

Innovation and New Technologies to Promote Circular Economy in the Plastics Sector in Sri Lanka - A Roadmap

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Executive Summary

Introduction and context

This report presents a comprehensive assessment of innovations in technology, business models, and system level enablers that have contributed towards circular economy in plastics value chain. It draws on international developments, experience and status in Sri Lanka to analyse the role of innovations and recommend the actions needed to achieve the same in Sri Lanka in the form of a roadmap.

Globally, plastics production has exceeded 460 million tonnes annually, with packaging representing the largest application and waste stream. Sri Lanka mirrors this challenge, generating approximately 249,000 tonnes of plastic waste per year, of which only a small fraction is effectively recycled. Despite a relatively high collection rate (~73%), a significant share remains mismanaged due to leakages in downstream systems, contributing to land, river, and marine pollution. Plastic pollution has become a critical environmental issue in Sri Lanka, particularly affecting coastal and marine ecosystems, while also posing risks to human health through microplastics. Although regulatory frameworks such as the Polythene and Plastic Management Regulations (2017) and the National Action Plan on Plastic Waste Management (2021–2030) have established a policy foundation, implementation challenges persist in enforcement, infrastructure, and monitoring systems.

The project activities involved plastic value chain analysis, policy analysis and engaging with MSMEs (Micro Small and Medium Enterprises) in the value chain. The findings from the project showed that small scale collectors, large scale collectors and local authorities play an important role in collecting plastic waste from sources such as households, hotels, restaurants, businesses, and organizations. Informal sector plays a critical role in waste collection and material recovery but they are not insufficiently integrated into formal planning, monitoring, and reporting systems. There are also issues of lack of sufficient funding, equipment, infrastructure as well as inadequate coverage for collection. Recyclers are faced with challenges of feedstock contamination and limited markets for recycled products. Extended Producer Responsibility would need these challenges to be addressed.

Against this backdrop, the report examines innovation pathways that are technically feasible and relevant to Sri Lanka. It covers alternate materials such as bioplastics, innovations in end-of-life management including recycling and life cycle studies.

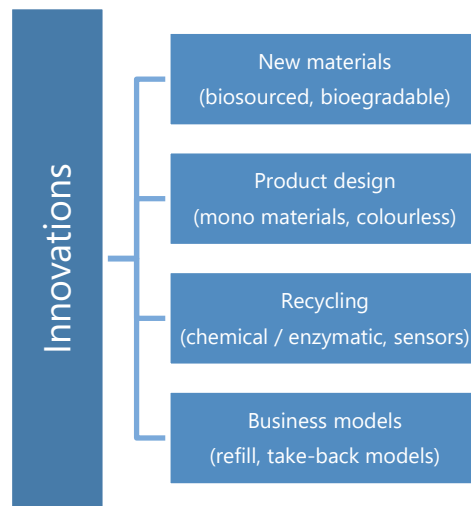
Innovation and technology

A wide range of materials, including bio-based plastics, biodegradable and compostable polymers, starch-based materials, cellulose derivatives, seaweed- and mycelium-based solutions, are being developed and are increasingly available at commercial or near commercial scale. They have the potential to reduce reliance on fossil feedstock and their properties are being improved to meet the requirements. However, the biodegradability or compostability leads to environmental benefits only when they are segregated and composted under the prescribed conditions. The other challenges include the need for proper certification, cost competitiveness and consumer acceptance.

The End-of-Life management options cover advances in technology for identification and sorting, recycling, product design for improved end of life management and circular business models. Mechanical recycling remains the most immediately viable pathway for commonly used plastics such as PET, HDPE, LDPE and PP which are supported by existing informal collection networks. Advanced technologies, such as chemical recycling, enzymatic recycling, and emerging technologies such as vitrimerisation of thermoset

plastics, show longer term potential, especially for complex and contaminated waste streams. However, the economic viability, resource and infrastructure need to be considered. There is scope for improving sorting through use of sensors and digital tools. Circular business models such as reuse, refill, Deposit Return Schemes and product as a service demonstrate potential to reduce material throughput and environmental impacts. Pilot initiatives in Sri Lanka indicate growing interest in these approaches; however, consumer acceptance is needed for its success.

The selection of alternatives needs to be supported by life cycle analysis. For instance, in the case of bioplastics, the benefit from composting is only present when there is effective waste segregation, and controlled composting infrastructure. The overall environmental impact would also be influenced by local agricultural practices related to the biomass used. In the case of alternatives such as glass, the benefit would depend on the recycling rate and number of times it is reused.



Different aspects of innovation along the plastics value chain

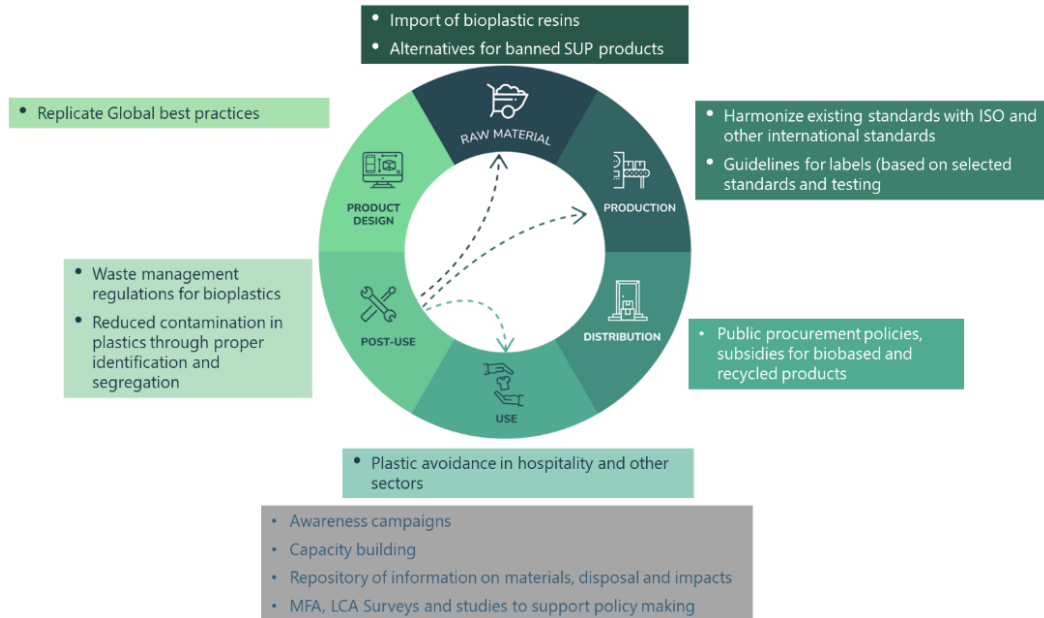
Strategic pathways and priority actions

Addressing Sri Lanka's plastics challenge and promoting circular economy cannot be addressed through isolated interventions. Material substitution without corresponding waste management infrastructure risks shifting environmental burdens rather than reducing them. Similarly, end of life technologies and circular business models will not scale without supportive regulatory frameworks, market incentives, and institutional capacity. Therefore a phased and systems-oriented transition that aligns material innovation, business models, infrastructure investment, and governance mechanisms is needed. In this context, Sri Lanka's EPR regulations and National Action Plan on Plastic Waste Management (2021–2030) provide opportunities for frameworks, financing, and monitoring.

The short term (1-3 years), medium term (4-6 years) and long term (7-10 years) recommendations are described below in relation to the circular economy themes. The key stakeholders include Government agencies (with the Central Environmental Authority playing an important role), private sector (big brands can contribute significantly through implementation of Global best practices and supporting logistics), civil society (consumer acceptance is key for success of any changes made) and finance sector (to promote investment in green products and innovations). These recommendations will also contribute towards

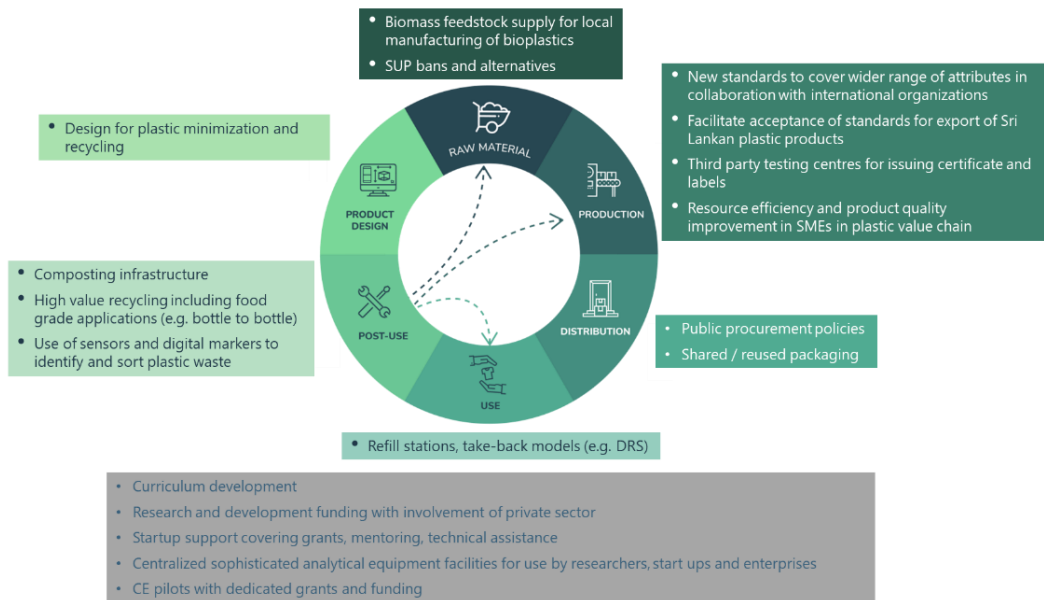
several goals (reduced plastic use, increased collection and recycling, enhanced knowledge and community participation) in the National Action Plan on Plastic Waste Management (2021–2030).

Short term actions



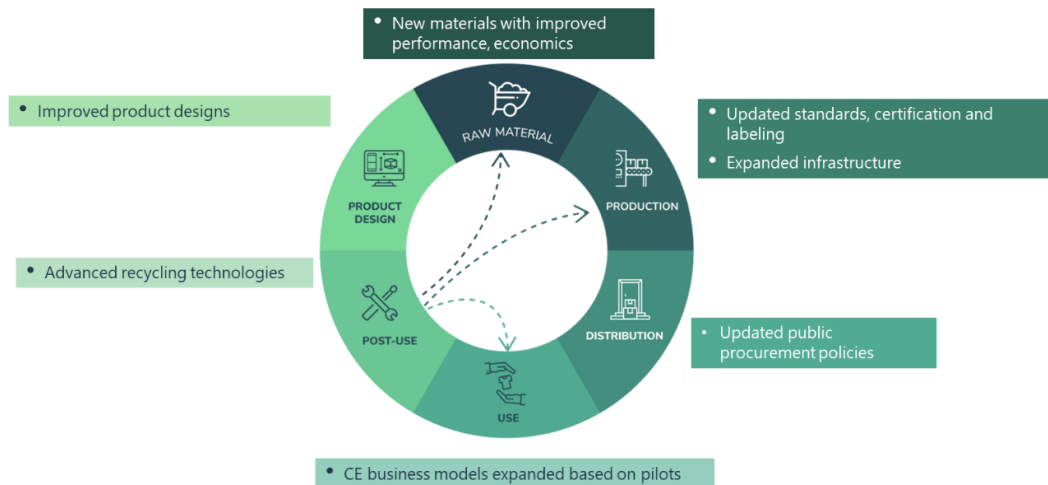
There are already bans and presence of bioplastics in the market. In this scenario, there is need for proper labelling of products based on testing and certification combined with awareness among users about products. Proper segregation and recycling will contribute towards reduced contamination and the move towards high value recycling. There is also scope for reducing plastic use through simple measures, especially in the hospitality industry. The move towards alternatives should be supported through LCA studies to ensure that there is overall positive impact.

Medium term actions



Through national research programmes and start up support, new materials that can replace single use plastics (SUP) and local manufacturing can be promoted. Setting up of infrastructure for testing, certifying as well as sophisticated analytical equipment infrastructure would support this. Use of technologies for identification and sorting as well as creating suitable composting facilities will contribute towards improved end of life management. Circular Economy pilots funding will enable testing of multi stakeholder solutions. These can include refill stations, take-back models. Markets for new materials and recycled materials can be promoted through public procurement.

Long term actions



In the long term, advanced recycling techniques can be adopted which will lead to improved quality and recycling of complex materials. The circular economy measures can be replicated and scaled up based on results from the pilots. Continued research will contribute towards better performance and economics of alternatives. The improvements in product design, public procurement, standards and labelling would need to be updated and continued based on the developments.

These actions would lead to reduced plastic leakage and pollution, increased circularity, stronger institutional and regulatory systems and enhanced ecosystem for innovation.

Table of Content

Executive Summary.....	i
List of Figures	vii
List of Tables	viii
List of Abbreviations.....	ix
1. Introduction.....	1
1.1 Global outlook	1
1.2 Scenario in Sri Lanka	2
1.3 PLASTICS project and its findings.....	5
1.3.1 Value chain status.....	5
1.3.2 Policy framework.....	6
1.3.3 MSME engagement.....	6
1.4 Role of Innovation and technology.....	7
2. Innovations in plastics	8
2.1 Biodegradable plastics	8
2.1.1 Polylactic Acid (PLA).....	8
2.1.2 Polyhydroxyalkanoate (PHA)	9
2.1.3 Thermoplastic starch.....	10
2.1.4 Other bioplastics	10
2.1.5 Biobased conventional plastics.....	12
2.1.6 Standards for degradability of bioplastics.....	12
2.2 Innovations in Sri Lanka.....	14
3. Innovations in end-of-life management	16
3.1 Technological innovations	16
3.1.1 Biodegradation and composting technologies.....	16
3.1.2 Chemical technologies.....	16
3.1.3 Enzymatic recycling.....	17
3.1.4 AI-powered and robotic sorting.....	18
3.1.5 Vitrimization of thermoset plastic waste.....	19
3.2 Product design for improved end of life management.....	20
3.3 Business model innovation.....	21
4. Lifecycle studies	23
4.1 Single-Use plastic bags versus alternatives.....	25
4.2 Plastic bottles versus alternatives	26
5. Recommendations for incorporating innovation for circular economy	28
5.1 Expanding use of bioplastics and other alternatives	28
5.1.1 Standards, certifications and labelling	28
5.1.2 Infrastructure for testing, certification, disposal.....	29
5.1.3 Awareness.....	30
5.1.4 Promoting markets for ecoproducts	30
5.1.5 Promoting research, development and commercialization	31
5.2 Minimizing plastic use.....	32

5.2.1	Product design	32
5.2.2	Packaging optimization	33
5.2.3	Facilitating plastic ban implementation	33
5.3	Recycling.....	34
5.3.1	Better product segregation and reduced contaminants.....	34
5.3.2	High value recycled products.....	35
5.3.3	Advanced recycling technologies	36
5.4	Overarching themes.....	36
5.4.1	Data based decision making.....	37
5.4.2	Circular Economy pilots.....	37
5.5	Stakeholders.....	37
5.6	Link to National plastic waste management plan.....	39
5.7	Concluding remarks	39

List of Figures

Figure 1. Collection status of plastic waste	3
Figure 2. Status of collected plastic waste	3
Figure 3. Sources of leakages	3
Figure 4. Sources of plastic waste collected by Municipal Council / Urban Council	6
Figure 5. Sources of plastic waste collection by informal collectors in Western Province	6
Figure 6. Classification of bioplastics and their interrelationships.....	8
Figure 7. Examples of product design interventions	21
Figure 8. Circular business models related to plastic packaging	22
Figure 9. Comparison of PET bottle with PLA and glass.....	27
Figure 10. Recommendations and their link to the Circular Economy themes.....	40

List of Tables

Table 1. Commercially available PLA products.....	9
Table 2. Commercially available starch based plastic products.....	10
Table 3. Overview of seaweed-based products and development status	11
Table 4. Certification schemes for biodegradable / compostable plastics	13
Table 5. Support needed for startups working in the area of plastics and alternatives.....	15
Table 6. Indicative impacts of bio-based and fossil-based polymers	24
Table 7. Comparison of single use plastic bag with PLA and paper bags	25
Table 8. Stakeholders and their areas of involvement.....	38

List of Abbreviations

DRS	Deposit Return Scheme
EPR	Extended Producer Responsibility
GWP	Global Warming Potential
HDPE	High-Density Polyethylene
LCA	Lifecycle Assessment
LDPE	Low-Density Polyethylene
MRF	Materials Recovery Facility
MSME	Micro Small and Medium Enterprises
Mt	Million Tonnes
NIR	Near Infrared
PBAT	Polybutylene Adipate Terephthalate
PBS	Poly(butylene succinate)
PCL	Polycaprolactone
PE	Polyethylene
PET	Polyethylene Terephthalate
PHA	Polyhydroxyalkanoates
PLA	Poly(lactic acid)
PP	Polypropylene
PS	Polystyrene
PVA	Polyvinyl alcohol
PVC	Polyvinyl Chloride
SCP	Sustainable Consumption And Production
SUP	Single Use Plastic
TPA	Terephthalic acid

1. Introduction

1.1 Global outlook

Plastics have become an integral part of global industries, offering economic, durable and lightweight solutions for many applications. Their versatility has spread its applications in sectors such as packaging, building and construction, healthcare, consumer goods and industrial logistics. In 2019, the global plastic production was 460 million tonnes (Mt) and the waste generated was 353 Mt¹. In all segments, growth has been projected by 2050, with maximum growth projected for the packaging segment². Packaging contributes to more than 30% of plastic consumption and also to 42% of plastic waste generation³.

Plastic packaging is manufactured using different polymers, each resulting in different physical properties, durability and applications across industries. The type of plastic is chosen based on functionality, cost and application-specific demand, making them a go-to for diverse industries.

Some of the commonly used plastics in packaging are summarized below:

- *Polyethylene Terephthalate (PET)*: PET is widely used in food and beverage packaging. Its lightweight and transparent nature combined with excellent barrier properties makes it ideal for preserving freshness and preventing contamination, particularly for bottled water, soft drinks and food containers.
- *High-Density Polyethylene (HDPE)*: It is commonly found in milk jugs, detergent bottles and industrial packaging. Its strength and durability make it a preferred choice for household and industrial containers to ensure leak-proof and long-lasting storage.
- *Low-Density Polyethylene (LDPE)*: It is a soft, lightweight and flexible material used for plastic bags, shrink wraps and squeezable bottles. Its moisture-resistant properties make it ideal for food packaging.
- *Polystyrene (PS)*: PS is commonly used for disposable utensils, food service containers and protective packaging. It is also used as a cost-effective cushioning material for packaging fragile items.
- *Polyvinyl Chloride (PVC)*: It is a versatile material that can be rigid or flexible and it has good chemical resistance and durability making it suitable for use in cling wraps, pharmaceutical packaging.

The improper handling of plastic materials has emerged as a global concern which is linked to unsustainable patterns of production and consumption. Large volumes of plastics are produced and discarded within the same year, causing millions of tonnes of primary resources that are not recovered or integrated back into the economic market⁴. Currently, the increase in the use of single-use packaging materials contributes to most of the waste generated on a global scale. It is estimated that packaging waste makes up approximately 15-35% of solid household waste worldwide⁵.

Improper management of plastic waste comes with significant environmental consequences that threaten

¹ OECD (2022), Global Plastics Outlook: Economic Drivers, Environmental Impacts and Policy Options, OECD Publishing, Paris, <https://doi.org/10.1787/de747aef-en>.

² Dokl, M., Copot, A., Krajnc, D., Van Fan, Y., Vujanović, A., Aviso, K.B., Tan, R.R., Kravanja, Z. and Čuček, L., 2024. Global projections of plastic use, end-of-life fate and potential changes in consumption, reduction, recycling and replacement with bioplastics to 2050. *Sustainable Production and Consumption*, 51, pp.498-518.

³ OECD (2022), Global Plastics Outlook: Policy Scenarios to 2060, OECD Publishing, Paris, <https://doi.org/10.1787/aa1edf33-en>.

⁴ Diggle, A. and Walker, T.R., 2022. Environmental and economic impacts of mismanaged plastics and measures for mitigation. *Environments*, 9(2), p.15.

⁵ Tencati, A., Pogutz, S., Moda, B., Brambilla, M. and Cacia, C., 2016. Prevention policies addressing packaging and packaging waste: Some emerging trends. *Waste management*, 56, pp.35-45.

both sustainable development and resource efficiency. Poorly managed plastic waste often infiltrates ecosystems, polluting soil, waterways and marine habitats. Degradation of plastic materials produces microplastics, which threaten biodiversity and human health. Despite numerous initiatives to improve collection and sorting, a huge amount of plastic waste ends up in landfills or incinerators. Plastic production is heavily reliant on fossil fuels, leading to carbon emissions and resource depletion.

Globally many initiatives have been taken for Plastic Waste Management as summarized below⁴:

- **Extended Producer Responsibility (EPR):** Many countries enforce EPR policies, holding the manufacturers accountable for the plastic waste generated. It promotes recycling and reduces landfill waste.
- **Advanced recycling technologies:** Innovations such as chemical recycling help reduce the dependence on virgin plastic by transforming plastic waste into reusable materials.
- **Waste segregation and collection:** Countries like Japan and Sweden maintain stringent waste segregation and collection systems that improve recycling benchmarks.
- **Single-Use plastic regulations:** Many nations have enacted bans and limitations on single-use plastics, greatly reducing plastic pollution.
- **Public awareness and community engagements:** Educational initiatives and grassroots movements have successfully fostered responsible plastic use and waste management.
- **Deposit Return Scheme (DRS):** Countries such as Germany and Norway have effectively put DRS into action, providing incentives for returning plastic bottles, resulting in recycling rates of over 90%.

Summary

- Global plastic consumption is high (460Mt production and 353Mt waste generation in 2019) and projected to grow, especially in packaging segment which contributes to more than 30% of plastic consumption and 42% of plastic waste generation.
- Poorly managed plastic waste enters soil, waterways and marine habitats and its degradation produces microplastics, which threaten biodiversity and human health. Further, the use of fossil fuels for its production leads to carbon emissions and resource depletion.
- Measures such as Extended Producer Responsibility (EPR), stringent waste segregation and collection, single-use plastic regulations, advanced recycling technologies, public awareness and Deposit Return Scheme (DRS) are used globally to address the problem

1.2 Scenario in Sri Lanka

Sri Lanka is increasingly confronted with environmental challenges arising from the rapid growth of plastic consumption driven by urbanization, economic expansion, tourism, and changing consumption patterns⁶. Over the past two decades, plastics have become deeply embedded in everyday life, particularly in packaging and other short-lived applications including food packaging, shopping bags, sachets, and disposable containers. Recent estimates indicate that a significant proportion of plastic waste remains inadequately managed⁷.

Sri Lanka generates approximately 249,000 tonnes of plastic waste annually and approximately 181,000

⁶ Jayasinghe, R.R., Abeyrathna, W.P., Jayasingha, K.R., Hendawitharana, M.P., Bandara, T.S., Liyanage, C.L. and Williams, K.S., 2023. Exploring the plastic collection and recycling trends in Sri Lanka. *Recycling*, 8(6), p.94.

⁷ Ministry of Environment (2021). National Action Plan on Plastic Waste Management 2021-2030, "Sobadam Piyasa", Robert Gunawardana Mawatha, Battaramulla, Sri Lanka.

tonnes per year (73%) of waste is collected by a combination of formal and informal collection systems, out of which approximately 27,000 tonnes (11%) of plastic waste is estimated to be sent for recycling⁸. The leakage from the waste management system is around 101,000 tonnes leading to around 68% of plastic waste that is mismanaged which is often burnt or buried. The percentages are shown in Figures 1-3.

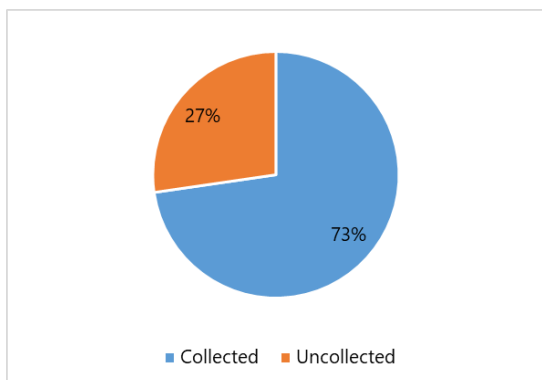


Figure 1. Collection status of plastic waste

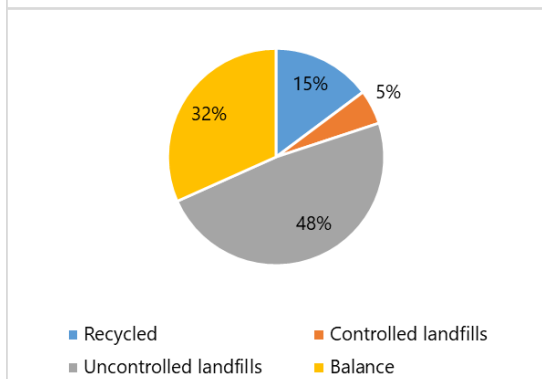


Figure 2. Status of collected plastic waste

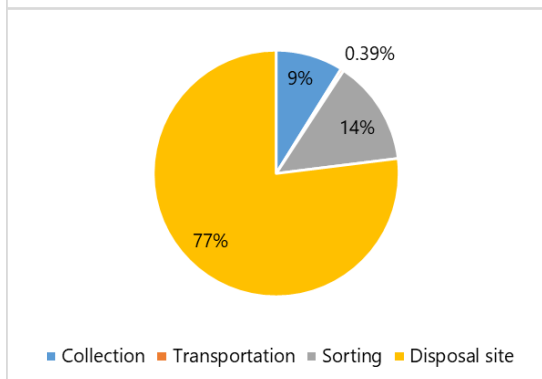


Figure 3. Sources of leakages

A substantial amount of plastic waste is gathered by informal waste pickers and recycling businesses, but the gaps in infrastructure and improper collection and segregation at ground level limits the recycling efficiency. Municipal solid waste management is decentralised to local authorities, many of which face shortages of funding, equipment, and trained personnel⁹. As of 2020, over 200 collectors and recyclers were registered in Sri Lanka, which is majorly concentrated in the densely populated South-West regions

⁸ Ministry of Environment (2024). National Plastic Waste Inventory for Sri Lanka: A Material Flow Approach, "Sobadam Piyasa", Robert Gunawardana Mawatha, Battaramulla, Sri Lanka.

⁹ Ruzaik, F. Nuskiya, H., & Nasurdeen, N. (2025). Plastic Waste Management in Sri Lanka: The Issues in Operationalizing the Management Practices with Local Authorities. SOBA, 34(1), 20-34.

like Colombo and Matara districts¹⁰. The plastic waste recycled at recycling centers consists of LDPE (38%), Polypropylene (PP) (26%), HDPE (20%), PET (10%) and PVC (6%)¹¹.

The environmental impacts of plastic pollution in Sri Lanka are particularly evident in coastal and marine ecosystems. Numerous studies have documented widespread contamination of beaches, lagoons, and nearshore waters with both macroplastics and microplastics¹². Microplastic particles have been detected in beach sediments, surface waters, and marine protected areas across the island, often at higher concentrations near urban centres, ports, and river mouths. Fibres and thin plastic films dominate observed microplastic fractions, with polyethylene, polypropylene, and polystyrene being the most frequently identified polymers. The X-Press Pearl maritime disaster caused release of billions of plastic pellets along the western coastline and a sharp increase in microplastic contamination of coastal sediments, with monitoring studies indicating persistent residues several years after the incident¹³.

Plastic pollution also raises public health concerns. Microplastics have been detected in commercially important seafood species consumed locally, indicating potential dietary exposure pathways for humans¹⁴. In addition, the practice of open burning of plastic waste which does take place in Sri Lanka releases hazardous air pollutants, including particulate matter and persistent organic pollutants, contributing to local air pollution and associated health risks, particularly in peri-urban and low-income communities¹⁵.

Sri Lanka has regulations to control plastic use and manage the plastic waste¹⁶. The Polythene and Plastic Management Regulations (2017), prohibits the manufacture, sale or use of polythene products below 20 microns in thickness, polystyrene food containers and certain single use plastics (SUPs), but enforcement remains inconsistent¹⁷. Plastic Material Identification Standards (2021) mandates improved labelling to enhance consumer awareness about the recyclability and plastic content encouraging informed choices and responsible disposal¹⁸. The National Action Plan on Plastic Waste Management (2021-2030) provides a strategic framework to reduce plastic consumption, strengthen recycling systems, and achieve an 80% reduction in marine plastic pollution by 2030; this focuses on minimizing both macro and microplastics entering the ocean from land-based activities. The Central Environment Authority (CEA) is formulating Extended Producer Responsibility (EPR) laws. These regulations will set enterprises accountable for the collection and disposal of their plastic products.

¹⁰ Plastic policies in Sri Lanka, Country Profile, European Union SWITCH-Asia Programme, 2024, https://switch-asia.eu/site/assets/files/4232/plastic_policies_sri_lanka_2.pdf.

¹¹ Jayasinghe, R.R. 2023 (see footnote 6).

¹² Koongolla, J.B., Andrady, A.L., Kumara, P.T.P. and Gangabadge, C.S., 2018. Evidence of microplastics pollution in coastal beaches and waters in southern Sri Lanka. *Marine pollution bulletin*, 137, pp.277-284.

¹³ Partow, H., 2021. X-Press Pearl Maritime Disaster: Sri Lanka-Report of the UN Environmental Advisory Mission.

¹⁴ Kandeyaya, K.B.K.D.K., Ranatunga, S. and Ranatunga, R.R.M.K.P., 2023. Occurrence of microplastics in some commercially important seafood varieties from Negombo, Sri Lanka. *Regional Studies in Marine Science*, 62, p.102958.

¹⁵ Wiedinmyer, C., Yokelson, R.J. and Gullett, B.K., 2014. Global emissions of trace gases, particulate matter, and hazardous air pollutants from open burning of domestic waste. *Environmental science & technology*, 48(16), pp.9523-9530.

¹⁶ Plastic Waste Management Country Situation Report - Sri Lanka, Centre for Environmental Justice 2021, https://ipen.org/sites/default/files/documents/plastic_waste_management_in_sri_lanka.pdf.

¹⁷ Jayasinghe, R.R. 2023 (see footnote 6).

¹⁸ Central Environmental Authority. (2021). Plastic Material Identification Standards Regulations No. 01 of 2021. CEA.

Summary

- Sri Lanka generates approximately 249,000 tonnes of plastic waste annually and though 73% of the waste is collected due to leakages from the waste management system around 68% of plastic waste that is mismanaged.
- Informal waste pickers and recycling businesses play an important role but there are challenges of infrastructure, improper segregation and shortages of funding, equipment, and trained personnel.
- Contamination of beaches, lagoons, and nearshore waters with both macroplastics and microplastics has been reported.
- There are regulations such as Polythene and Plastic Management Regulations (2017), Plastic Material Identification Standards (2021), National Action Plan on Plastic Waste Management (2021-2030) and formulation of Extended Producer Responsibility (EPR) to manage plastic waste.

1.3 PLASTICS project and its findings

The project Promoting Long-term Approaches for a Sustainable, Transformative and Inclusive Circular Economy in Sri Lanka-PLASTICS has been working along the plastics value chain in Sri Lanka to promote innovative circular economy approaches among the MSMEs (Micro Small and Medium Enterprises). The project has also engaged with policy stakeholders and analysed the policy aspects. The findings of the project are summarized in this section.

1.3.1 Value chain status

As part of the PLASTICS project, a value chain mapping and analysis was carried out. This was done through literature review and through primary research surveys covering MSMEs, various governmental and private entities, restaurants, hotels, schools, and other stakeholders. The mapping was done across the following activities: plastic raw material production and trading; plastic product production and trading; plastic product use, plastic waste management and end of life. Plastic raw material in the primary forms and derivative intermediates are imported to Sri Lanka. Plastic products for water supply, telecommunications, construction, packaging, automotive, medical, and electronics/consumer durables are produced locally using methods such as pipe and profile extrusions, cast film extrusion, injection moulding, and EPS moulding. The manufactured products are used in domestic market; finished goods along with intermediate products are also exported. The amount of plastic raw material exported is over 2016-18 is an average of 280,000 tonnes annually¹⁹ and the plastic processing industry has a capacity of 140,000 tonnes per year²⁰.

The plastic waste generation comes from a variety of users including households, hotels, restaurants, businesses, and organizations. The collection is through small scale collectors as well as through large scale collectors and local authorities. Collecting companies also play a significant role in procuring cleaned and sorted plastics of required type. The recyclers make plastic pellets or products or both. The sources of plastic collected are shown in Figure 4 and Figure 5. There are also examples of use of non-recyclable plastic waste in road construction. AGC Innovate has pioneered its PMAC technology and in 2018, a 500-meter stretch of the Ratmalana–Borupana road was paved using PMAC, marking the first such

¹⁹ Ministry of Environment (2021). See footnote 7.

²⁰ <https://www.srilankabusiness.com/plastic/overview.html> (accessed 10 Apr 2025).

initiative in Sri Lanka²¹.

The main gaps identified are insufficient infrastructure related to collection, recycling and disposal as well as inadequate collection coverage; lack of awareness among general public regarding environmental impact of waste and importance of management; need for improvement in the role of informal sector and their operations; lack of incentives for proper disposal; inadequate monitoring and enforcement of waste management regulations; lack of specifications related to implementation mechanisms for many policies.

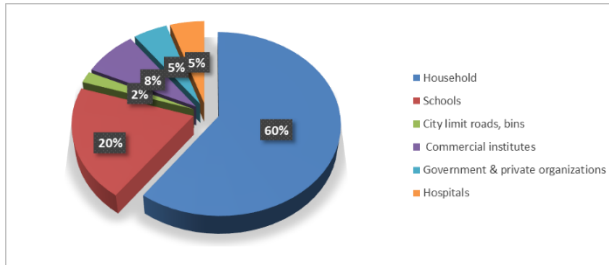


Figure 4. Sources of plastic waste collected by Municipal Council / Urban Council

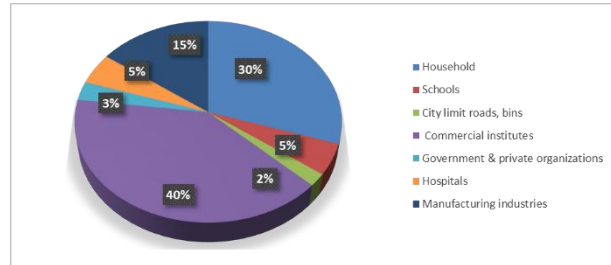


Figure 5. Sources of plastic waste collection by informal collectors in Western Province

1.3.2 Policy framework

International EPR frameworks were analyzed and some successful features were identified as clarity in the regulations with clear responsibilities of producers, consumers, and other stakeholders; collaboration among government, key stakeholders and the public; financial incentives and recognition for producers; consumer awareness; flexibility to adapt to changing markets and developments in product and recycling technologies

The challenges identified for Sri Lanka are non-segregation of waste; need for robust monitoring and evaluation; means for transparent reporting; unregistered plastic producers; limited private sector involvement; insufficient infrastructure and budget. These gaps need to be addressed in the EPR framework.

1.3.3 MSME engagement

The project engaged with MSMEs in the plastics value chain. It was observed that some large brands have initiated efforts towards alternate materials or improved recycling; some MSMEs are shifting to paper-based or bio-based alternatives for take-away packaging. In terms of availability for recycling, PET and HDPE collection is stable with active supply from informal collectors. Some industries are working on reverse logistics for EPR.

Several challenges were also observed. Recyclers face higher input of waste plastic than what they can process or sell leading to storage constraints. Contaminated feedstock for recycling reduces recyclability and quality and adds cost to processing. Systems are needed to support collection in rural areas and segregation at source. Financial and technical support is needed to handle low-value plastics. Alternatives are not economical, leading to continued reliance on low-cost multilayered sachets and bags. There is limited end-markets for the recycled plastics.

²¹ <https://www.lankabusinessnews.com/the-overseas-school-of-colombo-ties-up-with-agc-innovate-to-pave-sustainable-internal-school-driveway/> (accessed 10 Apr 2025).

Summary

- Value chain analysis showed the importance of small scale collectors, large scale collectors and local authorities for collecting plastic waste from sources such as households, hotels, restaurants, businesses, and organizations.
- The gaps are insufficient infrastructure related to collection, recycling and disposal as well as inadequate collection coverage; lack of awareness and need for improvement in the role of informal sector and their operations.
- For a successful EPR framework, proper segregation of waste, robust monitoring, sufficient infrastructure and budget are needed.
- For MSMEs plastics users, there is a need to shift towards to paper-based or bio-based alternatives. For MSME recyclers, challenges of contaminated feedstock and limited end-markets for the recycled plastics are present.

1.4 Role of Innovation and technology

Innovation and technology can play an important role in addressing the plastics problem. Actions can be taken for plastics use reduction, material substitution and innovations for End-of-Life management. However, there are challenges related to implementation of the solutions. These include availability of alternative materials; performance and cost; labelling; awareness of alternatives; responsible consumption and disposal; infrastructure for correct disposal or recycling and proper monitoring and enforcement.

This report considers the themes of innovations in plastics covering alternate materials, their advantages, commercial availability; innovations in end-of-life management and life cycle studies. For each theme, global and Sri Lankan developments, innovations, products and examples have been examined. The feasibility of implementing the solutions are considered. Finally the short term, medium term and long term suggestions for incorporating these innovation and technologies are provided. The link to the National Action Plan on Plastic Waste Management 2021-2030 is also presented²².

²² Ministry of Environment (2021). See footnote 7.

2. Innovations in plastics

With greater awareness of the plastic waste situation, there is increased demand for environment friendly plastics, especially in packaging. The solutions need to not only mitigate environmental impact but also offer functionality, durability and affordability for any given application. Several plastics options are emerging and are described below.

Bioplastics broadly refer to bio-based and / or biodegradable plastics. The different types within this are given below (Figure 6).

- **Biobased plastics:** these refer to plastics which are comprised entirely or partially of biological raw materials and not fossil raw materials. Not all biobased plastics are biodegradable.
- **Biodegradable plastics:** these are plastics that can be broken down by microorganisms in the environment in a reasonable timeframe, given specific conditions.
- **Compostable plastics:** they are a category within biodegradable plastics that undergo degradation by biological processes under industrial or home composting conditions to yield CO₂, water, and biomass at a rate consistent with other known compostable materials and leave no visible, distinguishable or toxic residue. Testing with standards such as ASTM D640023, ISO 1708824 and EN 1343225 need to be performed for labelling the products.

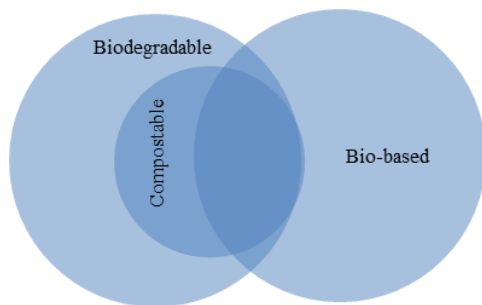


Figure 6. Classification of bioplastics and their interrelationships

2.1 Biodegradable plastics

2.1.1 Polylactic Acid (PLA)

Several plastics are now available that are biodegradable. Polylactic acid (PLA) is a thermoplastic aliphatic polyester derived from renewable resources like corn starch or sugarcane. It is commercially available at industry scale for food packaging, disposable tableware and medical applications. It is around three times more expensive than commercial plastics. Lower cost options that are blended with agricultural waste and natural fillers are also available. It does not degrade in nature but can be degraded in industrial composting since it needs temperatures above 60 °C to fully degrade. The commercially available PLA based products are summarized in Table 1.

²³ ASTM International. (2021). ASTM D6400-21: Standard specification for labeling of plastics designed to be aerobically composted. ASTM International.

²⁴ International Organization for Standardization. (2021). ISO 17088: Plastics—Organic recycling—Specifications for compostable plastics. ISO.

²⁵ British Standards Institution. (2000). BS EN 13432: Packaging—Requirements for packaging recoverable through composting and biodegradation. BSI.

Table 1. Commercially available PLA products

Company	Products and features
MATER-BI, Italy	<ul style="list-style-type: none"> • Bags, food packaging, cutlery, agriculture products such as mulching bag, twines. • Organic (PBAT, PBS) and inorganic fillers (Mg, Si, Ti-talc)²⁶
Nature Tec, USA	<ul style="list-style-type: none"> • Resins as well as finished products such as films, cutlery, straws
FUTERRO S.A, Belgium	<ul style="list-style-type: none"> • Food packaging, bags, films, bottles, engineering products • Developed LOOPLA chemical recycling for their products
Biotec Germany	<ul style="list-style-type: none"> • Bags, films, rigid products • (PLA) and potato starch²⁷ • Industrial or home composting
TotalEnergies Corbion, Netherlands	<ul style="list-style-type: none"> • Rigid and flexible packaging, cutlery, non wovens, durable goods • Recyclable (mechanical or chemical) • Anaerobic digestion or industrial composting
Novozymes A/S (Denmark) and Carbios, (France)	<ul style="list-style-type: none"> • Enzymes to embed in PLA for room temperature home composting
Nature Works LLC, USA	<ul style="list-style-type: none"> • Resins for different processing and applications • Industrial composting

Research studies are examining innovations to improve the mechanical, thermal and barrier properties of PLA. In the area of “active packaging”, where the packaging is not inert but provides protection against degradation and spoiling, modifications to PLA have been studied. This involves addition of other molecules, fillers and extracts as well as blending or layering with other biopolymers²⁸. To improve the blending of binary blends, addition of a third biopolymer to create ternary blends has been studied. However, the degradability of these blends need to be examined²⁹. The research to improve properties of PLA for applications such as 3D printing, biomedical applications and packaging has been reviewed. The developments include blending or incorporation of fillers, and improvements in production techniques. Areas such as improved moisture and thermal resistance and recyclability have been identified for future research³⁰.

In terms of PLA recycling, the use of a solvent free method to recycle PLA to polyurethane (PU) with enhanced properties has been examined. The PLA-PU could be recycled back to form PLA by depolymerization under vacuum³¹.

2.1.2 Polyhydroxyalkanoate (PHA)

Polyhydroxyalkanoate (PHA) is another biodegradable material produced by microbial fermentation of sugars or lipids which is compostable and can degrade in marine environments. Danimer Scientific is commercially manufacturing PHA under the brand Nodax™. It has applications for bags, linings, cutlery and is industrial and home compostable, water and marine biodegradable (ASTM D6400, ASTM D 6691,

²⁶ Bracciale, M.P., De Gioannis, G., Falzarano, M., Muntoni, A., Poletini, A., Pomi, R., Rossi, A., Sarasini, F., Tirillo, J. and Zonfa, T., 2024. Disposable Mater-Bi® bioplastic tableware: Characterization and assessment of anaerobic biodegradability. *Fuel*, 355, p.129361.

²⁷ Atli, A., Candelier, K. and Alteyrac, J., 2018. Mechanical, thermal and biodegradable properties of bioplast-spruce green wood polymer composites. *12*(5), p. 226.

²⁸ Akhrib, S., Djellali, S., Haddaoui, N., Karimian, D. and Carraro, M., 2025. Biocomposites and poly (lactic acid) in active packaging: a review of current research and future directions. *Polymers (Basel)* 17 (1): 1–27 [online].

²⁹ De Luca, S., Milanese, D., Gallichi-Nottiani, D., Cavazza, A. and Sciancalepore, C., 2023. Poly (lactic acid) and its blends for packaging application: a review. *Clean Technologies*, 5(4), pp.1304-1343.

³⁰ Kaptan, A. and Kartal, F., 2024. Advancements in polylactic acid research: From material properties to sustainable applications. *Eur. Mech. Sci*, 8, pp.104-114.

³¹ Luo, Z.X., Tian, G.Q., Chen, S.C., Wu, G. and Wang, Y.Z., 2024. Solvent-free one-pot recycling of polylactide to usable polymers and their closed-loop recyclability. *Macromolecules*, 57(14), pp.6828-6837.

ASTM D 5271, EN 13432). CJ Biomaterials manufactures the PHACT™ brand PHA using sugarcane or corn sugars for film and extrusion products, especially for packaging. They are TUV certified for home and industrial compostable as well as marine and soil biodegradable. Kaneka had the brand Green Planet™ for PHBH (Poly(3-hydroxybutyrate-co-3-hydroxyhexanoate)) for applications such as bags, cutlery and packaging. This material has OK Biodegradable Marine certification. Other manufacturers include Bluepha, Tianan Biologic, PhaBuilder, Shellworks.

2.1.3 Thermoplastic starch

Plastics made using starch from sources such as potato, tapioca, corn etc. are being developed for various applications. Starch is comprised of polysaccharides, and the exact composition of starch depends on the plant source it is derived from. Starch is converted to thermoplastic starch using a plasticizer and often blended with other plastics to incorporate the required properties. The commercially available brands are summarized in Table 2 below.

Table 2. Commercially available starch based plastic products

Company	Products and features
NuPlastiQ®, USA	<ul style="list-style-type: none"> • Thermoplastic starch blended with conventional and biodegradable plastics for different properties and applications • Biocompostable material blended with PLA or PBAT for packaging and film applications
Plantic Technologies Limited, Australia	<ul style="list-style-type: none"> • Amylose starch from corn and is compostable • When used with conventional plastics in multi-layer format, can be recycled since Plantic material dissolved in the process
Biome Bioplastics, UK	<ul style="list-style-type: none"> • Potato starch, corn starch and cellulose • Films and extruded products

Many studies have examined methods to make the starch based plastic products match the properties of conventional plastics. This includes blending with other bioplastics or adding natural materials as fillers. Use of multiple plasticizers, addition of functional agents (for example use of essential oils for antimicrobial properties) and multi layered design have also been examined³².

2.1.4 Other bioplastics

There are also options from biological sources such as **cellulose acetate** from wood pulp. Clarifoil is a commercially available film for packaging made with cellulose acetate. It has been certified bio based (USDA and DIN-Geprüft), water biodegradable, home and industry compostable for up to certain thicknesses (ASTM D 6400 EN13432). Recent studies have looked at improving performance with incorporation of additives^{33,34}; improved recycling of cellulose acetate using dissolution, phase separation and controlled evaporation³⁵; alternate raw materials other than wood pulp³⁶.

Poly(butylene succinate) (PBS) is a heat-resistant, compostable plastic with applications in food

³² Surendren, A., Mohanty, A.K., Liu, Q. and Misra, M., 2022. A review of biodegradable thermoplastic starches, their blends and composites: recent developments and opportunities for single-use plastic packaging alternatives. *Green Chemistry*, 24(22), pp.8606-8636.

³³ Bouftou, A., Aghmih, K., Lakhdar, F., Abidi, N., Gmouh, S. and Majid, S., 2024. Enhancing cellulose acetate film with green plasticizers for improved performance, biodegradability, and migration study into a food simulant. *Measurement: Food*, 15, p.100180.

³⁴ Siew, Z.Z., Chan, E.W.C. and Wong, C.W., 2024. Enhancing the tearability and barrier properties of cellulose acetate bioplastic film with polyethylene glycol 1450 as an LDPE replacement for food packaging. *Food and Bioprocess Technology*, 17(8), pp.2265-2276.

³⁵ Slejko, E.A., Tuan, A. and Scuur, N., 2024. From waste to value: Characterization of recycled cellulose acetate for sustainable waste management. *Waste Management Bulletin*, 1(4), pp.67-73.

³⁶ Jayakrishnan, A., Shahana, S. and Ayswaria, R., 2024. Preparation and evaluation of bioactive cellulose acetate films from *Musa acuminata*. *RSC Sustainability*, 2(8), pp.2335-2347.

packaging, disposable tableware and agricultural films. PBS that is partially biobased using plant based polybutylene succinate is commercially available under the brand name BioPBS (PTT MCC Biochem). The product is available for film and extrusion products and is certified for industrial and home composting. PBS lined boxes for food is being manufactured by Detpak in combination of paper board and/or PLA.

Polybutylene Adipate Terephthalate (PBAT) is a flexible and biodegradable polyester used in biodegradable shopping bags, mulch films and flexible packaging. BASF's ecoflex® has been available since 1998 and currently bio based feedstock are also being included in the raw material and attributed through biomass balance. LG Chem's COMPOSTFUL™ uses PBAT along with PBS and PLA to make compostable (TUV OK Compost for industrial composting) for different applications (carry bags, mulch films, coffee, capsules and paper coatings).

Seaweed derived materials are available in various forms. Seaweed has polysaccharides (alginate, agar, and carrageenan) and fibres that can be used along with other additives. There are many companies with market ready products and those under development. These are summarized in Table 3 below.

Table 3. Overview of seaweed-based products and development status

Company	Products and features
Sway Seaweed Packaging, USA	<ul style="list-style-type: none"> Resins and films with majority seaweed components are available Windows and bags available for purchase; pellets and films are available for pilot TUV home and industrial composting certification under processing
Notpla, UK	<ul style="list-style-type: none"> Food containers, cutlery, and paper are available through outlets Other products are under development When used as lining on paper, it can still be recycled Home compostable
Loliware, USA	<ul style="list-style-type: none"> Resins, straws, utensils being developed Straws available to consumers for purchase Resins being distributed through Entec, a plastic resin distributor Compostable
Plantsea, UK	<ul style="list-style-type: none"> Paper and film Paper available to shop on website Compostable
Bzeos Green Tech, Norway	<ul style="list-style-type: none"> Different types of resin pellets are being developed for applications such as films, thermoformed cutlery and rigid materials; TRL 7 was reached in 2024 Home compostable
FlexSea, UK	<ul style="list-style-type: none"> Pellets available for injection moulding and 3D printing Home compostable
Evoware, Indonesia	<ul style="list-style-type: none"> Seaweed films available to purchase and can be used for sachets, wrapping; not recommended for liquids
Zerocircle, India	<ul style="list-style-type: none"> Coatings for paper and pellets for films; collaboration with brands for product development Home compostable
ULUU, Australia	<ul style="list-style-type: none"> Pellets for rigid products available for customer trials; pellets for fabrics under development
Biopac, Indonesia	<ul style="list-style-type: none"> Many products are available for purchase (sachet, sheet, pouch, bag)

Composites of **mushroom mycelium** with other agro residues have been developed for protective packaging that can substitute polystyrene. It is growing in popularity due to natural composition and

capability to be grown into specific shapes for packaging purposes³⁷. These products are typically home compostable, marine and soil biodegradable. There are a few commercial companies and products available. Mushroom® Packaging (USA) is a division of Ecovative, producing custom-moulded protective packaging parts for a variety of applications made of mycelium and hemp hurd. They are providing packaging to several companies including IKEA. Mushroom Material (New Zealand) uses mushroom mycelium and agricultural waste for polystyrene (Styrofoam) alternative. They offer pellets and custom packaging for clients. Magical Mushroom (UK) has also developed packaging material using mycelium and agricultural waste as a substitute for polystyrene and polymer foam. They have tied up with several companies and are providing packaging. Grown Bio (Germany) also uses mycelium and local agricultural waste for their products. They have developed custom packaging for some companies and also have some standard products (bottle pack, cooler) for purchase.

Cellulose based materials also offer renewably sourced compostable alternatives. NatureFlex™ by Futamura offers cellulose based flexible packaging such as films / bags for tea/coffee, snacks, bread etc. The cellulose is made from wood pulp and has good oxygen and aroma barrier. Celanese Corporation's Clarifoil® film is home compostable, water biodegradable and available for various packaging applications. **Chitin** based biopolymers are also being developed such as Cruz Foam, a substitute for polystyrene which is home compostable.

A type of biodegradable polyester, **Polycaprolactone** (PCL), has seen an increase in demand in various industries due to its exceptional characteristics. Vizag Chemicals has a presence in the manufacturing and supply of this semi-crystalline, biodegradable polyester with a low melting point of 59-63°C³⁸. It is a biocompatible and versatile thermoplastic polymer with applications ranging widely from packaging, 3D-printing, healthcare, textile to electronics. PCL can be blended with other biodegradable polymers to achieve specific functional properties such as improved mechanical strength or physical characteristics³⁹.

2.1.5 Biobased conventional plastics

Conventional plastics typically prepared from fossil fuel have been prepared from bio based sources. The commercial products include Braskem's I'm green™ PET from sugarcane, Avantium's plant based Releaf® PEF (polyethylene furanoate), FKUR's Terralene® bio PET and bio PP.

Additives for making conventional plastics biodegradable are also available. BioSphere has additives in different forms that can be added to conventional plastics to make them biodegradable. The additive can also work in landfills to degrade the plastics and generate gas which can be used as a fuel. Polymateria has developed additives that can make conventional plastics biotransform and biodegrade. The product is mainly targeted at fugitive plastics that have escaped the waste management stream.

2.1.6 Standards for degradability of bioplastics

There are many standards that specify the testing for biodegradability of compostable bioplastics and these are used by various agencies for testing and certification. With new materials under development and entering the market, these certifications can guide the waste management guidelines and build customer confidence. The available global and local standards are summarized in Table 7Table 4.

³⁷ Pohan, J.N., Kusumawati, Y.A. and Radhitanti, A., 2023. Mushroom mycelium-based biodegradable packaging material: a promising sustainable solution for food industry. In E3S web of conferences (Vol. 426, p. 02128). EDP Sciences.

³⁸ Mohamed, R.M. and Yusoh, K., 2016. A review on the recent research of polycaprolactone (PCL). Advanced materials research, 1134, pp.249-255.

³⁹ Vizag Chemical. (n.d.). Vizag Chemical – Polycaprolactone (PCL) supplier, manufacturer and distributor in India. Retrieved January 9, 2026, from <https://vizagchemical.com/blog/vizag-chemical-polycaprolactone-supplier-manufacturer-and-distributor-india>

Table 4. Certification schemes for biodegradable / compostable plastics

Certification / Standard	Scope	Acceptance
EN 13432 (EU Standard)	Requirements for packaging recoverable through composting and biodegradation. It includes disintegration, biodegradability, heavy metal content, and ecotoxicity.	Widely accepted across the European Union and internationally for compostable packaging.
ASTM D6400 (USA)	Specification for compostable plastics intended for aerobic composting in municipal or industrial facilities and it covers time-bound disintegration and biodegradation benchmarks.	Accepted internationally. Required for BPI Certification.
ASTM D6868	It is used for items where a compostable film (e.g., PLA) is attached to non-compostable materials like paper or board.	Mainly used in the USA, relevant for multi-material products
DIN CERTCO Compostable	German certification body based on EN 13432 and ISO standards to certify industrial and home compostable plastics.	Accepted in Germany, Europe, South Korea, and parts of the Middle East.
TÜV Austria OK Compost – INDUSTRIAL	Certifies products that are compostable in industrial facilities. Based on EN 13432 or ISO 17088.	Accepted in EU, Asia (including Japan, Korea), and globally
TÜV Austria OK Compost – HOME	Stricter standard than industrial; ensures compostability at lower temperatures found in home composting.	Accepted in EU, Asia (including Japan, Korea), and globally
TÜV Austria OK BIOBASED	Measures bio-based content based on renewable input in the product.	Used globally to verify claims of renewable material content
Australia AS 4736 / AS 5810	Equivalent to EN 13432 with extra ecotoxicity tests. AS 4736 is for commercial composting and AS 5810 is for home composting.	Australia, New Zealand, and export markets requiring home compostability.
Korean Eco-Label Certification	Covers biodegradable plastics and bio-based packaging verified by Korea Environmental Industry & Technology Institute (KEITI)	Accepted in South Korea domestic market; used in government procurement.
SLS 1718:2021	This National standard for the safety, purity and performance criteria of compostable plastic sheets used in food wrapping which is mandated for local manufacturers of lunch sheets.	Accepted only in Sri Lanka
SLS ISO 22403:2020 ⁴⁰ (Sri Lanka / ISO equivalent)	For the biodegradability of plastics in marine environments, National adoption of ISO 22403	Accepted only in Sri Lanka

⁴⁰ https://slsi.lk/web/new_releases/sls-iso-22403/ (accessed 21 November 2025)

Summary

- Polylactic acid (PLA) derived from renewable resources like corn starch or sugarcane is commercially available; however, it needs industrial composting and is more expensive than conventional plastics.
- Seaweed based natural polymer materials are in different stages of development; these are compostable without leaving any residue.
- For protective packaging, composites of mushroom mycelium with other agro residues are available as replacement for polystyrene.
- Other materials include starch based plastics, cellulose acetate, Poly(butylene succinate) (PBS), Polybutylene Adipate Terephthalate (PBAT), Polyhydroxyalkanoates (PHA), cellulose and Polycaprolactone (PCL).
- Conventional plastics have been made with biobased sources.

2.2 Innovations in Sri Lanka

There are several innovations related to plastics and alternatives that are in different stages of development. Sri Lanka Institute of Nanotechnology SLINTEC has developed a compostable packaging material sourced from corn husk and paddy waste. This technology earned the gold award at Lanka Star 2024 Packaging Awards and the technology has been transferred to Modern Pack Pvt. Ltd. for large scale production aiming to provide sustainable alternatives to packaging materials⁴¹. However, more details about the compostability, certification and disposal routes are not available.

There are many products based on natural materials. Kudil Products manufactures plates and cutlery using banana fibre leaves, and areca leaves. The company was motivated to start this enterprise since it offered an eco-friendly solution, converted waste to wealth and contributed to women empowerment. The challenges are the transportation cost and a return on investment of 4 to 5 years which makes scale up difficult. This can be replicated as cottage industry with semi-automatic machines which women can be trained to use⁴².

Other available products include the following:

- Cally Reusable Bags: bags made from lightweight, washable, reusable cotton fabric.
- Bio Pack & Technology (Pvt) Ltd: Kraft paper lunch boxes and trays, Some are coated with PLA or PE so disposal needs to be managed appropriately.
- Eco Lanka Food Packaging: biodegradable lunch box from plant-based materials (compostable).
- Critco: compostable bagasse plates and trays; compostable paper plates, cups; wooden cutlery; bagasse and cardboard boxes; some items such as cups come with PE coating or lids where disposal needs to be managed appropriately.
- Wasthra Ceylon, Eco Pack: plates, boxes, cutlery from banana fibers, it is claimed that the products undergo "Fast Biodegradation" breaking down naturally within 8-10 weeks.
- Plastic Packaging Pte Ltd: Naturplus range bags for various applications; home composting with TuV OK certificate.

⁴¹SLINTEC. (2024, January 10). SLINTEC won big at Lanka Star 2024 Packaging Awards. Sri Lanka Institute of Nanotechnology. Retrieved from <https://www.slintec.lk/slntec-won-big-at-lanka-star-2024-packaging-awards/> (accessed 10 Apr 2025)

⁴² Personal communications, 20 Nov 2025

- Dilmah: The company uses paper / cardboard boxes for packaging, PLA is being used for the filter in tea bags.
- Bio Plastic (Pvt) Ltd.: bags; compostable cutlery; recyclable containers; edible cutlery and containers made with rice flour, cassava starch and corn starch
- Polydime BioComp: lunch sheet using starch based material BioComp® from Italian brand Sirimax with EN13432 certification
- Clean Poly Packaging: lunch sheets and shopping bags that are biodegradable and made from corn starch. It is mentioned that the product completely decomposes in soil however there is no mention of certificates.
- Dharshana Bio Packaging Pvt Ltd: Bag, film, food packaging with PLA, PBAT and corn starch; TUV and National home and industrial composting certificates

In addition to products available in the market, there are also start ups exploring alternative products. This includes seaweed and mushroom based plastics. Teshvo Biotech is involved in seaweed plastics. The product is home compostable, food grade and similar to plastic thin film. It is currently at laboratory scale. One of the factors in using seaweed is that its quality seaweed must be taken into consideration. For scale up, partnership with other manufacturers is needed as well as reliable supply chain and customers⁴³. The support identified for startups is summarized in Table 5.

Table 5. Support needed for startups working in the area of plastics and alternatives

Support required for startups
<ul style="list-style-type: none"> • Laboratories with testing facilities can be very expensive. A shared system with affordable pricing would be beneficial • Access to mentors with specific technical knowledge • Guidance on regulatory standards, certification before going to market • Facilitation for getting investors to scale up • Access to funding, exposure through conferences, visits

Though these alternatives are available in Sri Lanka, many consumers are still heavily reliant on conventional plastic due to cost and convenience, which poses a barrier to the adoption of more sustainable packaging solutions⁴⁴.

Summary
<ul style="list-style-type: none"> • There are many products from nature based materials • Some have compostability certificates while in others it is not clear • There are start ups working on innovations who need support for scale up and commercialization

⁴³ Personal communication, 21 November 2025

⁴⁴ Ilangasekara, A.S.P. and Siriwardana, M.L.D.A., 2022. Consumer Buying Behaviour towards Sustainable Packaging in FMCG Market: A Study among High Income Earners in Colombo. International Journal of Research and Innovation in Social Science, 6(12), pp.835-840.

3. Innovations in end-of-life management

3.1 Technological innovations

3.1.1 Biodegradation and composting technologies

Biodegradable plastics are designed to degrade through microbial activity into natural substances like water and carbon dioxide under specific conditions. One of the most widely used method is to add natural polymers to enhance the biodegradability of the plastic by providing a carbohydrate source that microorganisms can utilize. For example, starch-based plastics such as thermoplastic starch (TPS) blended with other polymers like polyvinyl alcohol (PVA) or polyethylene (PE) resulted in improved degradation under various conditions⁴⁵. The degradation rate depends on factors such as polymer type, starch content and composting environmental conditions. Pro-oxidant additives like metal salts (e.g., iron and cobalt) also help in making the degradation easier by promotion of the formation of free radicals that break down the plastic structure. These additives when incorporated into PE and PP enhance the plastics' susceptibility to microbial attack. Research on the effectiveness of these additives has shown promising results, though further studies are required to ensure complete biodegradation of fragments without the formation of microplastics⁴⁶.

Composting technologies are critical for managing plastic waste. Industrial composting facilities that offer controlled temperature, moisture and oxygen facilitate rapid degradation of the plastic waste. PLA requires industrial conditions to decompose effectively. Many studies have investigated the decomposition of PLA-starch blends and have observed that the addition of starch improves the degradation even under home composting conditions⁴⁷.

3.1.2 Chemical technologies

Chemical recycling is an advanced method for breaking down plastics into their original monomers or other valuable byproducts. This method turns out to be especially useful for bioplastics like PLA, which can be hard to recycle using traditional mechanical processes. By utilizing heat or catalysts, bioplastics are broken down into their monomers, which can then be reused to create new plastic products⁴⁸.

Hydrolysis uses water and chemicals to separate the plastic into smaller molecules. For PLA, an acidic catalyst like sulfuric acid can be used for acidic hydrolysis in the presence of water. Research has been conducted on using milder acids or enzymatic hydrolysis to reduce the environmental effect and cost associated with conventional acidic hydrolysis⁴⁹. For PHA, recycling is challenging as it is not usually collected separately from other waste plastics. The polymer bonds for PHA can be broken and depolymerized into its monomeric units by exposing it to a basic solution, often containing sodium hydroxide. Researchers are exploring the possible use of catalysts and optimized reaction conditions to

⁴⁵ Kyrikou, I. and Briassoulis, D., 2007. Biodegradation of agricultural plastic films: a critical review. *Journal of Polymers and the Environment*, 15(2), pp.125-150.

⁴⁶ Sciscione, F., Hailles, H.C. and Miodownik, M., 2023. The performance and environmental impact of pro-oxidant additive containing plastics in the open unmanaged environment—a review of the evidence. *Royal Society Open Science*, 10(5).

⁴⁷ Mayekar, P.C., Limsukon, W., Bher, A. and Auras, R., 2023. Breaking it down: How thermoplastic starch enhances poly (lactic acid) biodegradation in compost—A comparative analysis of reactive blends. *ACS Sustainable Chemistry & Engineering*, 11(26), pp.9729-9737.

⁴⁸ Alaghemandi, M., 2024. Sustainable solutions through innovative plastic waste recycling technologies. *Sustainability*, 16(23), p.10401.

⁴⁹ McKeown, P. and Jones, M.D., 2020. The chemical recycling of PLA: A review. *Sustainable Chemistry*, 1(1), pp.1-22.

improve the rate and efficiency of PHA hydrolysis to make it more viable for large-scale applications⁵⁰. PBAT typically involves acidic hydrolysis where the polymer is treated with an acid and water to break the polymer chains to yield the monomers terephthalic acid and adipic acid which can be reused to produce new PBAT. Recent studies are focused on optimizing the hydrolysis conditions to achieve selective depolymerization to minimize side reactions and enhance the recovery of high-quality polymers⁵¹.

The efficiency of hydrolysis depends on the polymer's structure, with more crystalline plastics like PLA being harder to break down compared to more amorphous plastics like PBS. Moreover, bioplastics are often mixed with conventional plastics or additives which complicate recycling through chemical methods. Thus, advances in separation techniques are necessary to enhance the quality of recovered monomers.

Polyethylene terephthalate (PET) is one of the most widely used plastics found in everyday products such as polyester fibers, food packaging, plastic films, and electronic devices. Traditional recycling methods, such as mechanical recycling face limitations due to the degradation of plastic quality during the process. One of the most promising chemical recycling methods is hydrolysis which consists of depolymerizing PET into its basic building blocks—terephthalic acid (TPA) and ethylene glycol (EG). These monomers can be used to repolymerize PET or even for the synthesis of biodegradable plastics and metal-organic frameworks. However, conventional hydrolysis methods often rely on strong acid or base catalysts that are not easily recoverable, which increases the cost of production and creates environmental hazards in the form of acidic or alkaline wastewater. A recent innovative approach proposes the use of TPA itself as a catalyst to promote the hydrolysis of PET which offers simple recovery and reuse of the catalyst which helps in reducing the environmental impact associated with the separation and disposal of traditional acid or base catalysts. The study reports that under optimized conditions (using 2.5 g of PET, a TPA concentration of 0.1 g/mL, a PET: H₂O mass ratio of 1:8, 220°C temperature, and 180 minutes of reaction time), up to 100% PET conversion and 95.5% TPA yield were achieved. The produced TPA exhibited a high purity of 99% like fresh TPA and could be easily recovered for reuse in subsequent hydrolysis cycles. This method demonstrated impressive efficiency, maintaining a high level of hydrolysis performance even after eight consecutive reaction cycles. The findings suggest that this innovative approach to PET hydrolysis has the potential to significantly improve the chemical recycling process, offering a greener and more efficient pathway to recycling PET plastics on an industrial scale.⁵²

3.1.3 Enzymatic recycling

Enzymatic recycling is an innovative process that utilizes specific enzymes to depolymerize synthetic polymers into their monomeric constituents to facilitate the production of new, high-quality polymers. For bioplastics, enzymes have been developed that can break it down into lactic acid, which can then be used to create new plastic products. Researchers have engineered depolymerizing enzymes capable of breaking down PET and textiles efficiently. Carbios has developed an industrial application of enzymes that render plastic waste compostable⁵³. Their new hydrolase enzyme was able to recycle 90% of PET plastic within 10 hours. This process is a cleaner option as it uses less energy and does not require harmful chemicals. However, there are still challenges such as making the process scalable and affordable.

⁵⁰ Ariffin, H., Nishida, H., Hassan, M.A. and Shirai, Y., 2010. Chemical recycling of polyhydroxyalkanoates as a method towards sustainable development. *Biotechnology Journal*, 5(5), pp.484-492.

⁵¹ Parodi, A., Arpaia, V., Samori, C., Mazzocchetti, L. and Galletti, P., 2023. Novel strategies for recycling poly (butylene adipate-co-terephthalate)-starch-based plastics: Selective solubilization and depolymerization–repolymerization processes. *ACS Sustainable Chemistry & Engineering*, 11(39), pp.14518-14527.

⁵² Yang, W., Liu, R., Li, C., Song, Y. and Hu, C., 2021. Hydrolysis of waste polyethylene terephthalate catalyzed by easily recyclable terephthalic acid. *Waste Management*, 135, pp.267-274.

⁵³ Carbios. (n.d.). Enzymatic recycling. Retrieved from <https://www.carbios.com/en/enzymatic-recycling/> (accessed 10 Apr 2025).

Another promising development in enzymatic recycling is the use of PETase which is an enzyme originally discovered and engineered in bacteria to break down PLA into its constituent monomers (lactic acid) to make the reaction products available for the synthesis of new plastic material. In recent years, enzymatic degradation of PET by *Ideonella sakaiensis* PETase (IsPETase), a cutinase-like enzyme, has also emerged as a promising strategy to completely depolymerize this polymer into its building blocks. This represents important progress in the accomplishment of a sustainable and complete degradation of PET waste to be recycled and turned into new valuable products⁵⁴.

The commercialization of enzymatic recycling technologies has gained momentum with the involvement of various companies. For instance, Samsara Eco, an Australian climate technology start-up, has developed a new enzyme capable of breaking down nylon 6, enabling indefinite recycling. Partnering with brands like Lululemon, Samsara aims to reduce waste in the fashion industry by returning plastics to their original molecules for repeated recycling⁵⁵.

Recent research and reviews have examined the of enzymes such as cutinases, lipases and esterases for degradation of PLA^{56,57,58}. The formation of lactic acid monomers in this process can enable the recycling of PLA. It has been found that cutinase enzymes can degrade PLA into lactic acid and could effectively break the ester bonds in PLA. Studies have also examined use of cutinases from various fungal species particularly *Fusarium solani* and *Thermobifida fusca* for the enzymatic depolymerization of PLA.

3.1.4 AI-powered and robotic sorting

The integration of Artificial Intelligence and robotics into waste-sorting processes has emerged as a transformative approach in the end-of-life management of sustainable packaging alternatives to enhance the efficiency and accuracy of sorting recyclable materials.

The RECLAIM project, funded by EU, has introduced a portable, AI-powered robotic material recovery plant designed for remote areas or regions with fluctuations in waste generation. This low-cost solution employs multiple robots equipped with various types of actuator pickers to efficiently collect and handle different waste materials based on their composition⁵⁹.

Companies like AMP Robotics have developed AI-driven robots capable of sorting recycling materials faster and more accurately than human workers. These robots utilize advanced vision systems to identify and categorize waste, significantly improving the efficiency of recycling facilities. AMP Robotics recently secured \$91 million in funding to expand its AI-powered recycling operations which show the growing investment in this technology.

AI-informed robots can analyse material characteristics such as colour and composition through

⁵⁴ Sevilla, M.E., Garcia, M.D., Perez-Castillo, Y., Armijos-Jaramillo, V., Casado, S., Vizuete, K., Debut, A. and Cerda-Mejia, L., 2023. Degradation of PET bottles by an engineered *Ideonella sakaiensis* PETase. *Polymers*, 15(7), p.1779.

⁵⁵ Samsara Eco. (n.d.). Samsara Eco and Lululemon unveil world's first enzymatically recycled nylon-66 product. Retrieved from <https://www.samsaraeco.com/news/samsara-eco-and-lululemon-unveil-worlds-first-enzymatically-recycled-nylon-66-product> (accessed 10 Apr 2025)

⁵⁶ Shalem, A., Yehezkeli, O. and Fishman, A., 2024. Enzymatic degradation of polylactic acid (PLA). *Applied Microbiology and Biotechnology*, 108(1), p.413.

⁵⁷ Alvarado, E., Castro, R., Castro-Rodríguez, J.A., Navarro, A. and Farrés, A., 2024. Poly (lactic acid) Degradation by Recombinant Cutinases from *Aspergillus nidulans*. *Polymers*, 16(14), p.1994.

⁵⁸ Murguiondo, C., Barriuso, J. and Prieto, A., 2025. Optimized enzymatic PLA hydrolysis by a recombinant fungal cutinase: A step towards a closed PLA cycle. *International Journal of Biological Macromolecules*, 301, p.140482.

⁵⁹ Fang, B., Yu, J., Chen, Z., Osman, A.I., Farghali, M., Ihara, I., Hamza, E.H., Rooney, D.W. and Yap, P.S., 2023. Artificial intelligence for waste management in smart cities: a review. *Environmental Chemistry Letters*, 21(4), pp.1959-1989.

integrated cameras and sensors, enabling precise segregation of plastic waste. The integration of cyber-physical systems, blockchain technology, machine learning, and the Internet of Things (IoT) further enhances the efficiency of identifying and sorting for recycling purposes.

Companies like Recycle Track Systems (RTS) utilize AI-powered waste sensor technology, such as Pello, to monitor fill levels in real-time, enabling dynamic scheduling of collections and reducing unnecessary pickups. This approach not only cuts operational costs but also minimizes environmental impact by lowering fuel consumption and emissions. In the realm of smart bin technology, Ecube Labs has developed smart, solar-powered waste compacting bins equipped with AI-driven sensors that can monitor fill levels and automatically compact waste, increasing capacity by up to 700%. The integration of AI allows for real-time data transmission to waste management platforms, facilitating efficient route planning and timely collections⁶⁰.

3.1.5 Vitrimerization of thermoset plastic waste

Thermoset plastics pose a significant challenge for Circular Economy pathways due to their permanently cross-linked molecular structure, which prevents melting, reshaping, or conventional mechanical recycling. Once cured, thermosets such as epoxy resins, polyurethanes, and phenolic resins are typically landfilled or incinerated at end of life. Vitrimerization has emerged as a promising approach to address this limitation by enabling the conversion of thermoset plastic waste into recyclable materials known as vitrimers.

Vitrimerization involves the incorporation or activation of dynamic covalent bonds within an otherwise permanently cross-linked polymer network⁶¹. These bonds enable bond exchange reactions to take place under external conditions, most often heat, while maintaining crosslink density. Consequently, the substance maintains the mechanical durability and chemical resistance of thermosets while gaining the reprocessability and reparability usually linked to thermoplastics. Vitrimerization allows thermoset waste to be converted into vitrimers that can be reshaped, welded, repaired, and recycled repeatedly, providing a practical method for closing material cycles⁶².

The primary mechanism facilitating vitrimer behaviour is dynamic covalent chemistry (DCC), in which covalent bonds participate in reversible exchange reactions while preserving the integrity of the network. Typical dynamic chemistries employed in vitrimer systems encompass transesterification, disulfide exchange, imine exchange, and imide bond rearrangement⁶³. Among these, transesterification has been extensively researched, especially for epoxy-based thermosets, because of their compatibility with current resin systems. Upon heating beyond a specific topology-freezing temperature, the polymer network experiences bond restructuring, permitting viscous flow without depolymerization⁶⁴.

From a waste management perspective, vitrimerization offers a potential pathway to address thermoset plastic waste streams that are otherwise non-recyclable, particularly epoxy- and polyurethane-based

⁶⁰ Ma, W.S., Yuen, S.H., Keung, C.N., Qureshi, M.F., Qureshi, U.M. and Umair, Z., 2024, February. Investigating object sorting problem for smart garbage application. In 2024 5th International Conference on Advancements in Computational Sciences (ICACS) (pp. 1-7). IEEE.

⁶¹ Gerdroodbar, A.E., Karimkhani, V., Dashtimoghadam, E. and Salami-Kalajahi, M., 2024. Vitrimerization as a bridge of chemical and mechanical recycling. *Journal of Environmental Chemical Engineering*, 12(3), p.112897.

⁶² Denissen, W., Winne, J.M. and Du Prez, F.E., 2016. Vitrimers: permanent organic networks with glass-like fluidity. *Chemical science*, 7(1), pp.30-38.

⁶³ García, F. and Smulders, M.M., 2016. Dynamic covalent polymers. *Journal of Polymer Science Part A: Polymer Chemistry*, 54(22), pp.3551-3577.

⁶⁴ Memon, H., Wei, Y. and Zhu, C., 2022. Recyclable and reformable epoxy resins based on dynamic covalent bonds—Present, past, and future. *Polymer Testing*, 105, p.107420.

materials⁶⁵. Research and pilot-scale studies have demonstrated vitrimer chemistry for cured epoxy thermoset waste, including resin-rich scrap, rejected moulded components, and manufacturing offcuts, where dynamic covalent networks enable mechanical size reduction followed by reprocessing through hot pressing or remoulding with limited loss of performance.

Similar approaches have been demonstrated for epoxy-based glass-fibre reinforced plastic (GFRP) composite waste, such as composite panels and production offcuts, enabling reshaping, repair, or re-consolidation of end-of-life components. Emerging studies have also explored vitrimer-like behaviour in crosslinked polyurethane foams, for example flexible foams used in automotive seating, and in vitrimer-based printed circuit board (PCB) substrates, which allow improved material recovery and reuse in electronic waste streams^{66,67}. However, vitrimerization of post-use thermoset waste remains largely at the research to pilot scale, with limited commercial deployment to date. Although there are benefits, challenges persist in expanding vitrimerization for broad waste management uses. These encompass enhancing thermal stability, aligning mechanical properties with reprocessability, minimizing reliance on catalysts, and attaining cost-effectiveness at an industrial scale⁶⁸.

3.2 Product design for improved end of life management

There are several initiatives towards product design to improve the end of life management, especially recycling. One of them is the use of **mono-materials**. Traditional packaging often consists of multiple layers of different materials making it hard to recycle. Companies like Nestlé and Unilever have introduced recyclable mono-PP flexible packaging for snack and personal care products. Amcor and Mondi have launched high-barrier PE pouches⁶⁹.

Another development is the move towards **clear plastics**. In the case of PET bottles, removing the colour makes it easier to be recycled back to food grade bottles due to higher quality. In Asia, clear bottles have a higher value than coloured bottles for recycling. An example of this change is the use of clear bottles for Sprite which was sold in green bottles for around 60 years⁷⁰. A similar examples is the case of HDPE milk caps which if coloured are difficult to recycle into food grade plastic. Waitrose has moved from coloured lids in milk bottles which indicated different grades to clear lid⁷¹. Plastic caps from bottles tend to end in litter though they are made from recyclable HDPE⁷². To prevent this, as per the EU directive⁷³, single use plastic beverage bottles up to 3 L now have **tethered caps** in Europe. Many brands are also moving

⁶⁵ Yue, L., Amirhosravi, M., Gong, X., Gray, T.G. and Manas-Zloczower, I., 2020. Recycling epoxy by vitrimerization: influence of an initial thermoset chemical structure. *ACS Sustainable Chemistry & Engineering*, 8(33), pp.12706-12712.

⁶⁶ Zhang, Z., Biswal, A.K., Nandi, A., Frost, K., Smith, J.A., Nguyen, B.H., Patel, S., Vashisth, A. and Iyer, V., 2024. Recyclable vitrimer-based printed circuit boards for sustainable electronics. *Nature Sustainability*, 7(5), pp.616-627.

⁶⁷ Liu, W., Zhang, Y., Chen, P., Shao, L., Cao, Y., Zhao, B., Lee, E.C., Wang, X. and Zhang, J., 2025. Scalable manufacturing and reprocessing of vitrimerized flexible polyurethane foam (PUF) based on commercial soy polyols. *Industrial Chemistry & Materials*, 3(2), pp.231-245.

⁶⁸ Röttger, M., Domenech, T., van Der Weegen, R., Breuillac, A., Nicolaÿ, R. and Leibler, L., 2017. High-performance vitrimers from commodity thermoplastics through dioxaborolane metathesis. *Science*, 356(6333), pp.62-65.

⁶⁹ <https://www.prescouter.com/2024/10/what-are-mono-materials-and-their-role-in-packaging/> (accessed 25 Nov 2025).

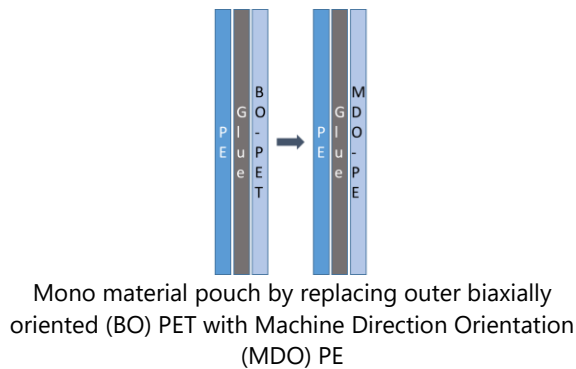
⁷⁰ <https://packagingeurope.com/news/coca-cola-to-transition-green-plastic-portfolio-to-clear-pet-bottles-in-north-america/8525.article> (accessed on 21 Nov 2025).

⁷¹ <https://packagingeurope.com/news/waitrose-permanently-scrap-coloured-milk-caps-after-successful-trial/8291.article> (accessed on 21 Nov 2025)

⁷² Morales-Caselles, C., Viejo, J., Martí, E., González-Fernández, D., Pragnell-Raasch, H., González-Gordillo, J.I., Montero, E., Arroyo, G.M., Hanke, G., Salvo, V.S. and Basurko, O.C., 2021. An inshore-offshore sorting system revealed from global classification of ocean litter. *Nature Sustainability*, 4(6), pp.484-493.

⁷³ https://single-market-economy.ec.europa.eu/single-market/goods/european-standards/harmonised-standards/plastic-caps-and-lids_en (accessed on 21 Nov 2025)

towards **lighter** thinner packaging using less plastics. These include less cap weight in Colgate Palmolive brand fabric softener and Coca-Cola’s beverage bottle. There is also development towards incorporating **traceability** in the products. This is being done through tracers such as rare earth or fluorescent dyes added to the polymer; optical identifiers such as bar codes or digital watermarks⁷⁴. To minimize the negative effects of **labels** in recycling, developments such as washable labels, embossing instead of using labels are being explored⁷⁵.



Tethered cap in bottles

Figure 7. Examples of product design interventions

3.3 Business model innovation

In addition to technological advancements there are also innovative business models that reduce waste, enhance material recovery and promote reuse (Figure 8). One of the key drivers has been **Extended Producer Responsibility (EPR)**. Germany implemented strict EPR laws under VerpackG requiring all companies to pay fees based on their packaging recyclability. It increased the packaging waste recycling to 70% in 5 years⁷⁶. Brands like Coca-Cola and Nestlé improved packaging recyclability to comply with EPR mandates. Countries like France, Canada and Japan have also strengthened EPR laws which needs the producers to finance recycling infrastructure and material recovery programs. One of the business models that supports compliance with EPR is the **Deposit Return Scheme (DRS)** which is a market-based instrument where a deposit charged at the point of sale is refunded when the empty container is returned to a designated collection point. A review of DRS systems in Europe found that transparent scheme with tight coordination led to greater efficiency⁷⁷.

Reusable packaging systems involve collecting, cleaning and redistributing packaging materials for multiple uses instead of disposing of them after one cycle. These models are gaining traction in food, beverage and personal care industries where packaging waste is a significant issue. Loop, a zero-waste packaging platform launched by TerraCycle in partnership with major brands like Nestlé, Unilever, and Procter & Gamble (P&G) offers products in durable, reusable containers that consumers return after use. A 90% return rate was observed in pilot programs in France, the UK and US that demonstrates strong

⁷⁴ Rumetshofer, T. and Fischer, J., 2023. Information-based plastic material tracking for circular economy—a review. *Polymers*, 15(7), p.1623.

⁷⁵ <https://www.packagingdive.com/news/coca-cola-eliminates-labels-sprite-bottles-uk/705827/> (accessed 25 Nov 2025)

⁷⁶ [verpackungsgesetz-info.de](https://www.verpackungsgesetz-info.de/). (n.d.). Packaging Act (VerpackG) – general information. Retrieved from <https://www.verpackungsgesetz-info.de/en/> (accessed 10 Apr 2025)

⁷⁷ Picuno, C., Gerassimidou, S., You, W., Martin, O. and Iacovidou, E., 2025. The potential of Deposit Refund Systems in closing the plastic beverage bottle loop: A review. *Resources, Conservation and Recycling*, 212, p.107962.

consumer interest in reuse models⁷⁸. The factors that pose as barrier to scaling up are high logistics costs and consumer convenience. Algramo’s smart refill systems enable pay-per-use consumption using durable containers and have been shown to reduce plastic packaging demand by 30-50% compared to single-use formats⁷⁹. In business-to-business applications, pooled reusable crates and pallets operated by IFCO and CHEP have demonstrated substantial reductions in packaging waste and resource use in food and retail supply chains⁸⁰. In 2019, Unilever installed two large high-tech refill machines in modern trade outlets in Sri Lanka that offered pre-set amount or fixed doses of personal and home care products from brands such as Dove, Sunsilk and Sunlight; however, the success and future plans are not reported⁸¹. Chakra Suthra Zero-Waste Solutions in Sri Lanka Zero provides Trash2Cash services, including smart machines that accept empty plastic bottles to incentivize the consumers.

	Reuse	Refill	Product as a service
Beverages	* Returnable glass bottles * Deposit return systems	Refill stations	Smart dispensing machines in restaurants
FMCG and personal care		Refill dispensers in store and other convenient locations	Reusable packaging through third party
Hospitality and food service	Reusable water bottles and food containers		Equipment as a service (e.g. coffee machine)
E commerce and logistics	Reusable delivery packaging		Pooled packaging system

Figure 8. Circular business models related to plastic packaging

Summary

- Enhancing the biodegradability of plastics through additives is being researched
- Chemical and enzymatic recycling can offer improved properties over mechanical recycling but are yet to be fully commercialized
- The use of sensors and digital tools in sorting as well as product design can minimize contamination and lead to better quality recycled products
- In addition to technology innovations, business model innovations can lead to efficient use of plastics especially in packaging applications

⁷⁸ TerraCycle. (n.d.). History of Reuse: Loop. Retrieved from https://www.terracycle.com/en-US/about-terracycle/history/reuse_loop?srsId=AfmBOoo9mT4XqSqNB2NjhFRWsnmsUpTrFX7sUxUhakUoEb1BEVZf6mq (accessed 10 Apr 2025)

⁷⁹ Ellen MacArthur Foundation, (2019) [Reuse-rethinking packaging](#).

⁸⁰ Packaging Gateway. (2025, January 31). IFCO’s reusable packaging solutions yield environmental savings. <https://www.packaging-gateway.com/news/ifco-reusable-packaging-solutions/> (accessed 11 Apr 2025)

⁸¹ Packaging South Asia. (n.d.). Refill in Asia. Retrieved from <https://packagingsouthasia.com/type-of-article/refill-in-asia/#:~:text=Similarly%2C%20in%20Sri%20Lanka%20in,as%20Dove%2C%20Sunlight%20and%20Sunsilk> (accessed 11 Apr 2025)

4. Lifecycle studies

Lifecycle assessment (LCA) is a helpful tool that is used to evaluate the environmental impacts of a material throughout its entire lifecycle. It can be used to understand the scope of impacts of a single product or to compare multiple products. It is used to assess all aspects of a product from raw feedstock extraction through its end-of-life (i.e., cradle-to-grave) or can focus on specific portions of a supply chain. LCA results are crucial for comparing the environmental trade-offs of various plastic alternatives, particularly with respect to energy consumption, emissions and waste generation⁸². The LCA studies of different alternatives are discussed in this section.

A review of lifecycle assessment (LCA) literature on plastic alternatives provides important comparative insights into the advantages, limitations, and trade-offs associated with different materials across production and end-of-life stages. Across most materials, the production phase contributes a substantial share of total environmental impacts, particularly in terms of energy consumption, resource depletion, and greenhouse gas emissions⁸³. For bioplastics such as polylactic acid (PLA) and polyhydroxyalkanoates (PHA), upstream agricultural processes strongly influence lifecycle performance. Studies show that the global warming potential (GWP) of PLA can be 1.5 to 3 times higher than conventional polyethylene in regions reliant on fossil-fuel-intensive electricity generation, due to energy use in polymerisation and feedstock processing. PHA generally exhibits lower GWP than PLA but requires higher agricultural inputs, leading to increased land use, water demand, and eutrophication potential⁸⁴. Bio-based polyethylene, typically derived from sugarcane, demonstrates a lower GWP than fossil-based polyethylene due to partial displacement of fossil feedstocks and biogenic carbon uptake during cultivation⁸⁵. However, these benefits are moderated by energy-intensive processing and potential land-use change impacts, and are highly sensitive to end-of-life treatment pathways⁸⁶.

A comparative assessment of bio-based and fossil-based polymers shows that, on a cradle-to-gate basis, fossil-based plastics such as polyethylene and polypropylene typically exhibit GWP values in the range of approximately 1.7-2.5 kg CO₂-eq per kg polymer⁸⁷. In contrast, bio-based plastics display a wider spread of impacts. PLA and starch-based plastics generally exhibit cradle-to-gate GWP values below 1 kg CO₂-eq per kg, reflecting biogenic carbon uptake, while PHA shows very low production-stage GWP values of around 0.3-0.6 kg CO₂-eq per kg. However, when end-of-life stages are included, the GWP of PHA-based products can increase substantially, reaching values of up to 3.1 kg CO₂-eq per kg, depending on disposal pathways and methane management assumptions. Bio-based polyethylene (Bio-PE) demonstrates particularly favourable climate performance at the resin production stage, with negative cradle-to-gate GWP values of approximately -0.7 to -0.8 kg CO₂-eq per kg, attributable to carbon sequestration during biomass growth. As summarised in Table 6, Bio-PE also shows primary energy demand in the range of 73-91 MJ per kg and water consumption between 1.4 and 9.5 m³ per kg, highlighting trade-offs related to agricultural water

⁸² Hellweg, S. and Milà i Canals, L., 2014. Emerging approaches, challenges and opportunities in life cycle assessment. *Science*, 344(6188), pp.1109-1113.

⁸³ Franklin Associates, 2018. Life cycle impacts of plastic packaging compared to substitutes in the United States and Canada—A theoretical substitution analysis.

⁸⁴ Braunegg, G., Lefebvre, G. and Genser, K.F., 1998. Polyhydroxyalkanoates, biopolyesters from renewable resources: physiological and engineering aspects. *Journal of biotechnology*, 65(2-3), pp.127-161.

⁸⁵ Vink, E.T., Davies, S. and Kolstad, J.J., 2010. The eco-profile for current Ingeo® polylactide production. *Industrial biotechnology*, 6(4), pp.212-224.

⁸⁶ Suarez, A., Ford, E., Venditti, R., Kelley, S., Saloni, D. and Gonzalez, R., 2023. Is sugarcane-based polyethylene a good alternative to fight climate change?. *Journal of Cleaner Production*, 395, p.136432.

⁸⁷ Walker, S. and Rothman, R., 2020. Life cycle assessment of bio-based and fossil-based plastic: A review. *Journal of Cleaner Production*, 261, p.121158.

use. Overall, the comparison illustrates that while certain bioplastics can outperform fossil-based polymers on climate change indicators at the life cycle stage, these advantages are highly sensitive to feedstock cultivation practices, energy sources, and end-of-life treatment, and should therefore be interpreted within a full life-cycle and system-specific context rather than assumed as inherent material benefit.

Table 6. Indicative impacts of bio-based and fossil-based polymers

Impact ⁸⁸	Bio-PE	PLA	PHA	PBS	Starch-based plastics
Global Warming Potential	Approximately - 0.75 kg CO ₂ -equivalent per kg, indicating a net removal of CO ₂ from the atmosphere	~0.5-1.0 kg CO ₂ -eq/kg	~0.3-0.6 kg CO ₂ -eq/kg (production stage)	~1.0-1.8 kg CO ₂ -eq/kg	~0.8-1.5 kg CO ₂ -eq/kg
Energy Consumption	73-91 megajoules (MJ) per kg	~45-65 MJ/kg	~40-60 MJ/kg	~70-90 MJ/kg	~30-50 MJ/kg
Water Consumption	Varies between 1.4 to 9.5 cubic meters/kg, depending on factors such as crop type and cultivation practices	Moderate to high	Moderate	Moderate	High

In the case of paper packaging, lifecycle emissions are dominated by energy-intensive pulping and drying processes, while acidification and eutrophication impacts are linked to chemical inputs in forestry and water-intensive processing⁸⁹. Nevertheless, LCAs consistently indicate that paper packaging can achieve favourable environmental outcomes when supported by efficient recycling systems that reduce reliance on virgin pulp.

Across materials, LCA studies consistently emphasize that end-of-life management is a critical determinant of overall sustainability. The environmental advantages of PLA, for example, are contingent upon access to industrial composting infrastructure; where such systems are absent, PLA may contaminate conventional recycling streams or be landfilled, eroding intended benefits. While PLA and PHA blends have been shown to degrade without forming persistent microplastics under controlled industrial composting and, in some cases, under home-composting conditions these outcomes depend strongly on treatment conditions and system design⁹⁰.

Overall, lifecycle studies demonstrate that material substitution alone is insufficient to deliver environmental gains. Meaningful improvements require alignment between material selection, product design, and end-of-life infrastructure, reinforcing the importance of integrated waste management planning within circular economy roadmaps. The LCA studies of different alternatives for specific products are discussed further.

⁸⁸ Ali, S.S., Abdelkarim, E.A., Elsamahy, T., Al-Tohamy, R., Li, F., Kornaros, M., Zuorro, A., Zhu, D. and Sun, J., 2023. Bioplastic production in terms of life cycle assessment: A state-of-the-art review. *Environmental science and ecotechnology*, 15, p.100254.

⁸⁹ Confederation of European Paper Industries. (2021). [Paper recycling in Europe: Sustainability and performance](#). CEPI. (accessed 11 Apr 2025)

⁹⁰ Ruggero, F., Belardi, S., Carretti, E., Lotti, T., Lubello, C. and Gori, R., 2022. Rigid and film bioplastics degradation under suboptimal composting conditions: A kinetic study. *Waste Management & Research*, 40(8), pp.1311-1321.

4.1 Single-Use plastic bags versus alternatives

Numerous studies have been conducted to compare the environmental impacts of single-use plastic bags with alternatives like paper bags, biodegradable bags, and biobased polyethylene bags. While biodegradable bags may reduce littering potential, they frequently exhibit higher climate change impacts due to energy-intensive production processes and upstream agricultural inputs, particularly when fossil-based energy is used⁹¹. These conclusions are highly sensitive to regional conditions; potential life-cycle benefits of alternative materials can often be diminished at the end-of-life stage due to poor waste management, reinforcing the need for life cycle-based decision-making that integrates local energy profiles and waste management realities rather than relying solely on material substitution claims.

Although biodegradable plastics such as polylactic acid (PLA) are often assumed to be more energy-intensive to manufacture than conventional fossil-based plastics, recent cradle-to-gate life cycle assessments indicate that this is not uniformly the case when biogenic carbon uptake is included within the system boundary. Third-party LCA data for Corbion's Luminy® PLA report a cradle-to-gate GWP of approximately 0.50 kg CO₂-eq per kg of PLA pellets, reflecting the incorporation of carbon sequestration during sugarcane cultivation and the use of renewable energy inputs such as bagasse cogeneration within the production system⁹². While PET generally exhibits higher cradle-to-gate GWP and primary energy demand, it tends to show lower eutrophication potential due to the absence of agricultural feedstock cultivation and associated fertiliser emissions.

Paper bag production is generally associated with higher greenhouse gas emissions, as well as higher acidification and eutrophication impacts, compared to lightweight plastic bags, largely due to the energy and water intensive nature of the forestry, pulp, and paper sector⁹¹. These impacts arise primarily at the production stage, where energy intensive pulping and paper-making processes, along with chemical inputs used in fibre processing and bleaching, contribute to elevated emissions into air and water. Life cycle assessment results show that a typical paper shopping bag needs to be reused 3-10 times, depending on its weight and carrying capacity, to achieve climate change impacts comparable to a single-use lightweight plastic bag. The environmental performance of paper bags improves substantially when recycling rates exceed 60-70%, as high material recovery is necessary to offset the higher impacts associated with paper production. Composting under well managed aerobic conditions can also contribute positively, whereas disposal in landfills or unmanaged dumping sites significantly reduces potential benefits due to methane emissions from anaerobic degradation and the loss of recoverable material. These findings are summarized in Table 7.

Table 7. Comparison of single use plastic bag with PLA and paper bags

Bag material	Environmental considerations	End of life considerations
Single-use plastic	Higher fossil resource use; persistence in environment	Can cause littering, marine pollution including microplastics if not properly managed
PLA	<ul style="list-style-type: none"> Benefits depend on energy source and inclusion of biogenic carbon Higher eutrophication due to agriculture 	Requires proper composting; limited benefit in landfill/unmanaged systems
Paper	Air and water pollution during production	Needs 3–10 reuses to match plastic; benefits improve with 60–70% recycling

⁹¹ Ekvall, T., Liptow, C. and Miliutenko, S., 2020. Single-use plastic bags and their alternatives: Recommendations from Life Cycle Assessments. United Nations Environment Programme: Nairobi, Kenya, pp.1-76.

⁹² Morão, A. and De Bie, F., 2019. Life cycle impact assessment of polylactic acid (PLA) produced from sugarcane in Thailand. Journal of Polymers and the Environment, 27(11), pp.2523-2539.

4.2 Plastic bottles versus alternatives

Plastic bottles are among the largest contributors to plastic waste streams, particularly those manufactured from polyethylene terephthalate (PET). Several life cycle assessment studies have examined the environmental performance of polyethylene terephthalate (PET) bottles in comparison with polylactic acid (PLA) bottles. Cradle-to-gate analyses generally indicate that PLA bottles can exhibit a lower GWP than fossil-based PET bottles, largely due to biogenic carbon uptake during biomass cultivation and the partial substitution of fossil energy in resin production⁹³. Bottle-specific LCAs report reductions in climate change impact of approximately 20-40%, with some studies observing reductions of around 30% when PET bottles are replaced with corn-based PLA under favourable production assumptions⁹⁴.

A review of LCA studies on PLA indicates that eutrophication impacts for PLA can be several times higher than those of fossil-based plastics, depending on crop type, agricultural practices, and system boundaries⁹⁵. For beverage packaging, reuse is typically limited due to hygiene and safety considerations, which places greater emphasis on end-of-life management. While PET benefits from established mechanical recycling systems, recycling and composting pathways for PLA remain comparatively limited, and their environmental benefits are realised only under specific and well-managed conditions. Overall, these studies suggest that although PLA bottles may offer climate advantages over PET in certain cases, their environmental performance cannot be considered universally superior and must be evaluated in relation to agricultural practices, energy sources, and realistic end-of-life pathways rather than material origin alone.

Glass bottles are often considered a viable alternative to plastic bottles due to their recyclability and chemical stability; however, life cycle assessments indicate that their environmental performance is highly dependent on use patterns and logistics. On a single-use basis, glass bottles typically exhibit higher GWP and energy demand than PET bottles, primarily due to the energy-intensive melting processes involved in glass production and the greater weight of glass, which increases transport-related emissions⁹⁶. Refillable glass bottles reused approximately 20-40 times, combined with short transport distances, return rates exceeding 85-90%, and recycling rates above 70%, can significantly reduce per-use impacts and offset the higher production emissions associated with glass⁹⁷.

These are compared in Figure 9.

⁹³ Vink, E. T. H., 2010 (see footnote 83).

⁹⁴ Nikolić, S.L.A.V.K.A., Kiss, F., Mladenović, V.A.L.E.N.T.I.N.A., Bukurov, M. and Stanković, J., 2015. Corn-based polylactide vs. PET bottles—Cradle-to-gate LCA and implications. *Materiale Plastice*, 52(4), pp.517-521.

⁹⁵ Fonseca, A., Ramalho, E., Gouveia, A., Figueiredo, F. and Nunes, J., 2023. Life cycle assessment of PLA products: A systematic literature review. *Sustainability*, 15(16), p.12470.

⁹⁶ Ferrara, C., De Feo, G. and Picone, V., 2021. LCA of glass versus pet mineral water bottles: An Italian case study. *Recycling*, 6(3), p.50.

⁹⁷ Le Féon, S., Gésan-Guiziou, G., Yannou-Le Bris, G., Aubin, J. and Pénicaud, C., 2024. Life cycle assessment based optimization of scenarios of reusable glass bottles using context-specific key parameters. *Cleaner Environmental Systems*, 15, p.100225.

PET bottle	<ul style="list-style-type: none">• Fossil fuel based• Recyclable• Negative environmental impact in case of littering and microplastic generation
PLA	<ul style="list-style-type: none">• Energy use depends on agricultural practices and inclusion of biogenic carbon• Eutrofication in the agriculture step• Composting infrastructure not widely established
Glass	<ul style="list-style-type: none">• Energy intensive production process• Advantageous when used 20-40 times with more than 70% recycling

Figure 9. Comparison of PET bottle with PLA and glass

5 Recommendations for incorporating innovation for circular economy

5.1 Expanding use of bioplastics and other alternatives

Bioplastics based products are already available in the Sri Lankan market such as PLA and starch based bags, films. Among biodegradable materials, PLA has a considerable share in the market. Though it is compostable, it requires industrial conditions with a temperature of 60 °C. Also, the LCA studies have shown that the benefits of bioplastics would depend on the upstream practices related to biomass production. The complete life cycle of the bioplastics needs to be considered to understand the benefits. The benefits would also depend on how the product is disposed.

Therefore, clear guidelines about the product and its disposal supported by testing, certification and labeling is needed. The required infrastructure to support this is also needed. There is also a need for widespread awareness among consumers and waste management authorities so that informed decisions are taken and the guidelines are followed. The recommendations covering these aspects are summarized below.

5.1.1 Standards, certifications and labelling

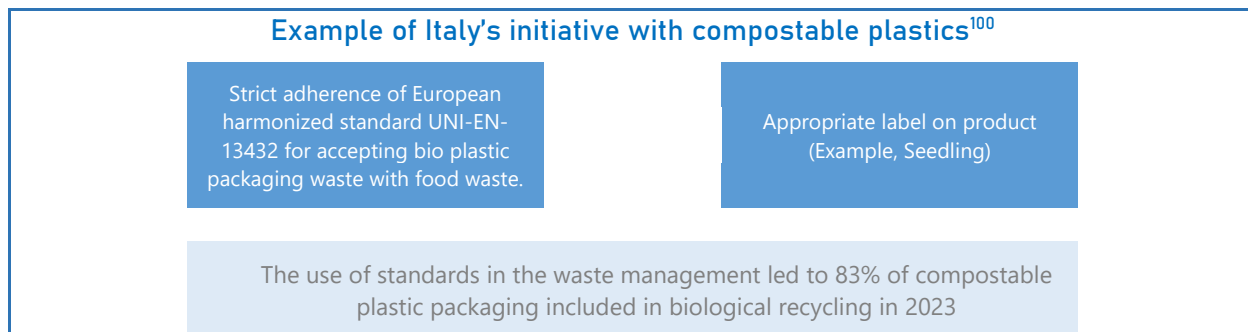
There are many standards defining the testing methodology for different aspects of bioplastics such as biobased content, compostability and biodegradability under different environments⁹⁸. The common ones are based on ISO (International Organization for Standardization), CEN (European Committee for Standardisation) and ASTM International (formerly American Society for Testing and Materials). There are also several national standards many of which are aligned with ISO standards. These standards are used by certifying organizations such as TÜV AUSTRIA, DIN CERTCO, Biodegradable Products Institute (BPI) that offer testing and certification. They also have unique logos that can be used in the labels of the certified products. In Sri Lanka, the Sri Lanka Standards Institution (SLSI) has different standards linked to bioplastics. This includes SLS ISO 22403:2020 which is equivalent to the international ISO 22403:2020, addressing plastics biodegradability in marine environments and SLS 1718:2021 for compostable plastic lunch sheets testing. The CEA requires importers and manufacturers of biodegradable and /or compostable polymers and products to be registered with CEA and comply with Sri Lanka Standards Institution (SLSI) standards for biodegradable and compostable plastic⁹⁹.

Recommendations

Short term (1-3 years)	Medium term (4-6 years)	Long term (7-10 years)
Harmonize existing standards with ISO and adapt new standards to cover wider aspects in collaboration with international organizations		
Prepare guidelines for labels (based on selected standards and testing) to be placed in products		
Facilitate acceptance of standards for export of Sri Lankan plastic products		

⁹⁸ https://docs.european-bioplastics.org/publications/pp/2025/EUBP_FS_Standards_and_Labels.pdf (accessed 25 Nov 2025)

⁹⁹ https://www.cea.lk/web/images/pdf/wm/INSTRUCTIONS_FOR_MANUFACTURERS_OF_Biodegra.and_Composti.-Final.pdf (accessed 30 November 2025)



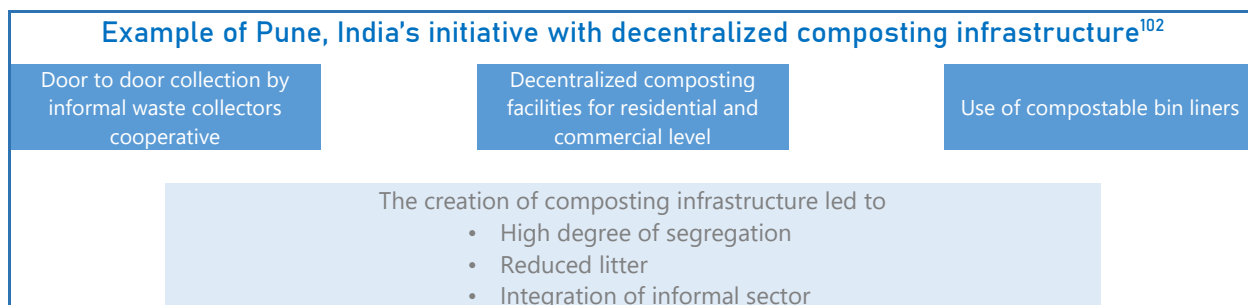
5.1.2 Infrastructure for testing, certification, disposal

To support the implementation of standards and certification, setting up of testing facilities are needed. There are a few laboratories for testing compostability (e.g. SGS, ITI). Laboratory Services Division of Sri Lanka Standards Institution (SLSI) has laboratory services including for polymers that performs compliance testing for a variety of materials. It would be beneficial to expand such facilities and also collaborate with certifying organizations such as TUV Austria to facilitate testing in Sri Lanka; this would support export of bioplastics.

It is important to ensure that the bioplastics are disposed in the correct manner based on the compostability characteristics. Industrial composting facilities are needed to effectively compost bioplastics such as PLA. For organic waste, Sri Lanka's Pilisaruru Program has established over 100 composting facilities across the nation to process biodegradable municipal solid waste (MSW)¹⁰¹.

Recommendations

Short term (1-3 years)	Medium term (4-6 years)	Long term (7-10 years)
Setting up of waste management regulations for bioplastics incorporating standards and certification		
Accredited third party testing centres for issuing certificate and labels. Partnerships can be established with international agencies for their certificates.		
Appropriate facilities for biological recycling of bioplastics in a phased manner		



¹⁰⁰ <https://www.biocycle.net/italy-compostable-plastics/> (accessed 25 Nov 2025)

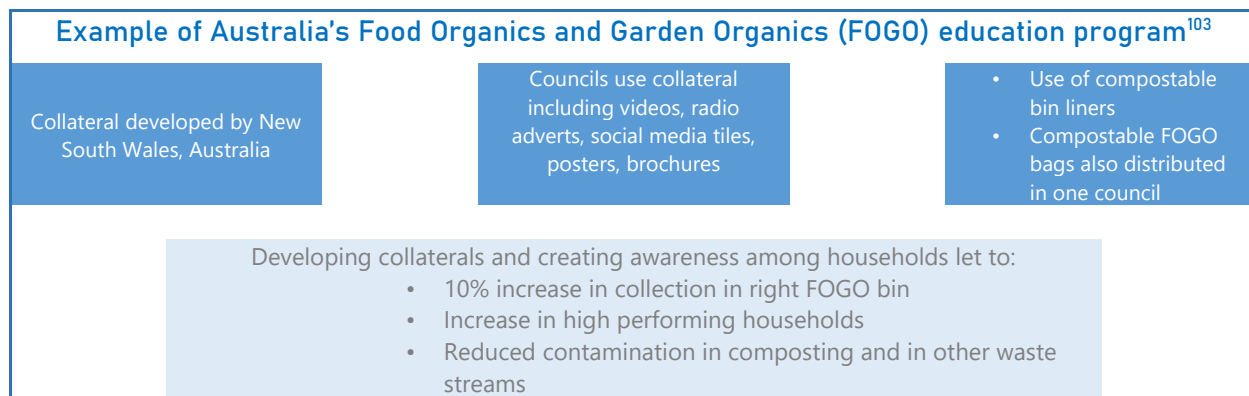
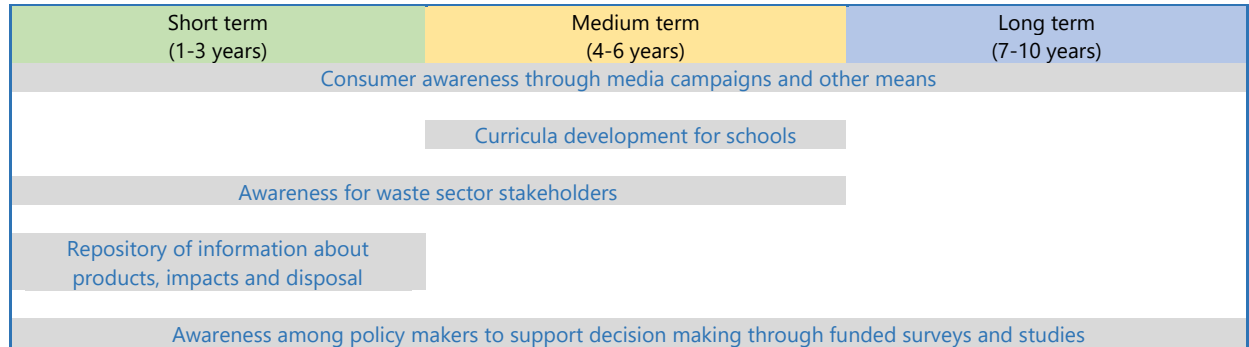
¹⁰¹ Roy, E.D., Esham, M., Jayathilake, N., Otoo, M., Koliba, C., Wijethunga, I.B. and Fein-Cole, M.J., 2021. Compost quality and markets are pivotal for sustainability in circular food-nutrient systems: a case study of Sri Lanka. *Frontiers in Sustainable Food Systems*, 5, p.748391.

¹⁰² <https://thegreenplanetsolutions.com/blog/municipal-composting-in-india-success-stories-from-pune-indore-surat/> (accessed 25 Nov 2025)

5.1.3 Awareness

Bioplastics comprise variety of options and consumers are not fully aware about the availability, properties, benefits and correct disposal of these materials. Driven by research and development, many new materials are also becoming available. The waste sector also needs to be aware about the separation of the different streams and disposal path. The policy makers need to make informed decision while planning bans and building infrastructure. Thus awareness creation is required among different stakeholders.

Recommendations



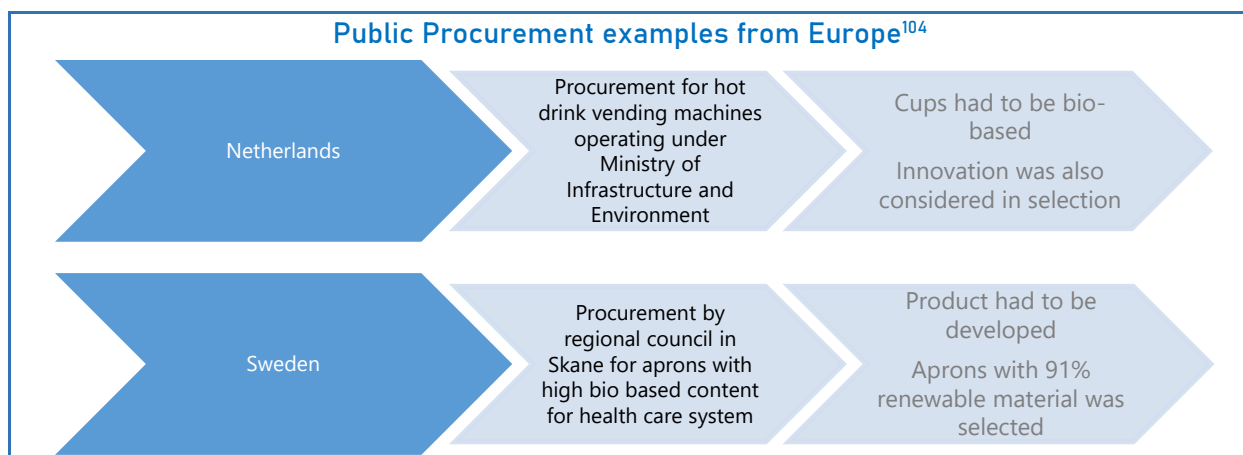
5.1.4 Promoting markets for ecoproducts

Growth in bioplastics is driven by factors such as regulations, consumer awareness and possibility of using local biomass resources. However, cost and availability in scale is a challenge. If market share is increased there will be more investment and manufacturing of such products. As part of increasing availability import of bioplastic resins can also be considered. Public procurement for items such as tableware, packaging will also contribute towards market growth of bioplastics. Targets can be set in a phased manner for green products.

¹⁰³ <https://www.epa.nsw.gov.au/Your-environment/Recycling-and-reuse/business-government-recycling/Food-organics-and-garden-organics/Scrap-Together> (accessed 25 Nov 2025)

Recommendations

Short term (1-3 years)	Medium term (4-6 years)	Long term (7-10 years)
Policies based on quotas and public procurement can play a role in increasing the market share of bioplastics for different applications		
Subsidies can make the costs competitive and motivate consumers		
Local manufacturing using locally available biomass can be promoted through financial schemes and agreements with farmers for feedstock supply		
Facilitating import of bioplastic resins for local manufacturing. These can also be used with locally available biomass fillers and tailored for specific local applications		



5.1.5 Promoting research, development and commercialization

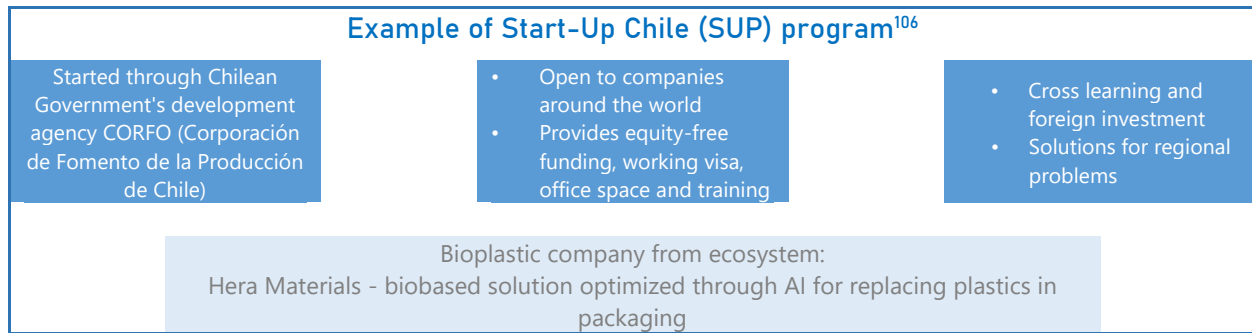
Research and development are leading to innovation in new materials, improved properties, higher processing efficiencies and better disposal options. In Sri Lanka many academic and research institutions are working on different raw materials such as starch, leaves and shells for bioplastics¹⁰⁵. There are start ups working on different materials for packaging and other applications. A research ecosystem with necessary funding and infrastructure can accelerate the development of locally relevant solutions.

¹⁰⁴ https://www.thegpsc.org/sites/default/files/innprobio_handbook-en_download_0.pdf (accessed 30 Nov 2025)

¹⁰⁵ Wijayasenarathne, K.A.S.H., Ariyawansa, R.T.K. and Dilini, R.M.A., 2025. Biodegradable Plastics in Sri Lanka: A Review of Current Status, Challenges and Opportunities. Biological Innovations for Environmental Sustainability

Recommendations

Short term (1-3 years)	Medium term (4-6 years)	Long term (7-10 years)
Research schemes with priority themes and private sector engagement		
Start up support to provide mentoring, grants, technical assistance		
Access to centralized analytical facilities and sophisticated instruments to support research		
		Regional collaborations



5.2 Minimizing plastic use

The move towards less plastic use for a given application is driven by bans, regulations and environmental factors. For many applications in the hospitality sector and packaging, there is scope for reducing the use of plastics through avoidance, product design or alternatives. Product design innovations can contribute towards less amount of plastic in a given product, longer lifetime of the plastic component or its reusability. The recommendations are given below.

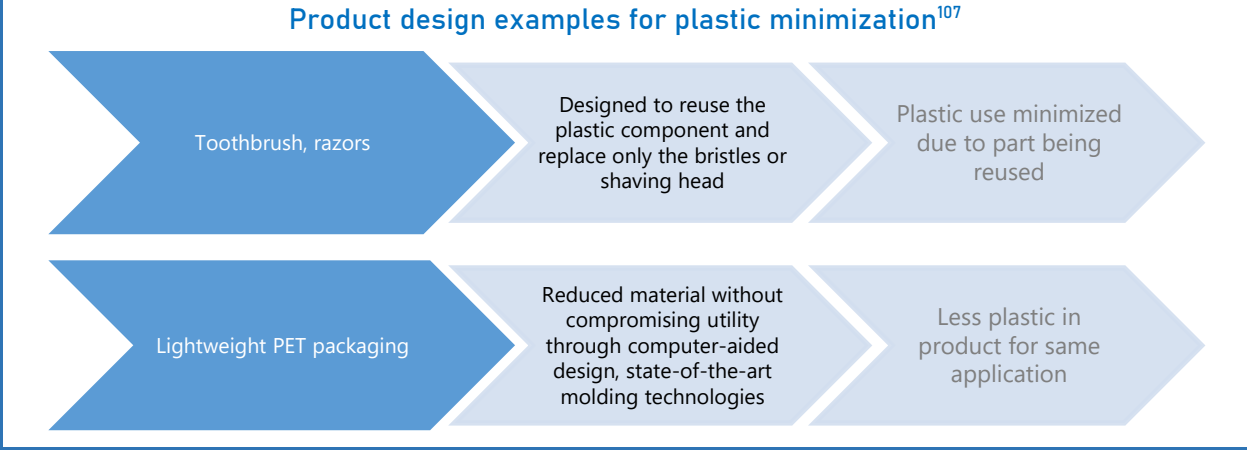
5.2.1 Product design

There are many developments towards minimizing plastic use such as lighter plastic bottles and doing away with smaller plastic components such as labels, gluing instead of plastic rings for beer cans. Such developments can reduce the plastic content per unit of product sold. In the hospitality sector, the avoidance of plastics can be brought about through measures such as water fountains for refills in own bottle instead of PET bottles and dispensers for toiletries in hotel rooms.

Recommendations

Short term (1-3 years)	Medium term (4-6 years)	Long term (7-10 years)
Encourage brands to replicate global best practices in Sri Lanka and also test innovations in Sri Lanka		
Promote best practices for avoiding plastic use in the hospitality sector and support decisions through consumer surveys		

¹⁰⁶ <https://startupchile.org/en/> (accessed 30 Nov 2025).

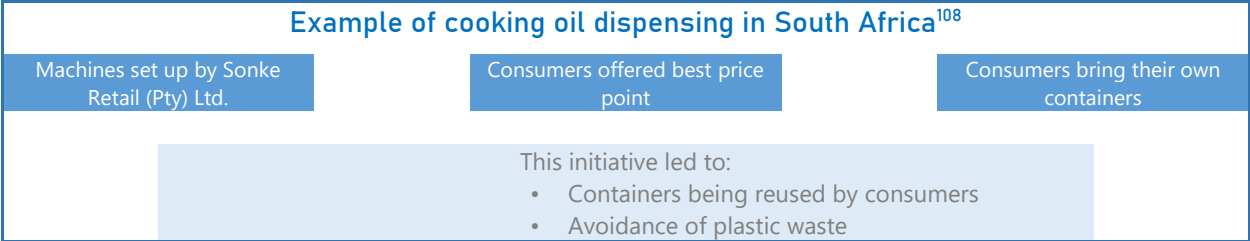


5.2.2 Packaging optimization

Packaging materials can be kept in use longer through different models. This includes refilling option where consumers use their own containers or return of packaging to manufacturer or logistics company who are responsible for maintenance. Refill model through vending machines has been tried in Sri Lanka; however, consumer acceptance and impact is not clear.

Recommendations

Short term (1-3 years)	Medium term (4-6 years)	Long term (7-10 years)
Optimise refill through vending machine for greater uptake after analysis of current experience		
Promotion of best practices in packaging among hospitality sector through dissemination and reward system		
Encourage brands and entrepreneurs to set up logistics operation for collection and reuse of packaging materials		



5.2.3 Facilitating plastic ban implementation

While ban has been in place, there are challenges in implementation due to availability of alternatives, their cost and performance. Further, as discussed earlier, as alternatives become available and are approved, their disposal logistics and infrastructure should be developed alongside.

¹⁰⁷ <https://www.packagingworldinsights.com/packaging-industry-articles/innovations-in-lightweight-pet-packaging-for-cost-efficiency/> (accessed 30 Nov 2025).

¹⁰⁸ Karsten, C., 2024. Where is the best place for an automatic sunflower oil dispenser?. CSIR Science Scope, 22(2), pp.52-53.

Recommendations

Short term (1-3 years)	Medium term (4-6 years)	Long term (7-10 years)
Repository of information about alternatives including specific information for the banned products (as mentioned in section 1.3)		
Next phase in SUP bans alongside information about alternatives		

Example of National portal for plastic waste reporting¹⁰⁹

Portal has section on resources with a section on available alternatives. Such portals would need to be updated regularly and disseminated among stakeholders.

5.3 Recycling

There are many collectors and recyclers in Sri Lanka. However, the rate of recycling is still low and most of them are small and medium enterprises. Most Materials Recovery Facilities (MRFs) in Sri Lanka are small-scale or semi-mechanized. They rely on manual sorting and do not use advanced automated technologies like Near Infrared (NIR) or robotics. NIR sorters are imported technologies, typically sourced from Europe or East Asia. The capital cost of NIR and robotic-assisted conveyors is high, and recyclers often lack access to finance or technical training to operate and maintain them efficiently. There is scope for improving recycling rates and quality of recycled products through incorporation of innovative technologies and business models.

5.3.1 Better product segregation and reduced contaminants

Sorting and cleaning are mostly done manually and due to improper segregation the processes are intensive and lead to poor quality products.

¹⁰⁹ <https://pwm.cpcb.gov.in/> (accessed 30 Nov 2025).

Recommendations

Short term (1-3 years)	Medium term (4-6 years)	Long term (7-10 years)
In addition to resin identification, the labelling can be more visual to facilitate ease of identification and sorting		
Awareness among consumers for better segregation of their plastic waste		
Training among informal sector and MRF facilities for improved segregation		
Reverse logistics and Deposit Return Schemes to promote collection of segregated plastic		

Examples of labels with information and colour coding



5.3.2 High value recycled products

By making high value recycled products that can be used in wider range of applications, dependence on virgin plastics is reduced. This can include bottle to bottle recycling, food grade applications with recycled content.

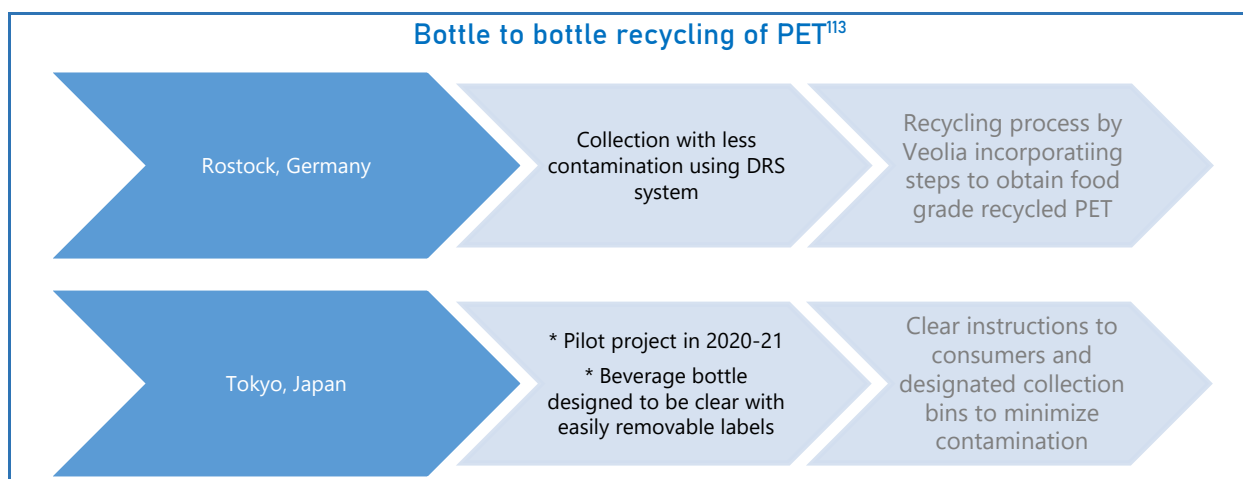
Recommendations

Short term (1-3 years)	Medium term (4-6 years)	Long term (7-10 years)
Collection of plastic waste with minimal contamination		
Promote manufacturing of recycled bottles - alongside standards and approval for food grade applications		
Improve product quality in existing SME recyclers through training, equipment upgradation (this can include improving energy efficiency of second hand machines)		
Incorporate use of sensors and digital markers to identify and sort plastic waste. This can be done in new automatic facility infrastructure as well as through portable equipment that the informal sectors are trained to use		

¹¹⁰ <https://how2recycle.info/about-how2recycle/> (accessed 30 Nov 2025).

¹¹¹ <https://oprl.org.uk/> (accessed 30 Nov 2025).

¹¹² <https://www.simplycups.com.au/single-post/what-is-the-artl> (accessed 30 Nov 2025).

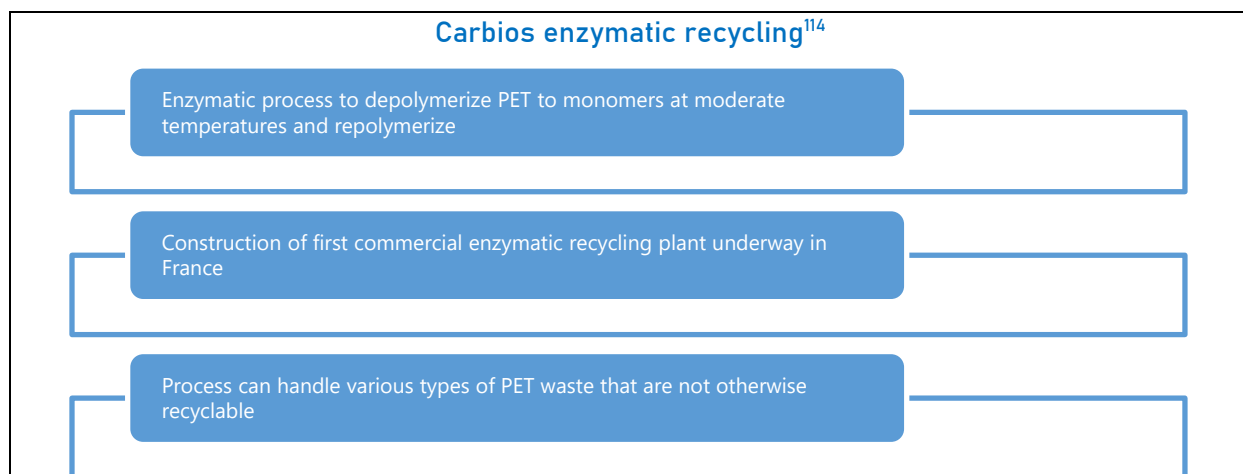


5.3.3 Advanced recycling technologies

Advanced recycling technologies such as chemical or enzymatic recycling can recover the monomer which can be used similar to virgin monomer for different products.

Recommendations

Short term (1-3 years)	Medium term (4-6 years)	Long term (7-10 years)
Through international tenders / collaborations, infrastructure can be developed once the collection logistics are upgraded		



5.4 Overarching themes

There are a few overarching themes that will support incorporation of bioplastics and other eco alternatives, plastic minimization as well as recycling. These are summarized below.

¹¹³ <https://www.veolia.in/about-us/cop21/our-solutions/bottle-bottle-rostock-germany>; <https://j4ce.env.go.jp/en/casestudy/086> (accessed 30 Nov 2025).

¹¹⁴ https://group.loccitane.com/sites/default/files/2024-05/PR_CARBIOS_LOCCITANE_EN_FINAL.pdf (accessed 30 Nov 2025).

5.4.1 Data based decision making

With new materials and claims flooding the market, it is important to get a holistic picture of the problem and impact of available solutions. Use of material flow analysis (MFA), life cycle analysis (LCA) can support the decision making. There are reported studies on MFA^{115,116} and LCA^{117,118} in Sri Lanka. These can be updated and expanded to cover different regions and scenarios.

Recommendations

Short term (1-3 years)	Medium term (4-6 years)	Long term (7-10 years)
Collaborate with international organizations to build expertise		
Fund studies for MFA and LCA in hot spot locations		
Training for capacity building in these areas		

5.4.2 Circular Economy pilots

Circular Economy interventions need multiple stakeholders in order to have a big impact. There is often a concern about the risks related to the changes made. Therefore, funded pilots would provide an opportunity to assess the results and address the challenges for full adoption.

Recommendations

Short term (1-3 years)	Medium term (4-6 years)	Long term (7-10 years)
Dedicated grants and challenges for funding CE pilots		

5.5 Stakeholders

Innovations can play an important role in tackling the environmental impact caused by plastics. However, to use the innovations safely, it is necessary to have a conducive eco system with awareness, transparency and informed decision making. A range of stakeholders are involved in contributing towards this eco system. Ministry of Environment and Central Environmental Authority play a central role in promoting sustainable consumption and production (SCP) in the plastics sector, including setting standards, supporting certification and labelling systems, driving awareness campaigns, and implementing product bans while facilitating information exchange on alternatives. Waste Management Authorities are responsible for strengthening on-ground implementation through improved disposal infrastructure, capacity building (including the informal sector), and adoption of advanced technologies. Economic and policy instruments are shaped by entities such as the Ministry of Finance, Customs, and the National

¹¹⁵ <https://www.iges.or.jp/en/pub/national-plastic-waste-inventory-sri-lanka-material-flow-approach/en> (accessed 30 Nov 2025).

¹¹⁶ Alahakoon, Y. and Karunarathna, A., 2020. Modelling of Post-consumer Plastic Flow in Municipal Solid Waste Stream: A Case Study in Few Major Local Authorities of Sri Lanka. In *Urban Mining and Sustainable Waste Management* (pp. 219-229). Singapore: Springer Singapore.

¹¹⁷ Kamalakkannan, S., Abeynayaka, A., Kulatunga, A.K., Singh, R.K., Tatsuno, M. and Gamaralalage, P.J.D., 2022. Life cycle assessment of selected single-use plastic products towards evidence-based policy recommendations in Sri Lanka. *Sustainability*, 14(21), p.14170.

¹¹⁸ Jayasekara, T., Wickrama Surendra, Y. and Rathnayake, M., 2022. Polylactic acid pellets production from corn and sugarcane molasses: Process simulation for scaled-up processing and comparative life cycle analysis. *Journal of Polymers and the Environment*, 30(11), pp.4590-4604.

Procurement Commission, which enable green public procurement, fiscal incentives, and regulation of imports such as bioplastics. Research-driven innovation is anchored by the National Research Council and academic institutions, which contribute to R&D, commercialization, and analytical studies such as material flow analysis (MFA) and life cycle assessment (LCA). The private sector plays a critical role in operationalizing circular economy business models while also adopting global best practices in product design and logistics. Civil society stakeholders can contribute towards awareness creation, training and supporting the implementation of circular economy models. These are summarized in Table 8 .

Table 8. Stakeholders and their areas of involvement

Stakeholder	Areas of involvement
<ul style="list-style-type: none"> Ministry of Environment Central Environmental Authority 	<ul style="list-style-type: none"> SCP in plastic manufacturing / recycling SME sector Standards, certification and labelling; testing infrastructure Awareness campaigns Repository of information about products, disposal and impacts Bans on products; coordination for information about alternatives among users CE business models with private sector
<ul style="list-style-type: none"> Sri Lanka Standards Institution 	<ul style="list-style-type: none"> Standards, certification and labelling; testing infrastructure Meeting standards for exports
<ul style="list-style-type: none"> National Research Council 	<ul style="list-style-type: none"> Research, development and commercialization, including with private sector participation Sophisticated analytical facilities
<ul style="list-style-type: none"> Ministry of Finance Customs National Procurement Commission (NPC) 	<ul style="list-style-type: none"> Public procurement guidelines covering green products Incentives for green products Import of bioplastics
<ul style="list-style-type: none"> Waste Management Authorities 	<ul style="list-style-type: none"> Awareness campaigns Capacitate staff and informal sector; incorporate use of sensors and other equipment Disposal infrastructure (e.g. industrial composting)
<ul style="list-style-type: none"> Private Sector 	<ul style="list-style-type: none"> Certification and labelling of products CE business models such as refill, DRS Global best practices in product design and logistics Entrepreneurship for new materials and technologies
<ul style="list-style-type: none"> Academic Institutions 	<ul style="list-style-type: none"> Research, development and commercialization Curriculum development MFA and LCA studies
<ul style="list-style-type: none"> Ministry of Education National Institute of Education 	<ul style="list-style-type: none"> Curriculum development
<ul style="list-style-type: none"> Ministry of Industry and Entrepreneurship Development National Enterprise Development Authority 	<ul style="list-style-type: none"> Local manufacturing of green products including start up support Upgradation of infrastructure and equipment for recyclers
<ul style="list-style-type: none"> Ministry of Tourism 	<ul style="list-style-type: none"> Best practices among hospitality sector in avoiding / minimizing plastic use
<ul style="list-style-type: none"> Financial Institutions 	<ul style="list-style-type: none"> Green financing
<ul style="list-style-type: none"> Civil Society 	<ul style="list-style-type: none"> Awareness, support circular economy model implementation

5.6 Link to National plastic waste management plan

Sri Lanka has developed the National Action Plan on Plastic Waste Management 2021-2030 with sixteen goals and actions under each goal¹¹⁹. Through several targets were set for 2025, it is not clear if these have been achieved. The recommendations in this report related to innovations in this sector will support and contribute towards some of the goals as shown below.

- Under **Goal 2**, the production and consumption of SUPs is to be reduced by 80% by 2025. The actions include registering alternate product manufacturers, promoting eco design and demonstration for upcycled products. The recommendations (section 5.1) related to research and development for alternatives, creating awareness about alternatives that are reliably certified with information about their disposal will contribute towards the implementation of the SUP.
- **Goal 3** refers to 80% collection of recyclables and non-recyclables plastics (including from e-waste) and 100% treatment and safe disposal by 2025. The actions including involving community based organizations such as Samurdhi for collection of plastic waste. It also mentions introducing technologies for plastics identification and sorting. **Goal 9** and **Goal 10** refer to increasing plastic waste recycling from 4% to 15% and PET recycling from 27% to 100% by 2025. This is proposed through improved mechanism for collection, certificate scheme for recyclers, mandatory resin code marking and product safety certification for recycled PET. The recommendations (section 5.3) related to labelling, improved segregation, collection and high value recycled products will support these goals.
- **Goal 4** and **Goal 6** are related to reducing packaging and non-packaging plastics by 30% by 2025. The actions involve national labelling standards, including recycled plastics in non-food packaging and green procurement. The recommendations related to minimizing plastic use (section 5.2) and improved recycling (section 5.3) will contribute towards this goal.
- **Goal 12** seeks to enhance knowledge and competency among relevant stakeholders in the area of plastic waste management by 2030 through various training and course development. **Goal 16** seeks to increase community participation. The recommendations (section 5.1) related to awareness and promoting research would contribute towards this goal.

Thus, the incorporation of innovation can support several of the goals and add to the benefits from the actions.

5.7 Concluding remarks

There innovations discussed in this report and the recommendations cover different aspects of circular economy (Figure 10). These innovations are rapidly growing in the global market and many are already available in Sri Lanka. However, a supportive eco system along with transparency and awareness is needed to ensure that there are no pitfalls and the issues are not transferred to another area. The decision making needs scientific data and evidence.

¹¹⁹ Ministry of Environment (2021). See footnote 7

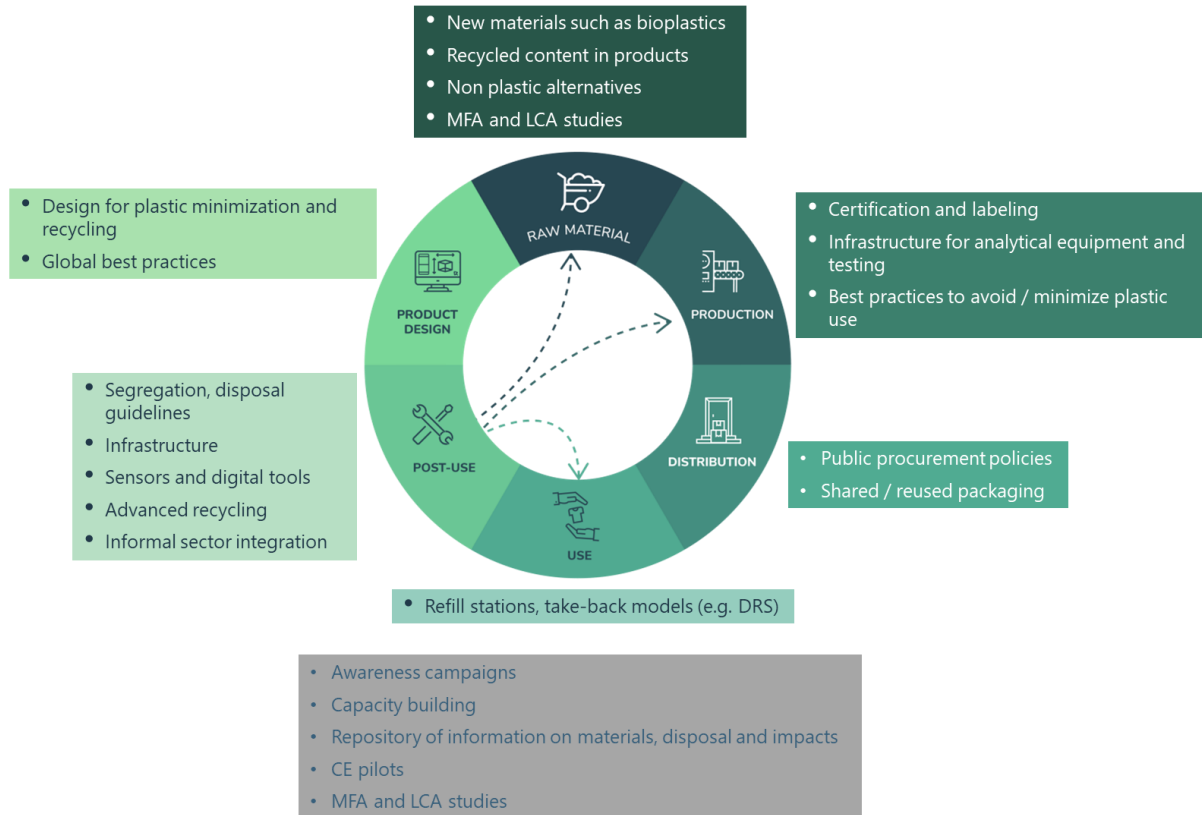


Figure 10. Recommendations and their link to the Circular Economy themes

All stakeholders, especially consumers need greater awareness about the options and guidelines for disposal. Private sector also has a major role to play in terms of product design, logistics and global best practices. These have to be integrated into the existing National plans so that they are implemented effectively.

These actions are expected to lead to innovation driven solutions in the area of materials, product design and recycling contributing to reduced plastic leakage, increased recycling rates and strengthened institutional frameworks and compliance mechanisms thereby supporting the EPR as well as the National Action Plan on Plastic Waste Management 2021-2030.