed waste – an overly abundant and previously untapped resource stream.

In combination, mixed waste sorting (MWS) and AMR have the potential to eliminate the quality and quantity gaps that exist along the value chain. MWS is used to greatly increase the amount of material that is recovered, while AMR is used to process that material into the highest quality recyclate.

Extended Producer Responsibility (EPR) has emerged as the dominant policy principle to reduce environmental impact, improve resource efficiency, and provide the funding needed for investment in infrastructure that can deliver circularity. As such, EPR schemes should be obliged to financially contribute to MWS in order to reach ambitious recycling and recycled content targets and give the recycling of this untapped treasure a substantial boost.

For AMR and MWS to be implemented at scale, their critical role in a circular value chain must be acknowledged, supported, and mandated under a harmonized EPR approach that prioritizes resource efficiency. Achieving circularity for packaging has moved beyond an aspiration. It is a reality, now.

Glossary

Advanced mechanical recycling
The conversion of mixed plastic waste into high-quality recycled plastic pellets through mechanical processes such as pre-sorting, shredding, hot wash treatment, decontamination, enhanced polymer and color sorting, deodorization, and extrusion.

Standard mechanical recycling
The conversion of plastic waste into lower-quality secondary raw materials through mechanical processes such as pre-sorting, shredding, cold wash treatment, optional color sorting, and reprocessing.

Chemical recycling
Chemical recycling splits the polymer chains to change and convert plastics into chemical building blocks that are used again as raw materials (crude oil, naphtha, or fuels).

Closed-loop recycling
A system in which materials are collected, sorted, and recycled for the highest quality and used over multiple cycles for the same or similar application (e.g., bottle-to-bottle recycling).

Converter
Manufacturers specializing in the combination of various raw materials and industrial-scale conversion or adaptation of materials into packaging.

Curbside and drop-off collection systems
Services established to collect general household waste and recyclables at the doorstep (curbside) or a designated location (drop-off).

Deposit return system (DRS)
A type of EPR scheme for beverage containers in which a small deposit is placed on the price of a beverage and repaid when the consumer returns the container for recycling. Also known as deposit return schemes, container deposit schemes, or bottle bills.

Downcycling
The process in which materials are downgraded to low-quality recycled content and used for a single cycle or less demanding application.

Eco-design
A principle and approach to designing packaging, products, systems, and services at the development stage to reduce their environmental impact.

Eco-modulated fees
A financial instrument to incentivize the eco-design of packaging by implementing a refined fee structure for a design that meets specified criteria. Also known as fee modulation.

Energy recovery
The conversion of waste that generates energy in the form of steam or electricity.

Extended producer responsibility (EPR)
An environmental policy principle in which a producer’s responsibility is extended to the entire lifecycle of their products.

EPR scheme or EPR system
A system set up to implement the EPR principle. It can be an individual system (or individual compliance system) where a producer organizes its own system, or a collective system (collective compliance system) where several producers decide to collaborate and thus fulfill their responsibility in a collective way through a specific organization.*

Extrusion (of recycled plastics)
A high volume manufacturing process in which secondary raw material is melted, degassed, filtered, and formed through a tool with a specialized shape.

Holistic resource systems
A framework approach to improving resource utilization through a combination of well-established waste management techniques, including deposit return systems, separate collections, and mixed waste sorting.

Informal sector
All workers in unincorporated enterprises that are active in waste management but are not formally registered. **

Mixed waste sorting (MWS)
The high-efficiency separation of recyclable materials from mixed municipal solid waste.

Odor-active compounds
The terminology for a variety of volatile chemical compounds that can be perceived by the human olfactory system. Odors can stem from aromas or fragrances that migrate into contact material.

Open-loop recycling
A system in which materials are collected, sorted, and recycled for a single cycle instead of multiple cycles.

Post-consumer plastic
Plastic waste produced by the consumer once the product or packaging has served its intended purpose or reached end-of-life.

Post-consumer recycled (PCR) content
Plastic items that were utilized and discarded by a consumer and then recycled and made into virgin-like material for new products and packaging.

Producer
A company or importer that places products on the market.

Recyclability
The ability for a product or packaging to be technically and feasibly recycled at scale, which is dependent on both the design of the product and the local infrastructure for collection, sorting, and recycling.

Recycled content
Virgin-like materials that have been made partly from pre- and post-consumer waste.

Recycling
The process of converting waste into secondary raw materials.

Resource hierarchy
A standard for the circular economy that aims to keep materials at their highest and best use, and establishes an order of waste management options from most to least preferred based on their environmental impact.

Return-to-retail model
A type of redemption model in a deposit return system that relies on beverage retailers to take back deposit containers.

Reusability
The ability for a product or packaging to be feasibly used multiple times.

Secondary raw materials
Recycled materials that can be used in manufacturing processes to replace virgin materials.

Sensor-based flake sorting
High-precision sorting systems that use a variety of sensors to detect shredded plastics flakes by their molecular structure and color.

Separate collections
The collection of used goods according to material type for recycling. Organic waste, paper, glass packaging, textiles, and e-waste are commonly targeted for separate collections.

Single-use plastic
A product or packaging made of plastic that is intended to be used once and then discarded.

Sorting
The process which separates waste according to material properties for recycling.

Source separation
An action taken by consumers, where they sort recyclable materials from their general waste and discard them in a dedicated container.

Waste disposal
The burning or landfilling of residual materials that cannot be recycled or recovered from waste.

Waste management
A collective term for the collection, transportation, processing, and disposal of waste.

* Based on the definitions of the UNEP/Basel Convention entitled ‘Draft practical manuals on Extended Producer Responsibility and on financing systems for environmentally sound management’ (2018). www.basel.int/Portals/4/download.aspx?d=UNEP-CHW-OEWG.11-INF-7.English.pdf

** Based on the definitions of the International Labour Organization. https://ilostat.ilo.org/resources/concepts-and-definitions/description-informality/

References

1. Plastics Europe, 2021, “Plastics – the Facts 2021. An Analysis of European Plastics Production, Demand and Waste Data.”

2. Borealis (2021). Borealis and TOMRA open state-of-the-art plant for post-consumer plastic waste sorting and advanced mechanical recycling. Retrieved from: www.borealisgroup.com/news/borealis-and-tomra-open-state-of-the-art-plant-for-post-consumer-plastic-waste-sorting-and-advanced-mechanical-recycling

3. Styrenics Circular Solutions (2020). Styrenics Circular Solutions demonstrates mechanically recycled polystyrene is suitable for food contact. Retrieved from: styrenics-circular-solutions.com/styrenics-circular-solutions-demonstrates-mechanically-recycled-polystyrene-is-suitable-for-food-contact.html

4. Styrenics Circular Solutions (2020). Retrieved from: styrenics-circular-solutions.com/styrenics-circular-solutions-demonstrates-mechanically-recycled-polystyrene-is-suitable-for-food-contact.html

5. CHEM Trust and Eunomia (2020). Chemical Recycling: State of Play. Retrieved from: chemtrust.org/wp-content/uploads/Chemical-Recycling-Eunomia.pdf

6. Schyns, Z., & Shaver, M. (2021, February). Mechanical Recycling of Packaging Plastics: A Review. Macromolecular Rapid Communications, 42(3). Retrieved from: europepmc.org/article/med/33000883

7. The Pew Charitable Trusts and Systemiq (2020). Breaking the plastic wave: A comprehensive assessment on pathways towards stopping ocean plastic pollution. Page 10. Retrieved from: www.pewtrusts.org/-/media/assets/2020/07/breakingtheplasticwave_report.pdf

8. Waste Dive. Retrieved from: https://www.wastedive.com/news/epa-chemical-recycling-Clean-Air-Act-emissions-regulation/627568/

9. Fulgencio-Medrano, L., García-Fernández, S., Asueta, A., Lopez-Urionabarrenechea, A., Perez-Martinez, B., Arandes, J. (2022). Oil Production by Pyrolysis of Real Plastic Waste. Polymers. 14(3):553. Retrieved from: www.researchgate.net/publication/358222323_Oil_Production_by_Pyrolysis_of_Real_Plastic_Waste

10. Schlummer, M., Fell, T., Maeurer, A., & Altnau, G. (2020). The Role of Chemistry in Plastics Recycling. Kunststoffe International. Retrieved from: en.kunststoffe.de/a/specialistarticle/the-role-of-chemistry-in-plastics-recycl-242578

11. Zero Waste Europe (2020). Understanding the Environmental Impacts of Chemical Recycling: Ten concerns with existing life cycle assessments. Retrieved from: zerowasteeurope.eu/wp-content/uploads/2020/12/zwe_jointpaper_UnderstandingEnvironmentalImpactsofCR_en.pdf

12. TOMRA (2022). EPR Unpacked: A Policy Framework for a Circular Economy. Retrieved from: circular-economy.tomra.com/resources/epr-guide

13. Consortia Management GmbH (2022). CosPaTox Consortium. Retrieved from: cospatox.com/about-cospatox/#

14. Directive (EU) 2019/904. The reduction of the impact of certain plastic products on the environment. Article 6 No. 5 (a) and (b). 32European Parliament, Council of the European Union. Retrieved from EUR-Lex: eur-lex.europa.eu/eli/dir/2019/904/oj

15. Ellen MacArthur Foundation (2021). Extended Producer Responsibility for Packaging - a necessary part of the solution to packaging waste and pollution. Retrieved from: plastics.ellenmacarthurfoundation.org/epr

16. TOMRA (2021). Rewarding Recycling: Learnings from the World's Highest-Performing Deposit Return Systems. Retrieved from: www.circular-economy.tomra.com/resources/drs-white-paper

17. TOMRA (2022). EPR Unpacked: A Policy Framework for a Circular Economy. Retrieved from: circular-economy.tomra.com/resources/epr-guide

18. UNEP/EA.5/Res.14 (2022). Resolution adopted by the United Nations Environment assembly on 2 March 2022. End plastic pollution: towards an international legally binding instrument. United Nations Environment Assembly of the United Nations Environment Programme. Retrieved from: wedocs.unep.org/xmlui/bitstream/handle/20.500.11822/39764/END%20PLASTIC%20POLLUTION%20-%20TOWARDS%20AN%20INTERNATIONAL%20LEGALLY%20BINDING%20INSTRUMENT%20-%20English.pdf?sequence=1&isAllowed=y

19. Packaging Europe (2022). NEXTLOOPP concludes the first packaging production trial of rPP resins. Retrieved from: packagingeurope.com/news/nextloopp-concludes-first-packaging-production-trial-of-rpp-resins/8391.article

20. Euromonitor (2020). Global Flexible Packaging: State of Play and Sustainability. Retrieved from: www.euromonitor.com/global-flexible-packaging-state-of-play-and-sustainability/report

21. OECD (2022). Global Plastics Outlook: Policy Scenarios to 2060. OECD Publishing. Retrieved from: https://www.oecd-ilibrary.org/environment/global-plastics-outlook_aa1edf33-en

About Us

TOMRA

TOMRA is a global impact leader in the resource revolution, creating and providing sensor-based solutions for optimal resource productivity. Founded in 1972 on an innovation that began with the design, manufacture and sale of reverse vending machines (RVMs) for automated collection of used beverage containers. Today, TOMRA provides technology-led solutions that enable the growth of the circular economy with advanced collection and sorting systems that optimize resource recovery and minimize waste in the food, recycling, and mining industries.

www.tomra.com

PublicAffairs@tomra.com

www.tomra.com