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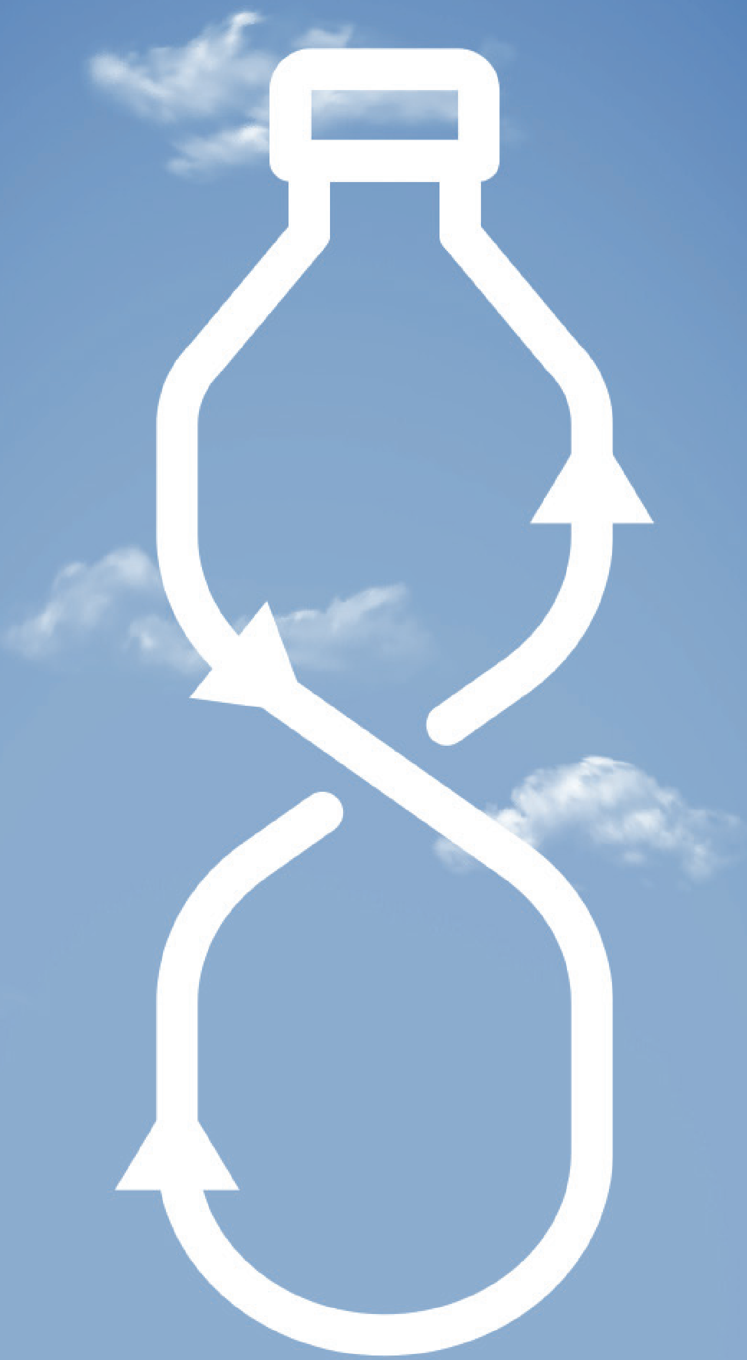
Stay in the cycle

Rethinking recycling with PLA bioplastics



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Introduction

Plastic permeates every aspect of our lives. From engineering applications, medicine, packaging, transport, and even to our hobbies and pastimes, we simply cannot do without the versatility, convenience, durability, and safety that plastic provides. And, while the scientific advances from the last century have facilitated the rise of plastics production and consumption, we now know just how problematic disposing of traditional plastics can be. Manufactured mainly from fossil fuels (99%) [1], traditional plastics significantly contribute to greenhouse gas emissions, global warming, and plastic pollution.

With over 300 million metric tons of raw plastic being produced in 2017 [2], our appetite for plastic products is unlikely to diminish: Estimates suggest that, if current production and waste management trends continue, roughly 12,000 million tonnes of plastic waste [3] will be in landfills or in our oceans and rivers by 2050. Efforts to build a circular plastic economy through reduction, reuse, recycling, and recovery of materials, together with a move away from the use of fossil carbon towards biobased resources is therefore crucial for the sustainability of the planet.

In a circular economy, products at 'end-of-life' provide materials with value rather than being 'waste streams'. They can form new products instead of being disposed of. We apply these principles to the biobased economy where products are produced from sustainable, natural resources and are reused and recycled. Innovative biobased materials such as PLA (Poly Lactic Acid) can be reused or recycled in different ways, even with options where recycling PLA results in rPLA with properties equal to virgin PLA and certifications, including food contact approval. This enables recycled PLA to be used in highly value-added plastics applications.

In this whitepaper, we show how the PLA approach results in a circular economy and examine options for continued recycling of PLA.

Summary benefits of recycling PLA

- Keeps items made from plastic in the recycling loop
- Reduces the consumption of natural resources and virgin materials
- Allows production of high quality products with food contact approval
- Reduces carbon footprint by using an energy-efficient process
- Fits existing sorting technologies with high sorting efficiency
- Lowers incineration and related GHG emissions
- Avoids contamination in other waste streams
- Decreases landfill and the related enviromental impact

Current state of plastic recycling

Since 1950, close to half of all plastic produced has ended up in landfill or has leaked into the environment, and only 9% of used plastic has ever been adequately recycled [4]. According to the report "Breaking the plastic wave" [5], annually, 91 million tons of plastic waste (41%) are mismanaged, resulting in 11 million tons ending up in the ocean, 49 million tons open burned and 31 million tons littering the terrestrial environment.

Despite worldwide legislative and corporate initiatives, plastics recycling is nowhere near to reaching its full potential: the estimated current global recycling rate for plastic packaging is just 10%, with 8% of that in cascading or downgrading applications, and only 2% in closed-loop or equivalent applications [6] . Detailed figures from a publication on the lifecycle of plastics in the Netherlands, an EU member country with relatively good waste management systems, states that of the 1994 ktons of plastic product demand in the Netherlands, only 316 ktons is actually recycled, representing just 16% of the plastics demand.

As we advance towards carbon neutral economies, governments will continue to develop legislation which moves away from fossil fuel consumption. EU recycling targets for plastic packaging waste are currently set at 50% for 2025 and at least 55% for 2030 [7]. However, proposals set to boost these rates are anticipated when amendments to the EU Packaging and Packaging Waste Directive (PPWD) are introduced at the end of 2022/beginning of 2023, with further announcements on percentages of recycled content contained in new plastic packaging expected at the same time.

This drive towards a circular economy will eventually phase out a linear use of plastics i.e., reducing our primary plastics demand, ensuring we reuse them, and that we recycle them. Solutions for waste collection, management, and recycling will continue to evolve.

Most importantly, a different approach is needed when designing and producing materials. It's clear we can no longer expect to bring products to market without ensuring a sustainable end-of-life at disposal. We must turn to innovative materials that allow for products to be endlessly recycled. This means switching from plastics sourced from petroleum feedstock (99%) to biobased plastics from feedstock produced from sustainable organic sources, such as sugar cane or corn starch; or from recycled granulate. This approach is already gaining momentum. Materials such as PLA enable product design consistency with options to compost, recycled and reuse.

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What is PLA?

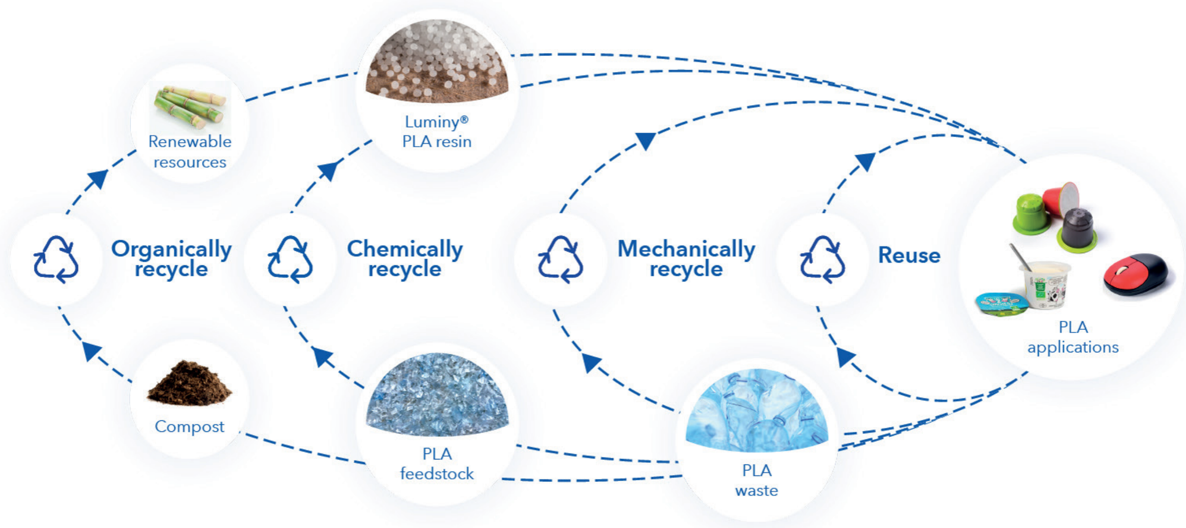
PLA, or Poly Lactic Acid, is a thermoplastic polyester – a bioplastic that is both biobased and biodegradable, offering new, viable end-of-life options, while retaining the benefits associated with traditional plastics. It is typically used in applications requiring good mechanical and optical properties and ease of modification. PLA can be efficiently recycled and is also industrially compostable. Offering a reduced carbon footprint compared to traditional plastics, it has the potential to improve product sustainability as it becomes widely adopted.

Current estimates indicate that PLA will have an average annual growth rate of 15% to 20% by 2030. This high potential for future growth and the sustainable nature of the material, positions bioplastics as one of the innovative solutions needed to enable the EU's Circular Economy Action Plan.

PLA in contrast to conventional petroleum-based materials is produced by using annually renewable carbon as feedstock. Its starting materials are obtained by fermenting carefully managed renewable agricultural resources (currently sugar or corn starch). After polymerization to poly lactic acid, the thermoplastic can be used for food packaging, disposable tableware, and textiles, as well as in numerous other industries such as electronics, automotive and 3D printing.

At the end of their useful life, products made of PLA, including TotalEnergies Corbion's Luminy® PLA brand, can be recycled using mechanical or advanced recycling processes. While mechanical recycling allows for an efficient melt extrusion re-processing, it currently results in a quality downcycle of the product, whereas the mild, selective process associated with advanced or chemical recycling, is capable of transforming the raw materials in products back to those with the same properties as the original PLA.

TOTALENERGIES CORBION
STAY IN THE CYCLE - RETHINKING RECYCLING WITH PLA BIOPLASTICS

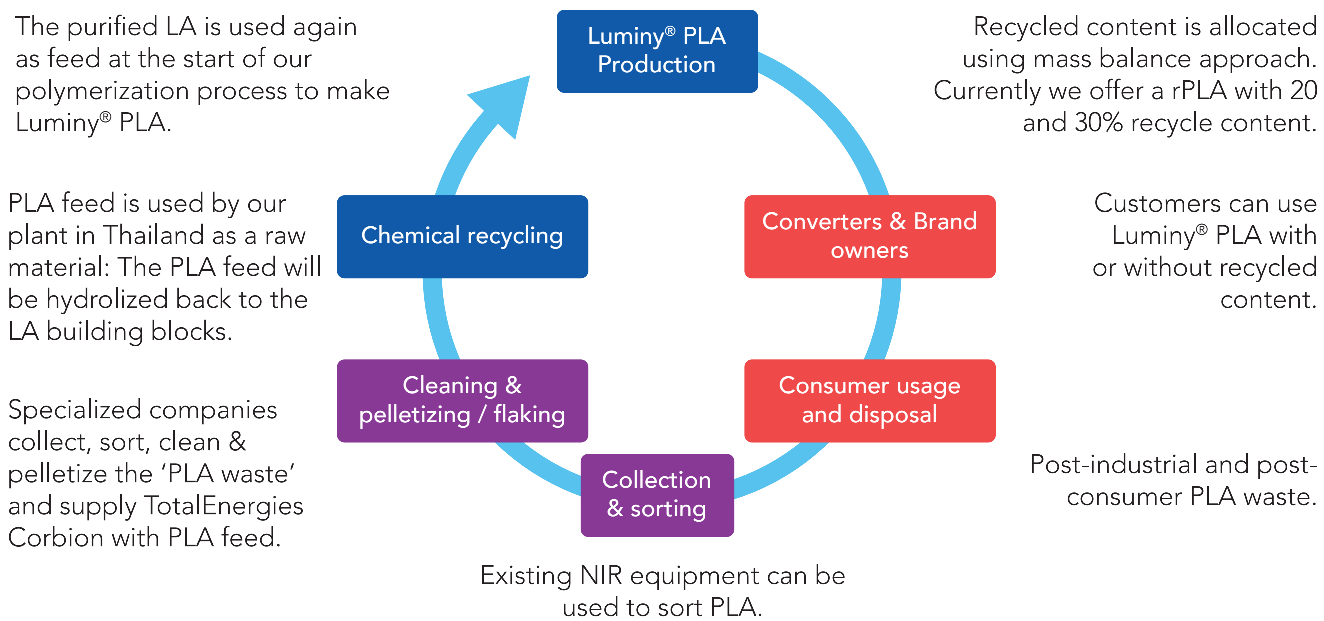


PLA and rPLA in the market

TotalEnergies Corbion is at the forefront of the move towards greater use of PLA bioplastics and is constantly working to encourage learning, understanding and use of PLA bioplastic by both consumers and product manufacturers and designers.

While PLA is relatively new compared to traditional plastics, it has an established production infrastructure behind it, including schemes to buy back recycled items and resell rPLA feedstock for reuse. The focus however must go beyond supply and resupply. A strategic approach is needed to continually assess commercial viability balanced with reducing carbon impact and meeting sustainability goals. TotalEnergies Corbion actively supports the development of all stages in the loop that facilitates recycling PLA.

PLA chemical recycling value chain



We work with customers to create closed-loop recycling schemes for their products. Such schemes support collection, recycling and renewal of feedstock. Sansu in South Korea and NaKu in Europe are examples of organisations operating specially designed collection schemes for consumers to return their PLA bottles for advanced recycling at our plant.

Luminy® rPLA with up to 30% post consumer and pre consumer PLA waste is commercially available from TotalEnergies Corbion. This rPLA is approved for use in food contact applications in Americas, Europe and Asia Pacific, complying with all relevant regional regulations that apply for plastics used in food packaging. The recycle content in rPLA has been 3rd party certified by SCS Global Services.

We also collaborate with waste management specialists in the field of sorting and processing so that we can ensure a sustainable end-of-life for PLA. Numerous field studies inform our ongoing product innovation as well as our advocacy to policymakers and stakeholders in end-of-life solution providers.

Recycling PLA

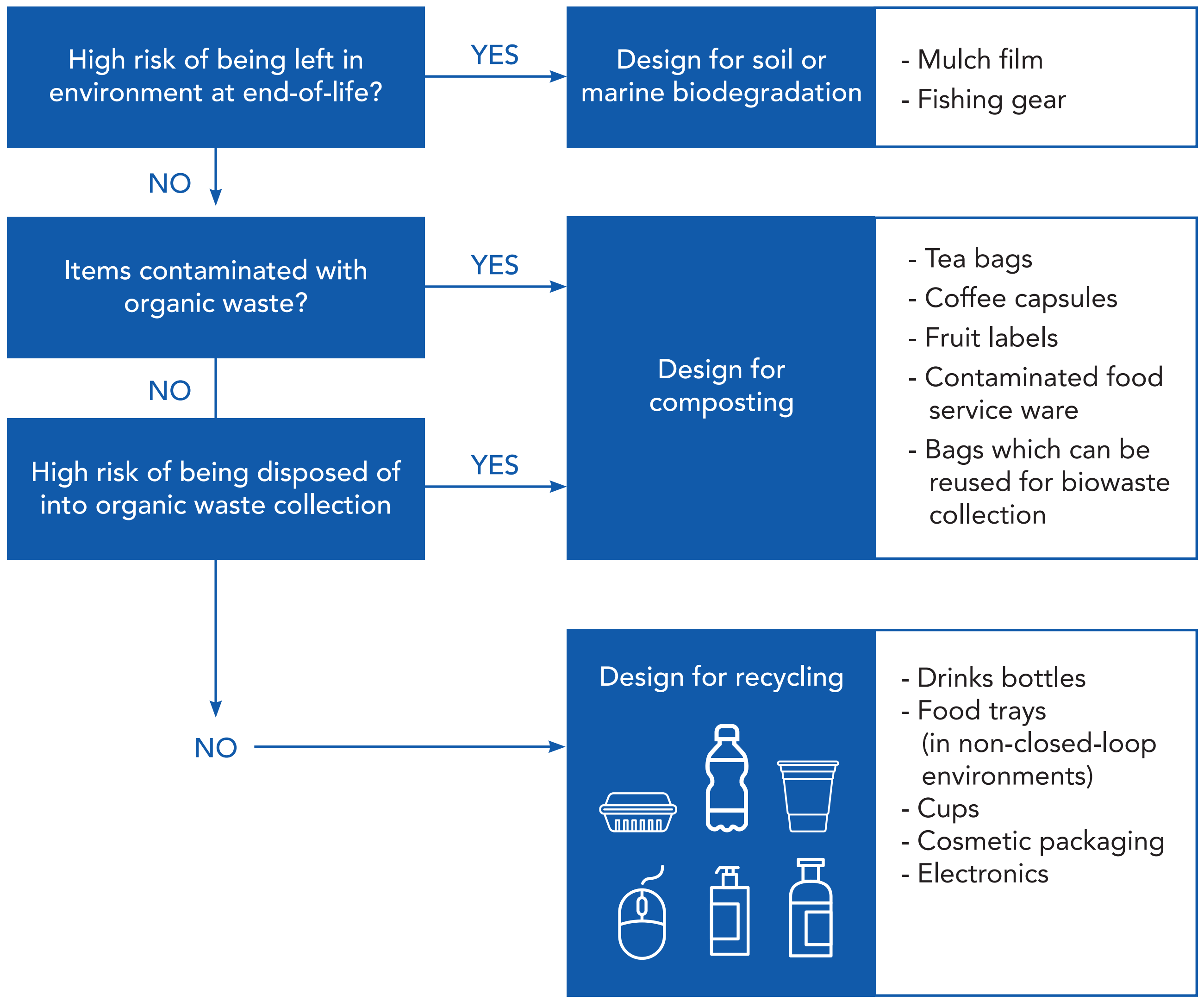
PLA can be recycled effectively in two ways:

MECHANICAL RECYCLING	ADVANCED RECYCLING
PLA waste is collected, sorted and cleaned then flaked and repelletized. Produces a viable material for items such as plant pots or electronics (e.g. a computer mouse).	PLA waste is collected, sorted, cleaned and flaked. Hydrolysis returns polymer flakes back to lactic acid monomer. Produces viable material for food contact, with the exact same mechanical and optical properties as virgin Luminy® PLA.

Considerations for designing products for recycling

From the earliest stages of new product design, it is envisioned that end-of-life scenarios are given equal importance to the other product properties, and when recycling is the preferred solution, the entire value chain must adapt accordingly. This white paper examines the options for products and their benefits, as well as examining, the types of

items that are most applicable for each process from collection through to sorting, flaking, and repurposing. In the design process, we also ask questions to help ascertain the best end-of-life fit.



Other areas of innovation in waste management are beginning to take hold right at the very first stages of a product's life, with items being redesigned to facilitate reuse and recycling.

Clear and consistent labelling is an area which is also helping waste sorting efficiency – invisible bar coding (water marks), for instance, can be identified by NIR regardless of the position or angle of the item.

Embossing rather than printing onto plastic items can also lessen contamination and can greatly contribute to the volume of items successfully recycled. This system can give much more information on the composition of the item, such as the food contact compliance, and the biobased or recycled content.

Sortability of PLA

In current mechanical recycling facilities, only a limited number of plastics are actually sorted and recycled. In general, the plastics with the highest market shares are sorted. These are PET, PP and HDPE.

Thanks to progress in Near Infrared (NIR) technology, density separation, AI and robotics systems in waste management, bioplastics such as PLA can technically be easily separated from other types of polymers on the sorting line. In fact, purities of 97% have been obtained using NIR sorting of PLA, higher than most traditional plastics [8, 9].

The use of NIR spectroscopy for instance, has become a standard in the sorting industry: each polymer has its distinctive infrared fingerprint spectra, which allows for correct identification of materials and the elimination of contaminants in sorting streams. NIR is capable of capturing 10 million recordings of each unique spectrum per second and enables pneumatical sorting of items according to their molecular characteristics [10].

When density separation sink-float techniques are applied in sorting, PLA can again be easily separated from PE and PP. Because PLA has a higher density than water, it will sink to the bottom of the tank and materials with a lower density than water like PE and PP will float.

Sorting PLA from a plastic mix including PET is an easy process using NIR. In collaboration with TOMRA, TotalEnergies Corbion conducted sorting tests using a TOMRA NIR sorting machine. All PLA trays were detected and separated out by the machine. A second test was performed separating PET from a mix of plastic containing PLA. No PLA trays were found in the sorted PET stream. Furthermore, the 2021 paper Near-Infrared Identification and Sorting of Polylactic Acid published results of tests separating PET from a mix of plastic containing PLA of varying thickness. It concluded that no PLA could be found in the final PET stream [9].

"Plastic waste collectors and sorters know that using the infrared technology, PLA plastic products can easily be sorted from other municipal plastic waste. In closed loop environments, where PLA bottles and PLA cups are exclusively used, the amount of PLA is sufficiently high to also make it economically feasible to collect, sort and clean the PLA."

***Jürgen Priesters,** Senior Vice President TOMRA Feedstock.*

Bioplastics and recycling

Bioplastics may be divided into ‘drop-in’ and ‘new’ materials. PLA, part of the 'new materials' category can be mechanically and chemically recycled, and there are no technical barriers to doing so.

"Recycling of bioplastics is technically and economically feasible and helps to keep bio-based carbon in the loop."

***Francois de Bie,** Senior Marketing and Supply Chain Director*

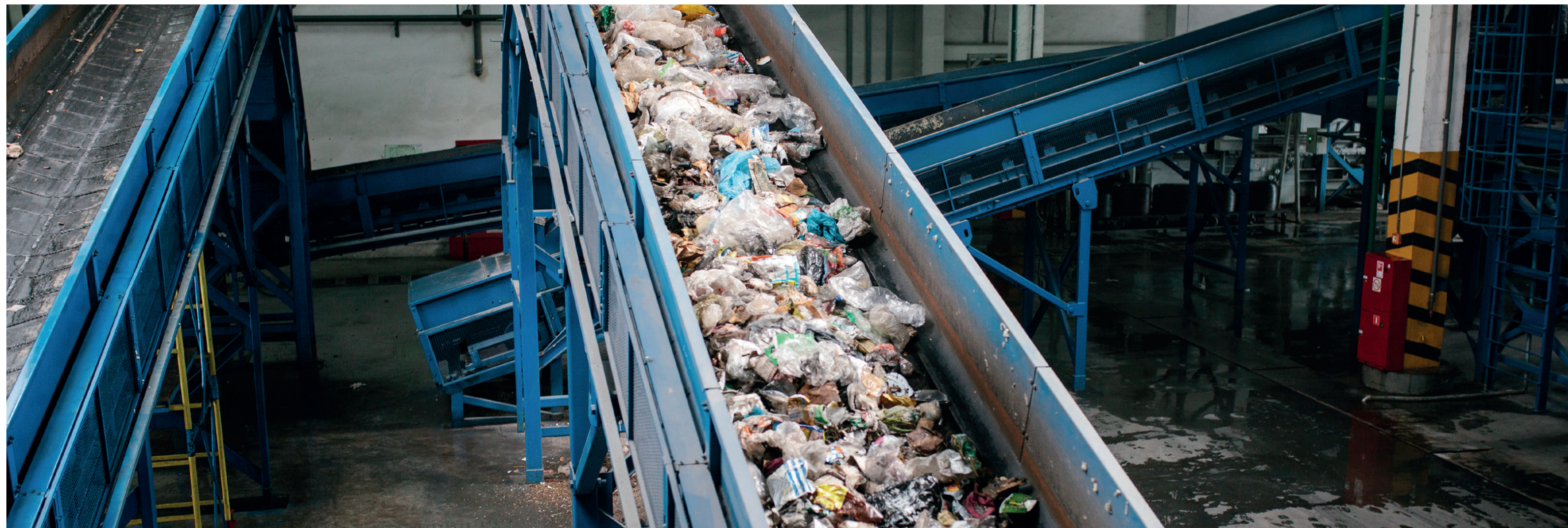
Mechanical recycling

Mechanical recycling takes sorted plastic waste, compacted into bales by MRFs (Material Recovery Facilities) and then typically sold on to recycling companies to remelt and repelletize them into recycled plastic granulate.

There are already several companies that recycle PLA waste, mainly from post-industrial or closed-loop environments. Pelletized PLA is used by converters to replace virgin resin and to produce new items.

The volumes of PLA in consumer municipal waste are currently low but are advancing towards the critical mass that will warrant its own recycling stream [11]. In the short-term, the bid to reduce plastic waste looks to closed-loop environments such as food service or hospitality events where use and collection can be integrated into the standard operation.

Waste management companies are developing Plastic Recycling Facilities (PRF) which sort mixed plastic coming from Material Recovery Facilities (MRF). The largest volumes of conventional plastics such as PET, PP and HDPE are removed from the stream, allowing the remaining volume of innovative plastics like PLA to be significantly higher, making the sorting process much more economically viable.



Advanced recycling

In recent years, there have been major developments in advanced recycling. Also known as chemical recycling, feedstock recovery or tertiary recycling, plastics in this process are converted into monomers, oligomers or hydrocarbons that can be used again to produce polymers.

Aliphatic polyesters like PLA offer the opportunity to hydrolyse the polymer chain directly into its monomer, in this case lactic acid. This reaction is highly selective, not least due to its low temperature requirements. Pyrolysis on the other hand, is a high temperature process producing a range of compounds where more than the desired monomer is obtained and this thermal degradation results in additional fragments that may impact downstream processing, process yield and efficiency.

Chemical depolymerization is the process adopted for the advanced recycling of PLA. Waste that has been sorted and cleaned may be broken down using hydrolysis under mild and selective conditions. The resultant lactic acid, can then be used as new feedstock. It can be used in the same range of applications from where it was recycled - including for food contact - creating a powerful, sustainable material loop in which the integrity of native properties is maintained. Moreover, it can be relatively easily performed in small-scale facilities and used for polyesters like PET and PLA. Depolymerization can address some of the shortcomings of mechanical recycling.

Advanced recycling has been commercialized by TotalEnergies Corbion and adopted in our Luminy® PLA recycling plant, where the company recycles both internal and external PLA waste streams.

"... the bioplastics industry has a responsibility to preserve material value in order to minimize our impact on our surroundings. Valorizing PLA waste as a feedstock for either chemical or mechanical recycling is a huge opportunity."

Gerrit Gobius du Sart, *Corporate Scientist, TotalEnergies Corbion*

Advantages of advanced recycling

- Unlike advanced recycling, mechanical recycling often results in a reduction in quality of the recyclate.

- Advanced recycling purification processes, results in more valuable polymers identical to original virgin feedstock. Advanced recycling is a solution to some of the quality issues of mechanical recycling, and it is complementary to it. Advanced recycling also allows the use of recyclates to produce food contact-compliant materials.

The impact of PLA in plastics recycling stream

A common misconception is that PLA bioplastic contaminates the plastic recycling streams of traditional plastics. Currently, bioplastics represent only around 1% of total plastic input [12,13], so the volume ending in the recycling stream is very low. Where they do enter traditional recycling streams, they do not impact the purity any differently than other traditional plastics [14, 15].

Various studies show that PLA does not contaminate the traditional plastic recycle stream more than other traditional plastics. For example, research conducted in 2017 showed that adding 10% PLA into polyolefin recycling streams has no different influence on the properties than adding 10% PET or PS to these streams. Furthermore, no specific threats were found from PLA contamination in the PET recycling stream [16]. Other substances like PVC and EVOH have a much greater negative impact on the quality of PET recycling.

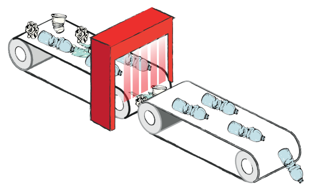
A WUR study of PLA in PET food tray streams showed that levels between 0.1% and 1% had a negligible effect on purity. This is especially encouraging when you consider that current concentrations of PLA in recycling PET in the Netherlands vary between 0% and 0.019%, and even if consumption rises, NIR technology can keep PLA concentrations below 1% [17].

"Technically it is perfectly possible to include biobased plastics in our recycling value chains and to lower the carbon footprint, but central orchestration is vital to make it a success"

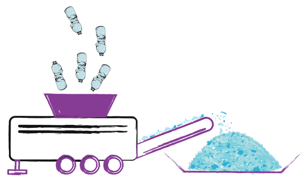
Dr. E.U. (Ulphard) Thoden van Velzen, *Senior Researcher in Packaging Technology and Recycling, Wageningen Food & Biobased Research*

Rethinking recycling with PLA

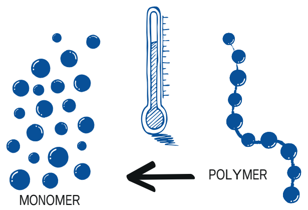
STEP 1. COLLECTION
Bottles made from PLA are collected through a dedicated network



STEP 2. CONDITION CHECK
Bottles are checked and sorted.



STEP 3. SHREDDING
Bottles are cleaned, flaked, and pelletized ready for advanced recycling.



STEP 4. ADVANCED RECYCLING
rPLA pellets are subjected to a hydrolysis process at TotalEnergies Corbion Thailand plant. The polymer is broken down into its monomers and can be subsequently repolymerized to produce PLA resin.

STEP 5. READY FOR PRODUCTION
PLA resin is ready to produce new bottles.

At TotalEnergies Corbion, we believe that mechanical and advanced recycling are viable, economically feasible and commonly used end-of-life solutions for PLA-based products. We are committed to developing the recycling value chain together with specialized stakeholders from the complete PLA value chain to stimulate demand for PLA, thereby increasing recycling rates for PLA-based products.

Case study: How Sansu closed the loop for PLA drink bottles

By using their existing logistics infrastructure, bottled water supplier Sansu in South Korea worked with our TotalEnergies Corbion recycling plant team to create a system to recover used PLA bottles. After consumption, the customer (this includes consumers and B2B customers, such as restaurants and hotels) gathers the bottles for collection The bottles are picked up by drivers as they deliver the next shipment. The same driver will also do a quick condition check of the batch, thereby optimising logistics in the resupply chain. Once a decent volume of bottles have been collected they are sent to a shredding factory. The flakes go through a dust removal process, before going through the hydrolysis process at TotalEnergies Corbion Thailand plant, to produce rPLA resin.

The path to robust bioplastic recycling

Currently, many MRFs do not sort PLA from post-consumer waste, as the volume is considered too small to justify installing a separate NIR sorting line. That does not mean that we should abandon the rewards promised by bioplastics. Indeed, PLA is being recycled today, and several specialised companies collect PLA waste from post-industrial sources (e.g., production scrap) and closed-loop environments (e.g., festivals).

By increasing the mechanical and advanced recycling rates of PLA, we believe that the overall market share of PLA will grow. This means that sorting PLA from household waste will become more economically feasible in the future. Until then, a mass balancing approach should be adopted to calculate the recycled content of PLA.

Enabling conditions for mechanical and advanced recycling should be guaranteed from stakeholders along the value chain:

1. The upscale of proper sorting technologies that would enable better waste streams and allow the recycling of PLA.
2. Extended Producer Responsibility fees as well as the several national "plastics" taxes paid by plastic producers, including PLA, should be "earmarked" for the upscale of NIR sorting technologies.
3. Commercial agreements among plastics recyclers, PLA producers and brand owners to guarantee the uptake of recycled PLA in new products.

A mass balancing method

It is TotalEnergies Corbion's preference that advanced recycling processes 'plug in' to our existing infrastructure to reduce costs and time-to-market. For this reason, recycled feedstock will most likely not exist in physically separate flows, also called 'identity preserved' flows. They are instead added together with the virgin raw materials in the manufacturing plant.

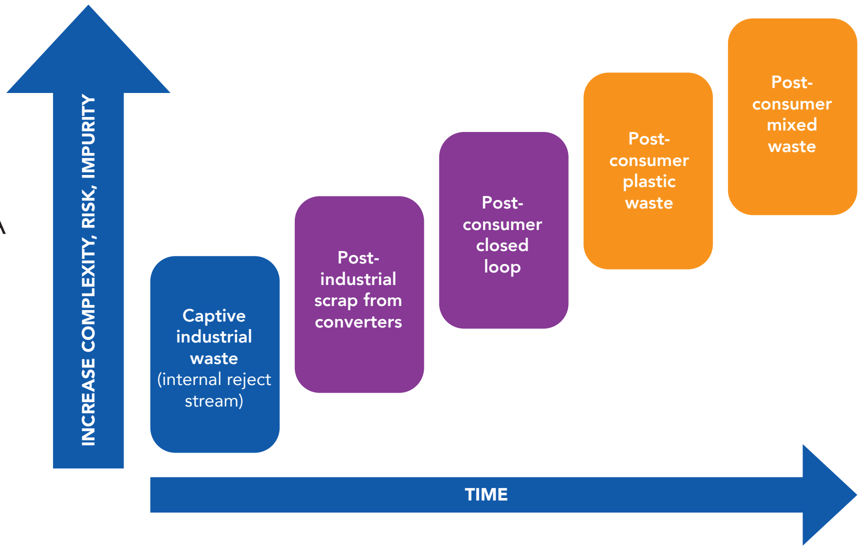
To be able to account for the recycled input, TotalEnergies Corbion proposes to use the principles of mass balancing according to the standard ISO 22095:2020 Chain of custody — General terminology and models. Mass balancing is a well-known chain of custody approach that is already successfully implemented in, for instance, the FSC, BCI and Bonsucro initiatives, where tracking identity preserved streams is costly and adds to the time-to-market.

TotalEnergies Corbion has the infrastructure in place to perform chemical depolymerization of PLA in its commercial plant in Thailand and is also working to develop this capability in Europe. Luminy® PLA with recycled content is now commercially available on the market as Luminy® RMB PLA (RMB meaning recycled mass balance). We currently have available RMB20 PLA with a 20% recycled content and plan to increase the recycled content progressively as PLA feed streams develop.

CERTIFIED RECYCLED CONTENT SCS GLOBAL SERVICES
20% RECYCLED CONTENT
POST-CONSUMER/PRE-CONSUMER
MASS BALANCE ALLOCATION

TotalEnergies Corbion rPLA containing 20% Recycled Content is third-party certified by SCS Global Services.

TotalEnergies Corbion's strategy is to develop this PLA depolymerization to recycle post-consumer plastic waste from mixed plastics



The benefits of using bioplastics to increase recycling rates

At TotalEnergies Corbion, we believe that PLA bioplastics can play an important part in our endeavours as we strive for a truly circular plastics economy where we provide additional end-of-life options compared to those available for traditional plastics.
Mechanical and advanced recycling that turns PLA back into PLA will become viable, economically feasible and commonly used end-of-life solutions for PLA bioplastics.
When recycling biobased plastic, the biobased carbon content is kept in the loop, and its benefits last longer. Biomass growth absorbs carbon from the atmosphere; this biobased carbon present in the plant is later stored in PLA. Recycling PLA does not release the carbon back into the atmosphere and stores it for a longer amount of time. Recycling PLA allows avoiding the environmental impact including carbon footprint from the biomass growth and lactic acid production. In the virgin PLA production, these stages represent 70% of PLA global warming potential.

"We commit to buying back collected & sorted PLA waste to help close the loop."
Maelenn Ravard, *Regulatory and Sustainability manager*

We aim to collaborate with third parties that collect, sort, and pelletize 'PLA waste' with consistent quality to add this to our chemical recycling unit in Thailand. After chemical recycling in our plant, the result will be food contact-approved recycled PLA. We are actively looking for partners worldwide that can help us close the loop for PLA recycling. In the pursuit for sustainability, TotalEnergies Corbion acquires PLA waste (post-industrial or post-consumer) from any parties willing to join our recycling journey.

To find out more about Luminy® PLA's cradle-to-cradle potential, visit https://www.totalenergies-corbion.com/about-pla/recyclability/

Definitions

Advanced recycling
Also called "chemical recycling". The process where polymers are chemically or thermochemically broken down and returned into its monomers to make new plastic resins.

Bioplastics
Plastics which are biobased, biodegradable or both.

Biobased plastics
Plastics wholly or partly derived from biomass used for bioplastics stems from e.g. corn, sugarcane, or cellulose according to the standard EN 16785-1.

Luminy® rPLA RMB20 and Luminy® rPLA RMB30
TotalEnergies Corbion PLA grades with 20% and 30% post consumer and pre consumer recycle content. The entire commercially available Luminy® PLA portfolio (including LX175, LX575, LX530, L175, L130, L105, LX975 and LX930) are available in RMB20 / RMB30 versions. (RMB20 – Recycle Mass Balance 20%; RMB30 – Recycle Mass Balance 30%)

Mass balance approach
Mass balance is a consideration of the input, output, and distribution of a substance between streams in a process or stage [3]. The idea of the mass balance approach is that a certain feedstock (bio-based/renewable or recycled plastics) replaces an equivalent amount of virgin feedstock at the beginning of the value chain (input) to be allocated to the product (output) in such a manner that the input and output match. This approach is defined in the standard ISO 22095:2020.

Mechanical recycling
The process of breaking down materials into secondary raw materials usually by crushing or shredding.

NIR
Near Infrared technology. Near Infrared (NIR) sorting is used commonly in the waste industry to recover materials of value from mixed streams. The technology uses differences in the wavelengths of infrared light that is reflected by polymers with different chemical structures.

rPLA
Poly lactic acid polymer which has been recycled

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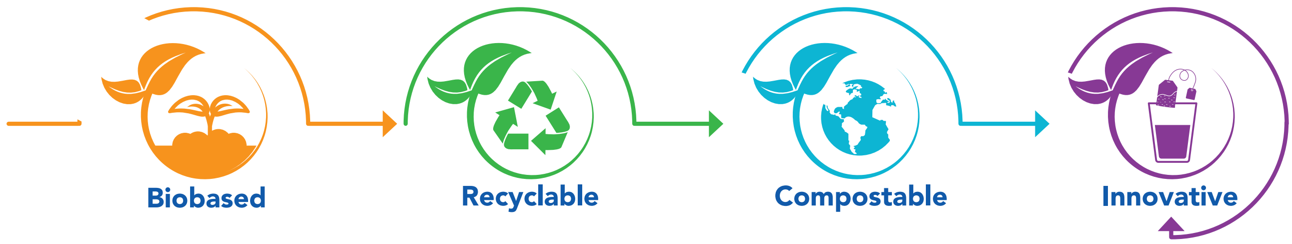
Luminy® PLA

Beyond conventional plastic



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