Milestone Study on Bioplastics Waste Management in the US & Canada

Transforming Recycling and Solid Waste Management in the US & Canada

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Glossary and List of Acronyms

ADEME	French Agency for Ecological Transition (*Agence de la transition écologique*) (France)
ANSES	National Agency for Food, Environmental and Occupational Health & Safety (*Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail*) (France)
ASP	Aerated static pile composting – composting systems that biodegrade organic waste without physically manipulating the material during primary composting and using equipment, usually perforated piping, to control and increase airflow through the compost pile (Rynk, et al. 2022).
ASTM	American Society for Testing and Materials, an international standards organization.
AD	Anaerobic digestion, a sequence of processes where microorganisms break down biodegradable material in the absence of oxygen, producing digestate and biogas.
BID	Inter-American Development Bank
Bio-based plastics	Plastics made from renewable, raw materials such as vegetable fats and oils, corn starch, woodchips, straw, and recycled food waste.
Biodegradable	Something that can decay or be decomposed naturally by bacteria or living organisms into harmless products.
Biogenic carbon	Carbon sequestered in biological materials such as plants or soil.
BioMEG:	Bio-monoethylene glycol, a wood-based glycol produced by UPM Biochemicals.
Bio-PA	Biopolyamide
Bio-PBS	Biopolybutylene succinate
Bio-PE	Biopolyethylene
Bio-PET	Biopolyethylene terephthalate
Bio-PTT	Biopolytrimethylene terephthalate
Bioplastic	A catch-all term for plastics that can be one of a combination or all of the following: bio-based (made from renewable raw materials); biodegradable/compostable; non-bio-based (made from non-renewable petrochemical/fossil-based raw materials); and oxy/oxo-degradable, oxy/oxo-biodegradable, and oxo-fragmentable (these are not genuinely biodegradable but fragment in nature creating microplastic pollution).
Biopolymer	A polymer produced from natural sources either chemically synthesized from a biological material or entirely biosynthesized by living organisms.
Bio-PP	Biopolypropylene
BNQ	Bureau de Normalisation du Québec (Canada)
BPI	Biodegradable Products Institute
CEC	Commission for Environmental Cooperation
CEPA	Canadian Environmental Protection Act
CIC	Composting & Biogas Association (*Consorzio Italiano Compostatori)* (Italy)
CMA	Compost Manufacturing Alliance

CO_2	Carbon dioxide
Compostable plastic	Compostable plastic refers to a number of polymers designed to biodegrade, in an industrial process or a home composting process, into biomass, water and carbon dioxide. Industrially compostable means that the plastic biodegrades in industrial composting or anaerobic digestion facilities and is compliant with an industrial compostability standard, such as the ASTM D6400 or EN 13432.
Conventional plastic	Plastic typically derived from fossil-based feedstocks that is not considered to be biodegradable or compostable in any reasonable timeframe.
Drop-ins	Bio-based, non-biodegradable plastics that have the same chemical structure to their conventional plastic counterparts, can be used for the same applications, and can be treated in the same way at end-of-life.
ECCC	Environment and Climate Change Canada
EoL	End-of-life
EPA	United States Environmental Protection Agency
EU	European Union
EPR	Extended producer responsibility
EREF	Environmental Research & Education Foundation
FTC	Federal Trade Commission (US)
Food waste capture	The collection of food waste, separate from other waste streams and materials, to send it to industrial compost or AD facilities for treatment (diverting it from landfill and thus reducing the associated greenhouse gas emissions).
Fossil-based plastics	Plastics made from non-renewable, petrochemical raw materials, e.g., crude oil.
GHG	Greenhouse gas
HDPE	High density polyethylene, commonly used for milk bottles, bleach cleaners, and most shampoo bottles.
HS	Harmonized system, a multipurpose international product nomenclature developed by the World Customs Organization that allows the identification of specific commodities.
Industrial composting	A blanket term that includes all forms of centralized aerobic organic waste treatment that is characterized by high levels of control and results in various forms of soil improver.
IVC	In-vessel composting, used to treat food and garden waste mixtures. These systems ensure that composting takes place in an enclosed environment, allowing control over temperature, moisture, and airflow (EPA 2022).
ISO	International Organization for Standardization
LCA	Life cycle assessment
LDPE	Low-density polyethylene, commonly used for carrier bags, bin liners and packaging films.
Ontario MOE	Ontario Ministry of Environment (Canada)
MRF	Materials recovery facility. This is a specialized facility that receives, separates and prepares recyclable materials for marketing to end-user manufacturers.

Nature biodegradable	Something that can decay or be decomposed naturally by bacteria or living organisms into harmless products within reasonable timeframes– specifically in natural environments on land or in water.
NOP	National Organic Program (US Department of Agriculture)
OMRI	Organic Material Review Institute
Open air windrow composting	Used to treat food and garden waste mixtures. Involves forming organic waste into rows of long piles called "windrows" and aerating them periodically by either manually or mechanically turning the piles. Pile sizes are large enough to generate heat and maintain temperatures and small enough to allow oxygen flow to the windrow's core (EPA 2022).
Organic waste stream	Source-separated biodegradable waste material, namely food and yard waste. Can be disposed and collected separately into a food waste and yard waste stream.
Oxy/Oxo-biodegradable Oxy/Oxo-degradable Oxo-fragmentable	Plastics that are not genuinely biodegradable but fragment in nature creating microplastic pollution.
PA	Polyamide (nylon), the largest family of engineering plastics with a very wide range of applications because of their good balance of properties. Polyamides are very resistant to wear and abrasion, have good mechanical properties even at elevated temperatures, have low permeability to gases and have good chemical resistance, good dimensional stability, good toughness, high strength, high impact resistance, and good flow.
PBAT	Polybutylene adipate terephthalate, a biodegradable polyester.
PBS	Polybutylene succinate, a plastic with similar properties to propylene film.
PCL	Polycaprolactone, a compound used in place of polyurethane plastic and has been found to be degraded by certain micro-organisms.
PE	Polyethylene, a type of resin and a polyolefin and one of the world's most widely produced synthetic plastic.
PEF	Polyethylene furanoate, a bio-based polyester with properties appropriate for replacing many plastics, including PET.
PET	Polyethylene terephthalate, a type of resin and a form of polyester. PET has some important characteristics such its strength, thermo-stability, gas barrier properties and transparency. It is also lightweight, shatter-resistant and recyclable.
Petrochemical	Chemical derived from petroleum and natural gas.
PFAS	Perfluoroalkyl and Polyfluoroalkyl substances, which are widely used, long lasting chemicals, the components of which break down very slowly over time. Also known as "forever chemicals."
PGA	Polyglycolic acid, which is commonly used for dissolvable stitches in the medical field.
PHA	Polyhydroxyalkanoate, a naturally occurring family of biodegradable polyesters.
PLA	Polylactic acid, a biodegradable polyester produced from lactic acid, used in wide range of service ware products and as filament for 3D printing.

Polymer	A chemical compound that contains a large number of recurring molecular repeating units. A plastic material is a type of polymer, typically modified with additives, which can be molded or shaped by pressure and temperature.
PP	Polypropylene, a recyclable polyolefin that is commonly used for margarine tubs, microwaveable meal trays, also produced as fibers and filaments for carpets, wall coverings and vehicle upholstery.
PS	Polystyrene
PTT	Polytrimethylene terephthalate, a type of polyester that differs from the common one polyethylene terephthalate (PET), as it contains one more methylene group in the aliphatic chain that links the terephthalic moiety.
PVA/PVOH	Polyvinyl alcohol, a compound soluble in water and used in food packaging among other uses.
PVC	Polyvinylchloride
RCC	Retail Council of Canada
RCRA	Resource Conservation and Recovery Act (US)
Recyclable	The report uses the term "recyclable" as defined by the Ellen MacArthur Foundation. According to the Foundation, plastic packaging is termed recyclable "if its [the packaging or packaging component's] successful post-consumer collection, sorting and recycling is proven to work in practice and at scale." In practice implies that the recycling system 'effectively recycles a significant share of all packaging of that type' placed on the market. At scale implies that recycling needs to 'to be proven to work in practice in multiple regions' representing a significant population size (Ellen MacArthur Foundation and UN Environment Programme 2020). The suggested threshold to assess if packaging is recyclable "in practice and at scale" is: achievement of a 30% post-consumer recycling rate in multiple regions representing 400 million residents at minimum or (if focusing on more local scales) in all markets where packaging is sold (Ellen MacArthur Foundation and UN Environment Programme 2020).
Renewable	Material made from natural resources that can be replenished.
Residual waste stream	The waste that is remaining following the separation of recyclable waste and, potentially, organic waste. Typically treated at end-of-life by landfilling or incineration (with or without energy recovery).
SHW	Special handling waste. Waste generated in productive processes, which does not meet the characteristics to be considered hazardous or urban solid waste, or which is produced by large generators of urban solid waste.
SKU	Stock keeping unit
Starch blends	The majority of bio-based plastics are currently manufactured using starch as a feedstock (c.a. 80% of current bio-based plastics). The current major sources of this starch are maize, potatoes, and cassava. Other potential sources include arrowroot, barley, some varieties of liana, millet, oats, rice, sago, sorghum, sweet potato, taro and wheat (WRAP 2020).
SUP	Single-use plastic
SUPPR	Single-use Plastics Prohibition Regulations (Canada)
Technically recyclable	"Technically recyclable" only considers whether the recycling of packaging into a new product is technically feasible and does not consider, unlike the term "recyclable," the successful and economically viable collection, sorting and recycling in practice and at scale.

USCC	United States Composting Council
USDA	United States Department of Agriculture
Urban solid waste	Urban solid waste, equivalent to municipal solid waste in the US and Canada. Waste generated in homes, resulting from the elimination of materials used in domestic activities, from the consumption of products, their containers, packaging or wrappings; waste from any other activity within establishments or on public roads with domiciliary characteristics, and waste resulting from the cleaning of public roads and places.

Abstract

This document is one of a set of three milestone studies prepared by Eunomia Research & Consulting on behalf of the Commission for Environmental Cooperation (CEC). These studies cover the markets and policy landscapes for post-consumer paper, plastics, and bioplastics waste from both residential and commercial sources in North America. Their purpose is to assess the current state of recycling in the paper, plastic, and bioplastic material markets as a contributor to a circular economy, identifying barriers to recycling and making recommendations for how to overcome these barriers and thereby increase circularity. This study focuses on Canada and the United States, and covers bioplastics, specifically covering all discarded bioplastics, prior to any decision on whether they are suitable for recycling or composting. A similar study focused on Mexico will be available in the upcoming months.

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1 Introduction

1.1 Background to Study

The World Bank estimates that approximately 2 billion tonnes of municipal solid waste were generated in 2016, with Canada and the United States generating 0.4–1.5 kg more waste per capita per day than the global average (Kaza, Yao, et al. 2018). North America has the highest per capita plastic and paper consumption in the world. The region represents 21% of total plastics consumption (Heller, Mazor and Keoleian 2020) and four times the global average in per capita paper consumption (Haggith, et al. 2018).

According to the World Bank, while waste is generally managed in an environmentally sound manner in North America, the global mismanagement of waste is polluting the oceans, clogging sewers, and causing flooding, transmitting diseases, and increasing respiratory problems and, according to 2016 data, generating 1.6 billion tonnes of carbon dioxide.

Reducing waste and closing material loops will help minimize the environmental impacts along the value chain of resources and products, as well as presenting considerable economic opportunities. Circular economy strategies, including various recovery options, are estimated to unlock US$4.5 trillion of economic growth around the globe (Accenture 2015). The World Business Council for Sustainable Development estimates that the global bioeconomy market could be worth up to US$7.7 trillion by 2030, with significant opportunities for circular solutions.

The transition to a circular economy and increased material recovery also offers solutions to mitigate climate change. The magnitude of avoided GHG-emissions benefits from material circularity is highly dependent on the type of material and the local circumstances for energy offsets. For example, the US EPA estimates that recycling of various paper products could result between 2.64 to 3.59 Mt CO_2e reduction per short ton of paper (ICF International 2016), and a study of the Canadian plastic sector estimates that diverting 90% of the plastic waste now going to landfills could result in 1.8 Mt of CO_2e reduction by 2030 (Deloitte and Cheminfo Services Inc. 2019).

The Commission for Environmental Cooperation (CEC) was established in 1994 by the governments of Canada, the United Mexican States (Mexico), and the United States of America (United States) through the North American Agreement on Environmental Cooperation, a side agreement concluded in connection with the North American Free Trade Agreement (NAFTA). As of 2020, the CEC operates in accordance with the Environmental Cooperation Agreement, which entered into force at the same time as the new trade agreement known as CUSMA, T-MEC and USMCA in each of these three countries, respectively. The CEC brings together a wide range of stakeholders, including the general public, Indigenous people, youth, nongovernmental organizations, academia, and the business sector, to seek solutions to protect North America's shared environment while supporting sustainable development for the benefit of present and future generations.

The CEC has commissioned this study as part of its Operational Plan 2021 project "Transforming Recycling and Solid Waste Management in North America,"[1] with the goal of promoting circular economy and sustainable materials management approaches and bring economic and environmental benefits to the region. This project supports Canada, Mexico and the United States in their efforts to promote circular economy and sustainable materials management approaches to encourage eco-design and thus increase product and material reuse, recovery, and recycling rates.

This publication represents one of a series of three milestone studies aiming to better understand the opportunities for the recycling sector and secondary material markets for paper, plastics, and bioplastics waste. The content focuses on the US and Canada, and a separate set of these studies focused on Mexico will be available in the upcoming months. Building on the results of these milestone studies and stakeholder input, the project will carry out pilot testing projects in a second phase to assess the feasibility of innovative technologies, policies, or practices for adoption at scale across North America.

1.2 Study Overview

This milestone study covers post-consumer bioplastics waste, from both residential and commercial sources, while the two other studies focus on paper and conventional plastics waste respectively. For this study, we have focused on the largest application of bioplastics in the US and Canada: packaging, including food service ware.

The information this study presents is designed to support stakeholder collaboration and knowledge sharing and provide policy makers with recommendations for improving the management of bioplastics in the US and Canada. Information was gathered through secondary research analyzing existing relevant publications and databases, and primary research through consultation with key stakeholders in bioplastics waste management in each country. This study considers the information and data available by December 2023.

This study encompasses:

- The definition of "bioplastics," including the different types of bioplastics and material groups this term encompasses;
- An overview of the value chain for bio-based and/or biodegradable plastics and key actors within it;
- An overview of the bioplastic waste market, including the current state of bioplastic production, waste generation and waste management;
- Market trends for bioplastics production and demand;
- Current and emerging policy and regulation related to bioplastics and bioplastic waste;
- Best practice, and key additional considerations and challenges for the role of bioplastics in a circular economy; and
- Findings and recommendations to improve the circularity of bioplastics in the US and Canada.

[1] CEC Operational Plan 2021 project "Recycling and Solid Waste Management in North America."

2 Value Chain Overview

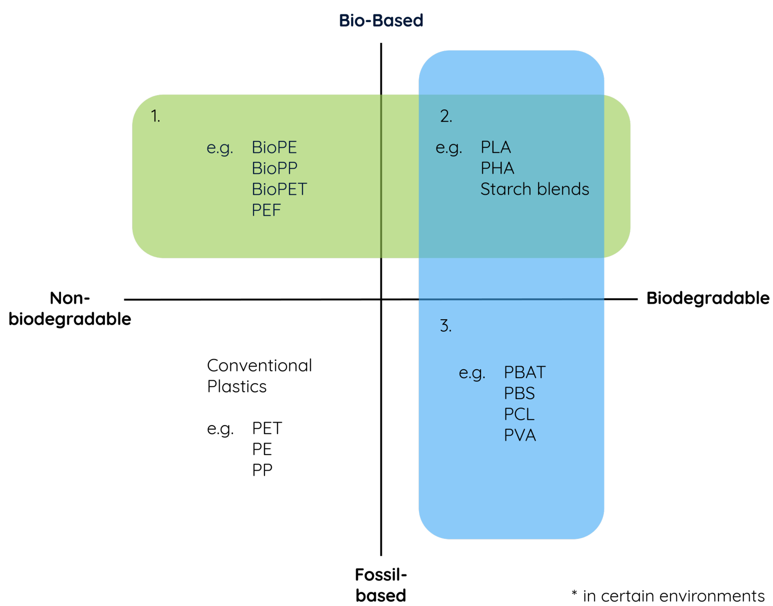
2.1 What are "Bioplastics"?

The term "bioplastics" is problematic, as it encompasses several materials with distinct properties, raw material inputs, production processes, and end-of-life management requirements (see Figure 1). This section introduces and explains the differences between these and defines the terminology this study will use to refer to them. This is important to avoid confusion not only for the reader but for consumers and stakeholders in knowing how to manage these materials and products made from them at end-of-life. It is also important for understanding and decision-making around the best uses of these different materials and the role they can play in a circular economy.

Figure 1 illustrates the two main components to consider when defining a type of plastic (these form the axes):

- The raw material input used to make the plastic (bio-based or petrochemical/ fossil-based); and
- Its physical properties (non-biodegradable or biodegradable).

Figure 1. Material coordinate system of different types of bioplastics



Source: Adapted from (European Bioplastics 2022)

Figure 1 shows the three main groups of "bioplastics," all of which are distinct from conventional plastics that are made from non-renewable, fossil-based/petrochemical raw materials (e.g., crude oil) and do not biodegrade within timescales practical for recovery systems. To biodegrade means to decay or to be decomposed naturally by bacteria or living organisms into harmless products (water, carbon dioxide and/or methane, inorganic compounds and biomass). Plastics that do biodegrade (biodegradable plastics) have the potential to be industrially composted or anaerobically digested. Furthermore, biodegradable plastics can technically be recycled, though the material is not currently recyclable at scale.

Henceforth in this study, these three main groups of "bioplastics" will be described as (refer to Table 3 in section 3.1.1 for more detail on the most common bioplastic polymers, their bio-based content and feedstock, producers and uses):

1. **Bio-based, non-biodegradable plastics**—these are made from renewable raw materials (bio-based), e.g., starch, glucose, vegetable oils, and cellulose from plants such as sugarcane, corn, or beets, and do *not* biodegrade. Examples of these include bioPP (biopolypropylene), bioPE (biopolyethylene), bioPET (biopolyethylene terephthalate). These are often referred to as "drop-ins" because they have the same chemical structure as their conventional plastic counterparts, e.g., PP, PE, PET, can be used for the same applications and can be treated in the same way at end-of-life, e.g., mechanically recycled (Hann, et al. 2020).
2. **Bio-based, biodegradable plastics**—these are made from renewable raw materials (bio-based) and *do* biodegrade (often only under certain conditions). Examples of these include PLA (polylactic acid, a compound from fermented plant starch) (Farah, Anderson and Langer 2016), PHA (polyhydroxyalkanoate, a compound produced by micro-organisms such as bacteria) (Adnan, et al. 2022) and starch-based plastics. These are the common types of "bioplastics" which comes to mind for the average consumer: a plastic made of renewable raw resources that is also biodegradable and can often be composted.
3. **Fossil-based, biodegradable plastics**—these are made from non-renewable, fossil-based/petrochemical raw materials, e.g., crude oil, and *do* biodegrade. Examples of these include PBAT (polybutylene adipate terephthalate), PBS (polybutylene succinate, a plastic with similar properties to polypropylene film) (Jacquel, et al. 2011), and PCL (polycaprolactone, a compound used in place of polyurethane (PU) plastic and has been found to be degraded by certain micro-organisms) (Tokiwa, et al. 2009). One of the most well-known examples is PGA, or polyglycolic acid, which is commonly used for dissolvable stitches in medicine (Chu 2013).

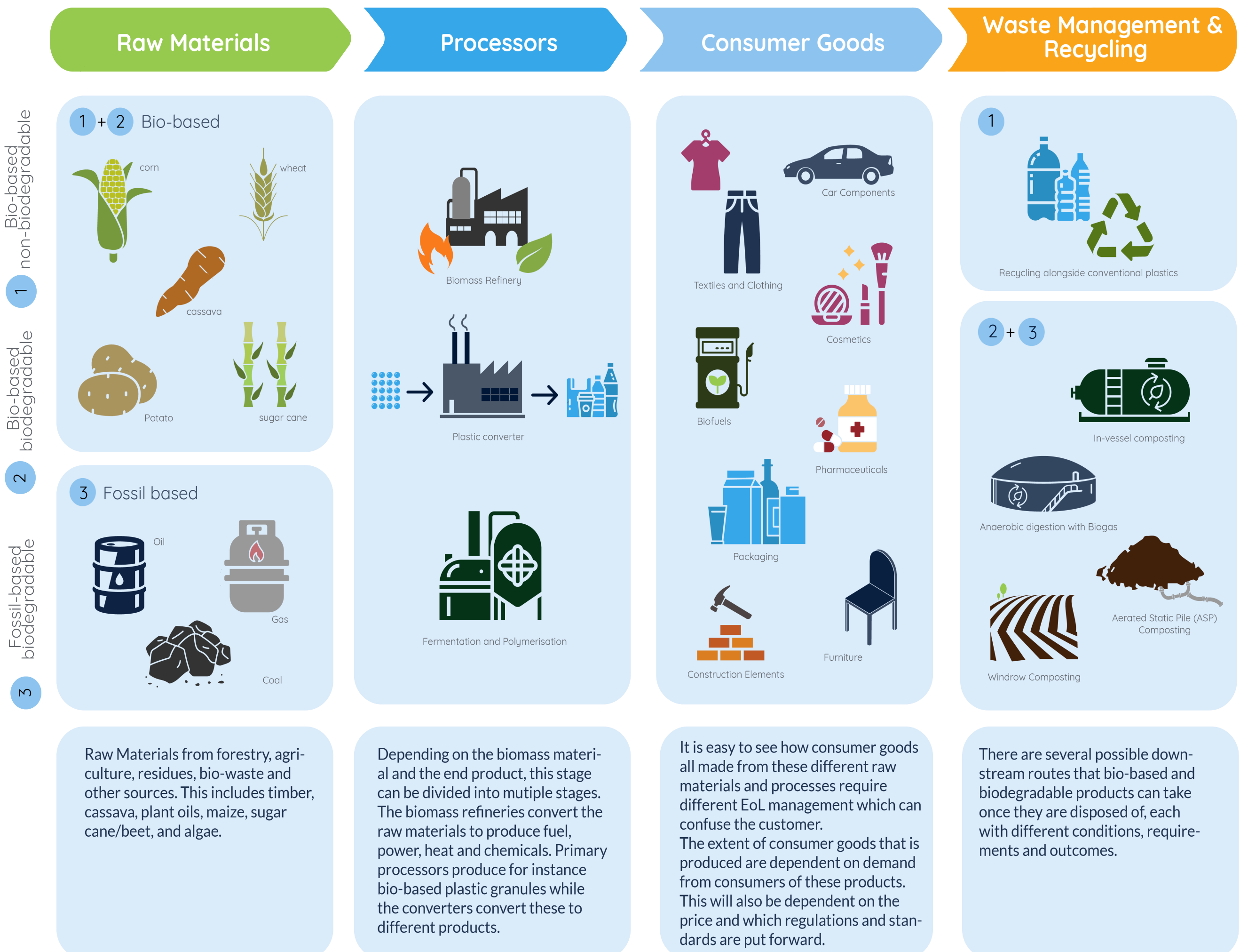
Regarding biodegradable plastics (both fossil- and bio-based), this report focuses on packaging. It is also important to make the distinction between biodegradable and compostable plastic (see detail in section 2.2.3): biodegradable plastic must be certified as compostable before it can even be considered for collection and end-of-life treatment.

This study does not cover "oxo-biodegradable"/ "oxy-biodegradable"/ "oxy-degradable"/ "oxo-degradable"/ "oxo-fragmentable" plastics, commonly used in single-use products and packaging such as carrier bags, blister packaging, bottles and film. These are materials of concern since they are modified conventional polymers with additives to accelerate fragmentation, leading to the production of microplastic pollution. Consequently, many countries and organizations worldwide support the banning of oxo-degradable plastics, including the European Union where they are already banned (Ellen MacArthur Foundation 2019).

2.2 Value Chain Summary

The value chain for all three of the "bioplastic" groups described above begins with the production of raw materials. These raw materials are then converted into many different bio-based and/or biodegradable plastic products by various processes, and these products have different end-of-life management requirements. Figure 2 provides a simplified overview of the value chain for the production of bio-based and/or biodegradable plastics, including examples of the different input feedstocks and processing technologies used for different industrial applications and products, and the possible waste management options. The following sections give more detail on each component of the value chain.

Figure 2. Bio-based and biodegradable plastics value chain



Source: Eunomia Research & Consulting

2.2.1 Raw Materials

Both biodegradable and non-biodegradable bio-based plastics use renewable biomass feedstock deriving from plant, animal, fungal and algal sources such as sugar cane, sugar beet, corn, potato, wheat, cassava, as well as waste and byproducts from the food and agricultural industries. The production of bio-based plastics usually relies on abundant and low-cost raw materials for the most cost-effective manufacturing process, which creates a large range of variation in the feedstock of bio-based plastics.

Fossil-based biodegradable plastics use the same feedstock as conventional plastics: crude oil, natural gas and coal.

There may be environmental benefits associated with bio-based plastics due to feedstock being renewable and containing biogenic carbon (sequestered from the air) rather than fossil carbon (locked up in the geology for millions of years). However, consideration should be given to the true sustainability of different biomass feedstocks, including the required water consumption and agricultural inputs, potential land-use change and the risk of deforestation.

The majority of bio-based plastics are sourced from first generation feedstock: carbohydrate-rich crops that can alternatively be used as food or animal feed. Therefore, there are concerns around environmental impacts and the land footprint of producing first-generation bio-based plastics, due to potential competition with food resources resulting in land use change. Current estimates place land use for bio-based plastic production as 0.8 million hectares in 2022, globally. This accounts for 0.015% of the global agricultural land area (~5.0 billion hectares) (European Bioplastics 2022). However, a 2020 study estimated that if bioplastics were to replace all conventional plastics used in packaging globally, it would require a minimum of 61 million hectares of land (an area about as large as the US state of West Virginia) and at least 388.8 billion cubic meters of water (Brizga, Hubacek and Feng 2020), more than ten times the amount of Canada's freshwater withdrawal in 2020 (Food and Agriculture Organization 2019). When focusing on bioplastic substitution of packaging in EU alone, authors found that bioplastic packaging production would require a mean 125 billion m^3 of water compared to conventional plastic production which requires, on average, less than 25 billion m^3 (Brizga, Hubacek and Feng 2020).

The same study above estimated the greenhouse gas (GHG) emissions associated with producing bio-based plastics to substitute conventional plastic packaging consumed in the EU, using results from life cycle assessments. Furthermore, bio-based plastic substitution in the EU would generate an average of 15 million tonnes of CO_2 equivalent emissions, about 73% lower than the average GHG emissions associated with conventional plastic packaging production (an average of 56 million tonnes CO_2 equivalent). However, several factors, including land-use change, can influence GHG emissions for bio-based plastic production and calculated emissions can thus vary widely (see section 6.1 for more detail) (Brizga, Hubacek and Feng 2020).

Further research needs to be completed in order to determine how land use for the production of first generation bio-based plastics may have unintended consequences on competition for land and reducing biodiversity (Simon 2022). Certification programs exist to help validate that bio-based plastic feedstock is sustainably and ethically sourced (e.g., RSB Global, ISCC Plus), although each scheme can be different in feedstock or geographical scope and in focus regarding minimum sustainability requirements (see section 2.3.2).

It is important to note, however, that crop residues are preferable to growing material specifically for bio-based plastic packaging. Research is being conducted into using second and third generation feedstock for bio-based plastic production. Second generation feedstocks include non-food crops (e.g., wood cellulose) and waste or byproducts from first generation biomass (e.g., food processing waste, agricultural waste). Using waste or byproducts can reduce the land footprint and other environmental impacts associated with the production of first generation bio-based plastics, however these second generation bio-based plastics have not reached a high degree of commercialization due to the high costs associated with feedstock pre-treatment and conversion (Wellenreuther, Wolf and Zander 2022) (Louw, Farzad and Görgens 2922). Third generation bio-based plastics use microorganisms (bacteria and algae) to directly source oils and sugars, though the technology is still in its developmental stages (Brizga, Hubacek and Feng 2020).

2.2.2 Primary Processors and Converters

The primary processing of raw material feedstock to produce bio-based plastics can include physical grinding, fermentation, digestion, filtration, dehydration and/or chemical processing. The feedstocks are further refined into isolated desired components, e.g., lactic acid, the main component of polylactic acid (PLA). This refining stage leads to the primary polymer, e.g., bio-based plastic granules, which are sold to converters to be made into products, e.g., packaging.

Some bio-based plastic products can be produced similarly to conventional plastics, for example, using blow molding, injection molding, and other methods. These products will be sold to brand owners who will oversee the design to their specifications and decide how the product is used and marketed. Afterwards, the product is sent to retailers who sell the finished bio-based and/or biodegradable plastic product or packaging.

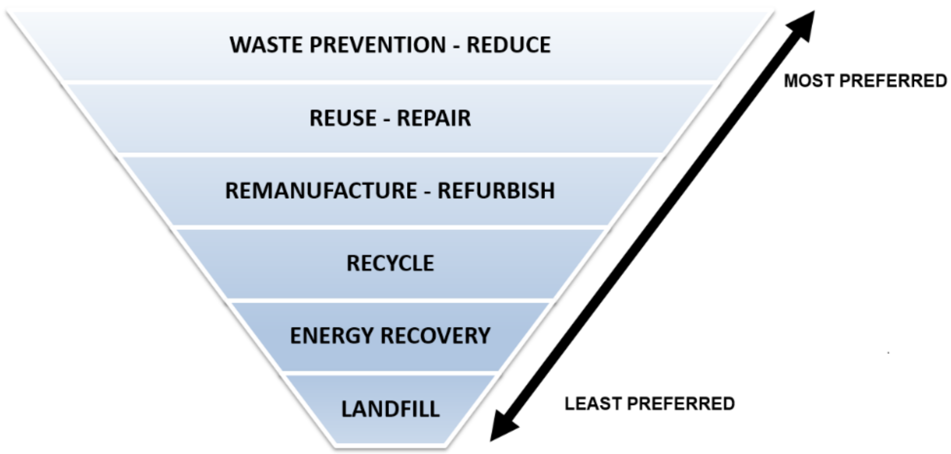
The main players responsible for bio-based plastic production are outlined in section 3.1.1. Between the US and Canada, the US has the highest number of bioplastic producers: NatureWorks, Danimer Scientific and Green Dot Bioplastics are all market leaders in the production of bio-based, biodegradable plastics (PLA, PHA and starch blends, respectively). Also based in the US, the Plant PET Technology Collaborative (PTC) is a market leader for the production of the non-biodegradable bio-based drop-in bio-PET. Though its bioplastics market value is approximately one-half that of the US market (at US$465.6 million, compared to US$870.5 million in 2021) (Global Data 2023), Canada is also one of the five largest producers of bioplastics globally (China, Germany, Brazil, and the US are the other four) (Global Data 2023). Some of the main Canadian producers include BOSK Bioproducts and TerraVerde Bioworks, which produce PHA polymers.

2.2.3 End-of-life Management

The waste hierarchy (Figure 3) outlines an order of preference for end-of-life management options in terms of their environmental impacts. Options that are best for the environment are at the top of the hierarchy, with less preferable options lower down, although the order can shift depending on specific circumstances. Recycling and composting are generally depicted on the same level, since both recycle valuable material back into the system—for organic waste, the nutrients in the organic matter are "recycled" back into the soil. In a circular economy, the objective is to establish closed-loop systems, reusing and recycling materials. In all circumstances, preventing waste in the first place is the preferred option. Incineration without energy recovery and landfill are typically the least desirable options and are not considered consistent with a circular economy. The role of incineration with energy recovery (waste-to-energy) in the circular economy is debated, but it is preferred to landfill in the waste hierarchy.

The following subsections discuss the different end-of-life management options for bio-based, non-biodegradable plastics and biodegradable plastics, and explain how recycling and composting of these materials can be more complex than for conventional plastics and organic waste.

Figure 3. The waste hierarchy



Source: (Government of Canada n.d.)

Bio-Based, Non-Biodegradable Plastics

Where plastics are collected for recycling, bio-based, non-biodegradable drop-in plastics should be co-collected with other recyclable conventional plastics. They can then be sorted and recycled alongside their conventional plastic counterparts since they have the same chemical make-up. For example, Coca Cola has produced the bio-PET PlantBottle© made of 100% bio-based PET (Coca-Cola 2021). This bottle can be recycled through the standard PET recycling stream as fossil-based PET.

Where plastics are not collected for recycling, these drop-ins will be sent to incineration or landfill along with other disposed waste. Incineration and landfill are not ideal disposal routes as they sit at the bottom of the waste hierarchy. However, when sent to incineration, bio-based plastics can generate lower net carbon emissions compared to fossil-based plastics, due to the sequestering of carbon during bio-based plastic raw material production (i.e., crop growing). Therefore, bio-based drop-ins can have an environmental advantage over their conventional counterparts when managed through less ideal treatment routes. In landfill they will behave in the same manner as conventional plastics, i.e., they will essentially be inert.

This is a complex area, however, and life cycle analysis (LCA) is often needed, for specific materials, to understand the impacts from manufacture and sourcing of different materials, including associated GHG emissions, water use and potential (in)direct land-use change (as mentioned in section 2.2). See section 6 for further detailed information.

Biodegradable Plastics

Both bio-based and fossil-based biodegradable plastics are designed to biodegrade, but the conditions in which they biodegrade vary. Few will fully biodegrade in “reasonable timeframes” directly in nature, on land or in water, meaning that they are not deemed nature biodegradable. Most biodegradable plastics will only biodegrade under certain conditions, dependent on time, temperature, humidity and other factors.

Defining a “reasonable timeframe” for nature biodegradable plastics is extremely difficult given the wide variation in environmental conditions (e.g., temperature, sunlight, moisture, pH, mechanical stress, microbial communities, etc.) found in nature (Emadian, Onay and Demirel 2017). There are limited standards for nature biodegradability due to the challenges associated with re-creating diverse and fluctuating environmental conditions in the lab (Harrison, et al. 2018). Long biodegradation timeframes and the incomplete biodegradation of nature biodegradable plastics can lead to the accumulation of these plastics in nature and generate microplastics. Just like conventional plastic pollution, biodegradable plastic accumulation, including microplastic accumulation, in nature can negatively impact organisms and ecosystems (e.g., through the ingestion of microplastics) (Qin, et al. 2021).

To put this into context, the EU standard EN 17033 for biodegradable mulch films in agriculture (i.e., on soil) specifies test methods and evaluation criteria regarding the biodegradation, ecotoxicity, film properties, and constituents of the biodegradable mulch films, and requires 90% CO_2 conversion within 24 months in a soil biodegradation test. While this may be a realistic timeframe for biodegradable plastic, two years seems a long time in which to allow material to remain on land within the potential to harm wildlife or impact the food chain. The longer a plastic-like material is present, as a film or fragments, the greater the chance of harm, like entanglement or ingestion, and washing into watercourses. Consequently, while it is hard to be definitive, it seems more “reasonable” for a material to biodegrade in days or weeks rather than years, under typical weather conditions (rather than extremes) for a given location.

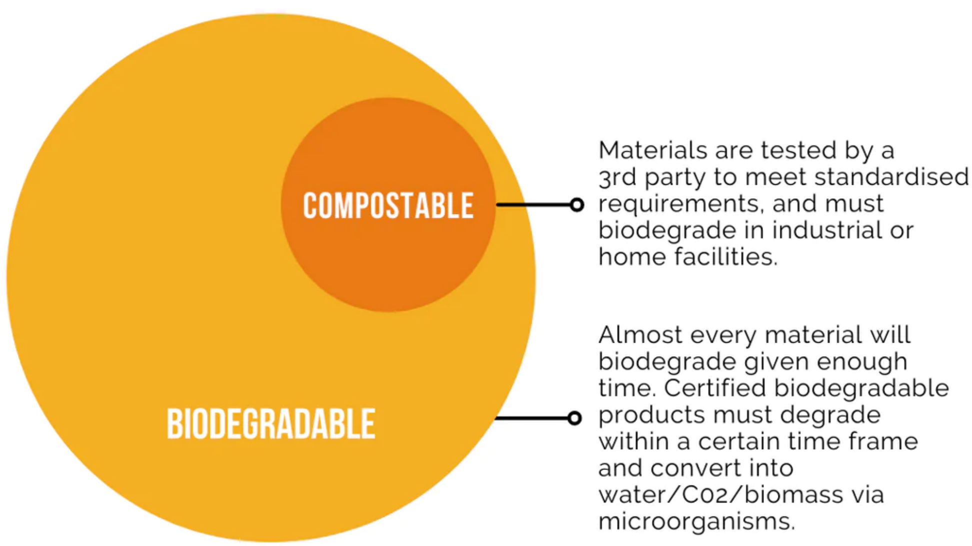
Relatively novel polymers such as polyvinyl alcohol (PVOH, a fossil-based and water-soluble plastic), Notpla (seaweed-based packaging) and Polymateria (polyolefins with additives to “enhance” biodegradability) are purported or marketed as nature-biodegradable, though greater efforts should be taken to further investigate these claims.

PVOH readily dissolves when placed in water and is commonly used in laundry and detergent capsule films. PVOH biodegradation is highly dependent on the presence of bacteria that can break down the polymer. Conditions in wastewater treatment plants vary and the ability for PVOH to biodegrade across these facilities is not fully understood and the polymer is likely being discharged into the environment (Rolsky and Klekar 2021). In uncontaminated water, including marine water, where bacteria are likely unacclimated to this type of waste, PVOH does not biodegrade and cannot be considered nature biodegradable (Allonso-López, López-Ibáñez and Beiras 2021).

Notpla is gaining popularity as a seaweed-based polymer that reportedly biodegrades within 4 to 6 weeks in home-composting conditions and shares similar status with other organic materials in terms of biodegradation in the environment (Notpla 2023). Polymateria also claims that their plastics are naturally biodegradable due to polymer additives that enhance the biodegradability of conventional polyolefins. The company claims that their plastic is not an oxo-degradable, which forms microplastics, but forms wax instead, which can be assimilated by microorganisms (Polymateria n.d.).

It is important to note that whilst all compostable plastics are biodegradable, not all biodegradable plastics are compostable (see Figure 4Figure) since specific environmental conditions and biodegradation timescales are required for composting and compostable plastic certification. Biodegradable plastics must be certified compostable to even be considered for organic waste treatment. The US State of California has increasingly discouraged the use of “biodegradable” (as well as continually strengthening the allowable definition of compostable) in an effort to minimize misleading claims (Cal. Pub. Res. Code § 42355 2021). Furthermore, there is another distinction between plastics compostable at home versus industrial facilities, where optimal conditions are maintained for decomposition. Adding to the complexity, plastics that are industrially compostable are therefore not always home compostable. Finally, whilst bio-based non-biodegradable plastics can be recycled, biodegradable and compostable plastics are typically non-recyclable at scale.

Figure 4. Not all biodegradable plastics are compostable



Source: (Invisible Company 2021)

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There are challenges associated with the identification, collection and sorting of biodegradable and compostable plastics, discussed in detail in section 3. Assuming that these materials are correctly identified, collected and separated, there are two potential circular waste management treatment options for them in the US and Canada: industrial composting and anaerobic digestion (AD). These are outlined below.

Given (1) the diversity of experimental methodologies used to compare biodegradability in anaerobic and aerobic conditions, (2) the wide-ranging polymer and product characteristics and (3) differences in composting operating conditions, there can be a significant variation in observed biodegradation (Ruggero, Gori and Lubello 2019). Given the difficulty in generalizing results across all compostable plastic products and composting technology configurations, field testing is especially important to ensure compostable plastics fully breakdown. This is discussed further in the next section (section 2.3) on standards and certifications for biodegradable and compostable plastics.

Industrial composting

Composting is an aerobic (in the presence of oxygen), biological process that involves the breakdown of organic materials by microorganisms into a biologically stabilized material (compost). Compost can then be used as soil amendment and/or fertilizer, by the agricultural, horticultural, landscaping, topsoil manufacturing and construction industries (e.g., for erosion control) amongst others.

There are three common composting options for plastics that are certified industrially compostable: windrow composting, aerated static pile (ASP) composting and in-vessel composting (IVC) (see Figure 5 for an overview of each technology) (EREF 2021). Composting facilities can use different methods to incorporate oxygen into the compost, including passive or active aeration. Anaerobic digestion (AD) is the biodegradation of organic waste by microorganisms, without oxygen. AD is not commonly used in the US and Canada; however, the number of AD facilities are increasing in Canada. In the US, there are some federal grant opportunities for AD projects (e.g., USDA's VAPG Program, AgStar sponsored by USDA and EPA, USDA's REAP Program), though these facilities can be controversial since they produce biogas and therefore can be seen as a waste-to-energy pathway.

Figure 5. Potential biological treatment options for biodegradable plastics

Photo Courtesy ECS

Photo Courtesy Regen Monterey

Windrow composting, in which organic waste is formed into rows of long piles and periodically turned, either manually or mechanically.

It is technically possible for **compostable** plastics to biodegrade in windrow composting.

Aerated static pile (ASP) composting, in which organic waste is mixed in a large pile and designed so that air can pass from the bottom to the top of the pile. Piles are often aerated with a network of pipes, or with air blowers that are activated by a timer or sensor.

In-vessel composting (IVC), in which organic waste is fed into a drum, silo, concrete-lined trench, or similar equipment. Inside, the temperature, moisture and airflow can be controlled, and material is turned or mixed to aerate it.

In most IVC systems, feedstock spends a limited time in the vessel, followed by ASP or windrowing; very few conduct 100% of their composting in the vessel.

Anaerobic Digestion (AD), in which bacteria break down organic waste without oxygen producing biogas and digestate.

Generally, AD plants are not set up to process compostable plastics and most facilities remove all types of plastic at the front end. Due to the absence of oxygen, compostable plastics are less likely to fully break down in AD plants, so, unless the facility has a secondary composting phase, this treatment option is problematic.

Source: Adapted from (Sustainable Packaging Coalition 2021); (US EPA 2022); (Biocycle 2019); (WRAP, The UK Plastics Pact 2020)

The ability of these different technologies to process biodegradable and compostable plastic depends on several factors including the timeframe for materials to break down (longer periods increase likelihood of complete biodegradation) and operating conditions such as oxygen levels, temperature and moisture levels (Sustainable Packaging Coalition 2021). Composting capacity for biodegradable and compostable plastics is also highly dependent on the facility's willingness to accept the materials in the first place.

Depending on the composting facility, some compostable plastic products may be more (or less) suitable for the system configuration and product being sold. Although compostable plastic can be accepted across all three industrial composting technologies, factors such as microbial diversity and activity, temperature, moisture and mixing can influence how quickly a compostable plastic biodegrades (Van Roijen and Miller 2022) (Sustainable Packaging Coalition 2021). Maintaining higher temperatures is especially important in improving biodegradation rates for both aerobic and anaerobic conditions (Ruggero, Gori and Lubello 2019). For example, PLA biodegradation is significantly slowed in cooler temperatures (i.e., under 50 °C) in aerated composting conditions as well as in anaerobic digesters (i.e., mesophilic conditions) (Van Roijen and Miller 2022)

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(Cazaudehore, et al. 2022). ASP and windrow systems can achieve and maintain high temperatures and are required to maintain these temperatures to reduce pathogens within compost. Some ASPs routinely operate at relatively high temperatures, for example at 77 ˚C. As with all systems, careful management of the system is required to ensure that the required conditions are met across all of the waste, which in windrow, for example, means care in how the material is turned and mixed.

Anaerobic digestion

AD is used to break down waste with microorganisms in the absence of oxygen, to create conditions that generate biogas (largely methane) to be used as an energy source, and a residual digestate that can be used as a nitrogen-rich fertilizer substitute (Pennington 2021).

There are differences between AD technologies arising from variation in operational specifications and technology design. Treatment of organic wastes can vary depending on the operating temperature (e.g., thermophilic, mesophilic), feeding-mode (e.g., continuous, batch) and solid content (wet versus dry). Wet AD systems operate at low total solids (less than 15%) and dry systems operate at high total solids (greater than 15%) (Pennington 2021).

Wet AD plants are restricted in the type of feedstock that can be fed into the reactor and produce digestate with a high-water content, leading to high costs associated with digestate treatment (sometimes split into a relatively dry fraction, and a liquid fertilizer). Dry AD systems offer benefits where there is a combination of organics, e.g., yard waste plus food waste. Additionally, digestate treatment costs can be reduced due to the lower water content of the residual digestate (Franca and Bassin 2020).

Challenges remain with optimizing dry AD systems. For example, high total solids content can lead to microbial inhibition from an accumulation of compounds such as ammonia and volatile fatty acids (Franca and Bassin 2020) (Wang, et al. 2023). Additionally, the methane production per kg of volatile solids produced by dry AD is lower compared to wet AD. Increasing water content has shown to improve biogas yields due to the dilution of inhibitors and improvements in homogenizing feedstock and promoting microbial interactions (Rocamora, et al. 2020).

Both types, dry and wet, can have secondary composting stages, where digestate is mixed with other organic waste such as yard waste, to improve product quality (Zeng, De Guardia and Dabert 2016).

It should be noted that certain compostables, such as PBS and PBAT, may not degrade easily within anaerobic digesters despite degrading well in aerobic conditions. On the other hand, starch-based plastics and PHB biodegrade in anaerobic digesters within a relatively short period of time across mesophilic and thermophilic conditions (Cazaudehore, et al. 2022). The retention time in the digester (often prescribed by facility economics) also plays a significant role in digestibility of compostable plastics.

Given (1) the diversity of experimental methodologies used to compare biodegradability anaerobic and aerobic conditions, (2) the wide-ranging polymer and product characteristics and (3) differences in composting operating conditions, there can be a significant variation in observed biodegradation (Ruggero, Gori and Lubello 2019). Given the difficulty in generalizing results across all compostable plastic products and composting technology configurations, field testing is especially important to ensure compostable plastics fully biodegrade.

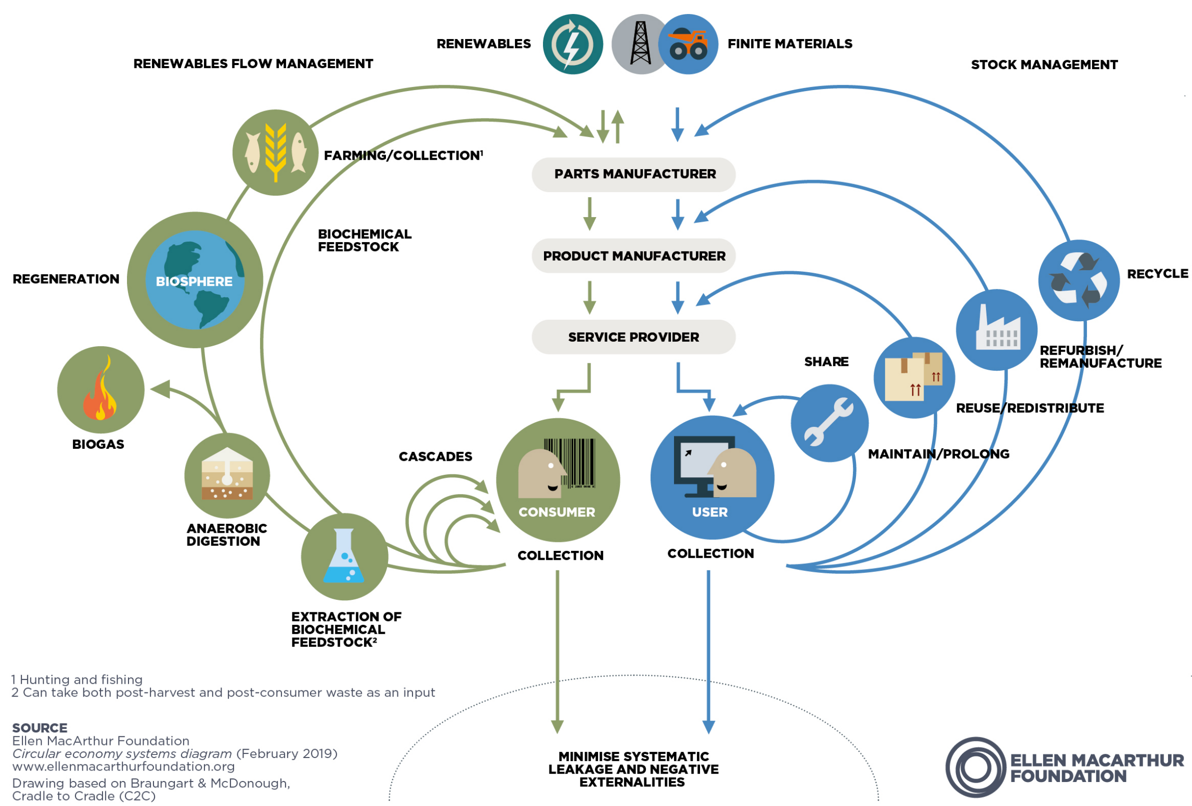
Current Infrastructure

Section 3.4 discusses existing waste management infrastructure in the US and Canada technically able to treat biodegradable plastics, as well as these facilities acceptance of these materials to give a more accurate indication of true treatment capacity. Challenges associated with identifying different biodegradable plastic types and their appropriate end-of-life management routes are discussed further in sections 3.3, 3.4 and 6.3.

Currently in the US and Canada, due to lack of collection programs and processing infrastructure able or willing to accept biodegradable plastics, most will be sent to incineration or landfill (this is discussed further in section 3). As with non-biodegradable plastics, incineration and landfill are not ideal disposal routes as they sit at the bottom of the waste hierarchy (see Figure 3). From a greenhouse gas emissions perspective, landfilling of biodegradable plastics should particularly be avoided.

As explained by the Sustainable Packaging Coalition, in landfills there is no completion of naturally occurring biological cycles as in the left-hand side of the Ellen MacArthur Foundation's well known circular economy "butterfly diagram" (see Figure 6). This is because landfills are engineered to prevent interaction between waste in the landfill and the surrounding environment. Organic waste in landfills biodegrades anaerobically (without oxygen), which generates much more methane than biodegradation at compost facilities (Sustainable Packaging Coalition 2021). Indeed, landfills are the third-largest source of anthropogenic methane emissions in the US (US EPA 2020). If a bio-based, biodegradable plastic cannot be biologically treated in a composting or AD facility, the best disposal route for it is in a waste-to-energy plant. However, waste-to-energy is not common across the US and Canada, making it important to regulate the appropriate use and waste management of biodegradable plastics to avoid them going to landfill.

Figure 6. The Butterfly Diagram: visualizing the circular economy



Source: (Ellen MacArthur Foundation 2019)

2.3 Standards and Certifications in the US, Canada, and the EU

2.3.1 Certifying Bio-Based Content

Bio-based polymers are often blended with conventional fossil-based polymers, and there is a need to identify the proportion of a final product's bio-based content. Without this approach, products can be misleadingly advertised as sourced from renewable feedstock, when bio-based polymers make up only a small proportion of the product weight.

There are two approaches to determining bio-based content in products:

- The bio-based biomass content approach, where the biomass is calculated as a percentage of the total mass of the product; or
- The bio-based carbon content approach, where the bio-based carbon is expressed as a percentage of the carbon contained in a product. Within this approach, carbon can be calculated by mass, total carbon content or by total organic carbon content.

Depending on the approach used, the calculated and certified bio-based content for the same product can vary significantly (Willemse and van der Zee 2018).

The American Society for Testing and Materials (ASTM) D6866 is the one US standard used for determining bio-based content in products, which uses the total organic carbon content approach. Inorganic carbon is not considered in the calculation and treated as if it were not present within the product, meaning that the bio-based organic carbon is divided by the total organic carbon in a product (TÜV Austria n.d.). The USDA BioPreferred Program, which requires the federal purchasing of bio-based products (both non-biodegradable and biodegradable), certifies products as bio-based subject to the product passing a minimum bio-based content threshold depending on product type (see Table 1). The certification uses the ASTM D6866 standard to calculate products' bio-based carbon content (Okamoto, et al. 2019).

In the EU there are two standards available to calculate bio-based content. The EN 16640 uses the carbon content approach but considers both organic and inorganic carbon within the product. In other words, the standard calculates the bio-based organic carbon as a percentage of the total carbon content of the product. Conversely, EN 16785-1 is based on the biomass approach and takes the total amount of bio-based carbon, hydrogen, oxygen and nitrogen and divides this by the mass of the product (Willemse and van der Zee 2018).

Finally, two international standards for bio-based content exist: ISO 16620-2 and ISO 16620-4 which determine the bio-based carbon and bio-based mass content for plastics respectively (TÜV Austria n.d.).

There are three large European certification schemes using varied standards:

- OK bio-based certification, owned and awarded by TÜV Austria (based on EN 16640), represented by a four-star classification system of bio-based carbon content (see Table 1). Products must have at least 30% total carbon and a bio-based carbon content of at least 20% (TÜV Austria 2020).
- DIN-Geprüft Bio-based owned and awarded by DIN CERTCO. The certifications are split into three quality levels: 20% to 50%, 50% to 85% and over 85% bio-based carbon content (see Table 1). The content is calculated based on the carbon approach and using the following standards: ASTM D6866 and/or ISO 16620 (parts 1 to 3). DIN requires a minimum threshold of 20% of bio-based carbon content and 50% of organic content for certification (DIN CERTCO 2020).
- Bio-based content label owned by the Royal Netherlands Standardization Institute (NEN) and awarded by TÜV Austria and DIN CERTCO (based on EN 16785-1) (see Table 1.) (NEN n.d.).

Of the three European labels for bio-based content, only the NEN label (see Table 1.) provides the specific level of bio-based content. The inconsistency of methodologies used across standards (ASTM, ISO and EN) and the associated bio-based content certifications means that labels are not always comparable to one another.

Table 1 compiles all the commonly used labels for bio-based plastics in the US and Canada mentioned here, as well as the labels used in Europe that may be found on products sold in the US and Canada.

Table 1. Certifications and labels for bio-based plastics and respective markets in which they are commonly used in the US, Canada, and the EU

Label	Certification Body	Reference Standard	Test Approach	Market
USDA CERTIFIED BIOBASED PRODUCT PRODUCT 86%	USDA	ASTM D6866	Measures total organic carbon content	US
OK biobased ≥20% and <40%; OK biobased ≥40% and <60%; OK biobased ≥60% and <80%; OK biobased ≥80% ≥80%	TÜV Austria	EN 16640	Measures total carbon content (inorganic and organic)	Europe; US & Canada
DIN Geprüft BIOBASED 20 - 50 %; DIN Geprüft BIOBASED 50 - 85 %; DIN Geprüft BIOBASED > 85 %	DIN CERTCO	ASTM D6866 and/or ISO 16620-2	ISO 16620-2: Measures bio-based carbon content	Europe; US & Canada
100% biobased PACKAGE ABC-12345	TÜV Austria and DIN CERTCO	EN 16785-1	Measures the biomass content	Europe; US & Canada

2.3.2 Certifying Material Origins and Chain of Custody

Although bio-based plastics are sourced from renewable feedstock, which can provide some environmental benefits relative to fossil-based plastics, careful consideration should be given to the potential negative effects. Increased production of bio-based polymers can generate (in)direct land-use changes and, through association with harmful agricultural practices, degrade soil and water quality, increase water consumption, increase deforestation, decrease biodiversity and generate carbon losses (e.g., through producing biomass on high carbon ecosystems) (as mentioned in section 2.2) (Daioglou, et al. 2020). Although second generation feedstock (e.g., agricultural waste) can potentially reduce the land footprint associated with first generation feedstock, most bio-based plastics placed on the market are sourced from first generation feedstock (Rosenboom, Langer and Traverso 2022). Standards and certifications are therefore necessary to prove that bio-based plastics are sustainably and ethically sourced.

There are several certification programs available for bio-based feedstock verification which can vary in scope and in terms of the sustainability requirements on which they are based. Examples of environmental and social criteria include water and soil quality, biodiversity, deforestation, agrochemical and genetically modified crop usage, energy consumption and GHG emissions, indigenous and community welfare, labor rights and gender equality. Additionally, certification programs can vary based on their governance systems (e.g., multi-stakeholder participation in standard setting) and auditing processes, such as the auditing frequency (Schlamann, et al. 2013).

Large and commonly used multi-stakeholder certification programs include the International Sustainability and Carbon Certification (ISCC Plus) and the Roundtable on Sustainable Materials Certification for Advanced Products (RSB Global) (Figure 7). Both programs use annual third-party auditing to ensure compliance with their environmental and social requirements (ISCC 2021) . The programs are considered to be amongst the most robust certification programs on the market due to their comprehensive coverage of environmental and social criteria and their relatively unrestricted feedstock, supply chain and geographical scopes (Schlamann, et al. 2013). RSB requires a minimum bio-based carbon content of 25% for product certification based on the EN 16640, ASTM D6866 or ISO 16620 standards RSB 2018).

Figure 7. ISCC and RSB corporate logos

Source: (ISCC 2022) and (RSB 2020)

ISCC Plus has a relatively strong emphasis on restricting agrochemical use, while soil quality and biodiversity are less of a focus (ISCC 2020) (ISCC 2021). Conversely, the environmental requirements under RSB have a stronger focus on biodiversity, water and genetically modified crop criteria, whilst there is less emphasis on agrochemical usage. Additionally, RSB introduced an optional module within their certification containing a criterion for biomass with low indirect land-use change (ILUC) risk (i.e., low risk of displacing land and shifting biomass production elsewhere). Low ILUC risk biomass can be certified as such if yield increases can be demonstrated without additional land conversion, if biomass was produced on non-arable land (degraded or unused) or if raw materials were sourced from existing supply chains (e.g., crop residues) (RSB 2016). Both programs provide good coverage of social sustainability criteria, though there are slight variations on the focus. RSB is more proactive with workers' rights and protecting local food security (RSB 2016) compared to ISCC Plus, which has a stronger focus on preservation of cultural heritage (ISCC 2020) (ISCC 2021).

Two well-known forest certification organizations include the Forest Stewardship Council (FSC) and the Sustainable Forestry Initiative (SFI), both established to promote the responsible and sustainable management of forests. Though bio-based plastics using wood as a feedstock have not reached a high degree of commercialization, FSC and SFI standards are relevant for certifying bio-based plastics sourced from wood. While, SFI covers the US and Canada, FSC is a global organization and has multiple standards across regional or national contexts. Both SFI and FSC have standards for forest management, responsible wood/fiber sourcing and chain of custody and both organizations require third party auditing with accredited certification bodies (Kadam, Dwivedi and Karnatz 2021) (SFI 2020).

Forest management standards from both organizations prohibit converting forests to another type of forest cover and generally prohibit the conversion of forest into non-forest uses, though FSC permits the latter under set conditions (SFI 2020). If a forest is SFI- or FSC-certified, these forest conversion criteria can help limit the scale of land-use change that production of first-generation bio-based plastics might induce. About 201 million ha combined are covered by SFI and FSC certification in Canada and the US (SFI 2022) (FSC 2023), covering about 30% of forest land across the two countries (FAO 2023).

2.3.3 Standards and Certifications for Biodegradable Plastics

It is important that products claiming to be made of biodegradable plastic meet the relevant standards and are certified as such by independent third parties. Currently a lack of consistent labeling of compostable products across US and Canada– and internationally since these products can be produced elsewhere and imported – makes identification by consumers challenging and risks inappropriate disposal routes and resulting contamination of food waste or conventional recycling. It is also a challenge for personnel at waste management facilities to identify these materials; although automated de-packaging technology exists at some larger compost and AD facilities in US and Canada, they are not common and generally removal of packaging is a manual process.

In the US and Canada, the Biodegradable Products Institute (BPI) is the main certification program for compostable products. BPI certification is based on the international ASTM standards D6400 and ASTM D6868 used to certify that packaging can be treated in industrial composting facilities (see Table 2). Both include multiple requirements that address issues of soil toxicity, disintegration, heavy metals and biodegradation (D6400 is for plastics, D6868 is for plastic and paper combinations). Apart from BPI, Compost Manufacturing Alliance (CMA) has a certification program to field test claims of industrial compostability of products against ASTM standards (Compost Manufacturing Alliance (CMA) 2023). In addition, five US states (California, Washington, Maryland, Minnesota) have some sort of labeling requirement for marketing biodegradable and compostable plastics, including Colorado which has just introduced one.

In Canada, the *Bureau de Normalisation du Québec* (BNQ) offers certification for industrially compostable bags and packaging products. The BNQ certification is based on CAN/BNQ 0017-088, which follows the international standard ISO 17088. However, the BNQ will withdraw the standard CAN/BNQ 0017-088 and will be transitioning to two new certification programs for compostable plastics (and other materials) based on the following standards: ISO 17088:2021 and ISO 18606:2013. According to the BNQ, these two new certification programs will be made available fall of 2023 (BNQ n.d.). BNQ is accredited by the Standards Council of Canada (SCC) and products certified "compostable" under BNQ can use the respective label (see Table 2). Though not yet enacted, the Government of Canada published a regulatory framework paper for recycled content and labeling rules for plastics, including compostable plastics (see section 5.2).

Two other certifications based on European EN standards may also be used on products sold in the US and Canada: the TÜV Austria OK Compost (industrial) certification based on the EN 13432 standard; and the European Bioplastic "Seedling" label based on the EN 13432 and EN 14995 standards (see Table 2). TÜV Austria also has a number of "OK bio-degradable" labels for "soil," "marine" and "water" (see Table 2) however these are not based on any international standards and real-world conditions vary enormously making them somewhat meaningless.

There is no US or Canadian certification for home compostability and no corresponding ASTM standard (Sustainable Packaging Coalition 2021). However, BPI is in the process of reviewing standards for home compostability to determine whether to create a home compostable certification program (BPI 2023).

In the EU, products may have the TÜV Austria OK Compost (home) certification (see Table 2) also based on EN 13432 but adapted to allow for biodegradation at lower temperatures of 20-30°C and time for reaching biodegradation extended to 12 months; time for reaching 90% <2mm is extended to 6 months and stricter limits on heavy metals and plant germination testing to guard against ecotoxicity. Another European certification program is the DIN CERTCO Home Compostable Certification Scheme (see Table 2), based on the French standard NF T51 800. The DIN CERTCO certification also requires over 90% biodegradation within 12 months and 90% disintegration (passing sieves less than 2 mm) within 6 months, in temperatures of 20 to 30°C (DIN CERTCO 2021). The French standard aligns with the EN 13432 for ecotoxicity testing (germination rate) and in limiting heavy metals, but also includes cobalt restrictions. NF T51 800 also restricts levels of certain organic substances such as endocrine disruptors and carcinogenic, mutagenic or toxic for reproduction (CMR) substances (Anses 2022).

Table 2 compiles all the commonly used labels for biodegradable plastics in US and Canada mentioned here, as well as the biodegradable, industrially compostable and home compostable labels used in the EU that may be found on products sold in the US and Canada.

Table 2. Certifications and labels for biodegradable, industrially compostable and home compostable plastics, and respective markets in which they are commonly used in US, Canada, and the EU

Label	Certification Body	Reference Standard	Test Conditions	Biodegradation Test Threshold*	Market
BPI COMPOSTABLE; BPI COMPOSTABLE IN INDUSTRIAL FACILITIES Check locally, as these do not exist in many communities. Not suitable for backyard composting. CERT # SAMPLE	BPI	ASTM D6400 and ASTM D6868	58°C ± 2°C	90% within 6 months	US and Canada
COMPOST MANUFACTURING ALLIANCE COMPOSTER APPROVED	CMA	Label awarded through field testing and not based on a standard. However, CMA only tests laboratory certified industrially compostable plastics.			US
COMPOSTABLE www.compostable.info	BNQ	CAN/BNQ 0017-088 to be replaced by ISO 17088:2021 and ISO 18606:2013**	58°C ± 2°C	90% in 6 months	Canada
OK compost TÜV AUSTRIA INDUSTRIAL	TÜV Austria	EN 13432	58°C ± 2°C	90% in 6 months	Europe; US & Canada
compostable	TÜV Austria and DIN CERTCO	EN 13432 and EN 14995	58°C ± 2°C	90% in 12 months	Europe; US & Canada

Label	Certification Body	Reference Standard	Test Conditions	Biodegradation Test Threshold*	Market
WATER OK bio-degradable TÜV AUSTRIA WATER SOIL OK bio-degradable TÜV AUSTRIA SOIL MARINE OK bio-degradable TÜV AUSTRIA MARINE	TÜV Austria	*Not based on any real standards for biodegradable plastics in uncontrolled conditions. The standards below are referenced for their test methods.* Water: EN 14987*** Soil: ISO 17556; ASTM D5988**** Marine: ASTM D6691*****	Water: 20°C to 25°C Soil: 18°C to 30°C Marine: 30°C ± 2°C	Water: 90% in 56 days Soil: 90% in 2 years Marine: 90% in 6 months	Europe; US & Canada
HOME OK compost TÜV AUSTRIA HOME	TÜV Austria	EN 13432 (adapted)	20°C to 30°C	90% in 12 months	Europe; US & Canada
HOME COMPOSTABLE DIN Geprüft	DIN CERTCO	NF T51 800	20°C to 30°C	90% in 12 months	Europe; US & Canada

* The percentage threshold for biodegradation into CO2.

** The BNQ certification based on standard CAN/BNQ 0017-088 will be withdrawn following a transition period to two new certifications based on ISO 17088:2021 and ISO 18606:2013. Both of these new standards have the same test conditions and biodegradation thresholds as CAN/BNQ 0017-088.

*** EN 14987 is the test method for the biodegradability of plastics in wastewater treatment plants, which are used as a proxy for freshwater environments.

**** ISO 17756 and ASTM D5988 contain test methods for determining the aerobic biodegradability of plastics in soil.

***** OK biodegradable certification for marine environments was originally based on ASTM D7081, a standard for non-floating biodegradable plastics in the marine environment. However, ASTM D7081 was withdrawn in 2014 and has yet to be replaced. ASTM D6691 contains the test method for determining aerobic biodegradation of plastic materials in the marine environment, however, it does not offer any pass/fail criteria (unlike the withdrawn ASTM D7081).

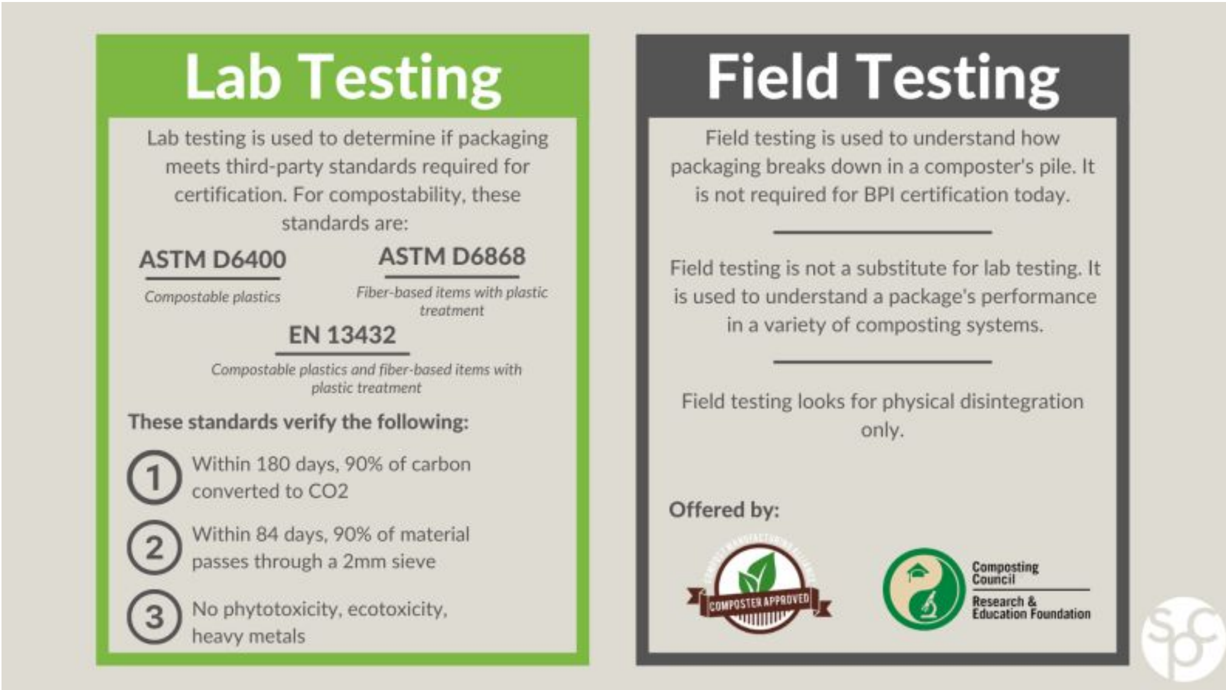
While certification agencies in the US and Canada (like BPI) have adopted ASTM standards D6400 and D6868, these standards are often criticized (by composters) for being both laboratory tests (not replicating real-world composting conditions) and because the time frame for biodegradation is 180 days, which is longer than the retention time in most commercial compost facilities. CMA conducts field tests in the US, across a range of industrial composting environments (aerated static pile, windrow, in-vessel composting) for products that have been approved "compostable" in the lab, to ensure that they will fully decompose in "real-world" conditions. Apart from depending on whether compostable plastic products pass laboratory and field testing, CMA certification is also dependent on whether:

- The product poses a contamination risk to composters by encouraging improper disposal of non-compostables (e.g., "come along" products);
- Collection systems exist for a compostable product so it can be properly disposed of; and
- The compostable product is related to food or yard waste (Compost Manufacturing Alliance (CMA) 2022).

CMA provides a list of products certified compostable, which technologies they can be composted in, and where affiliate facilities are in the US (Compost Manufacturing Alliance (CMA) 2023). Both BPI and CMA limit the levels of PFAS accepted in certified compostable products (Sustainable Packaging Coalition 2021).

In addition to this CMA testing, Closed Loop Partners and the US Composters and Composting Industry have recently begun a study to investigate in-field degradation of biodegradable plastics, the results of which aim to help clarify conditions and timescales required for biodegradable plastics to biodegrade (Closed Loop Partners 2023). Figure 8 outlines the differences between lab and field testing of the biodegradation of compostable packaging. Several entities have conducted in-situ (i.e., within composting facilities) testing of various compostable items over the last two decades, but material types, composting technologies, composting conditions and testing methodologies were not standardized. Given the vast differences in material types (and thicknesses) and composting conditions, gathering useful data from in-situ testing has proven challenging.

Figure 8. The differences between lab and field testing of compostable packaging in the US



Source: (SPC 2023)

2.3.4 Standards and Certifications for Compost and Digestate Quality

Compost or digestate quality reflects their performance, safety, visual and olfactory characteristics, and their capacity to successfully function in their end-applications based on these characteristics. Compost and digestate are commonly used to enhance soil characteristics for agricultural purposes (e.g., spreading digestate as a fertilizer). Certifying that compost or digestate meets quality standards is of high importance to facilities to ensure the resale value of their end-product is not diminished. Manufactured foreign matter (i.e., impurities) within compost often reduces its quality, regardless of whether impurities are of synthetic or biogenic origin. Compost quality standards therefore often contain restrictions on the amount of plastic impurities in the compost.

United States

The US has a national standard for compost acceptable for use in organic production systems (i.e., organic farming)[2] under the US Department of Agriculture's (USDA) National Organic Program (NOP). The NOP contains national standards for organic agricultural products sold within the US.

[2] There are multiple definitions of organic production, which can be based on published production standards. The FAO defines organic production as: 'a holistic production management system which promotes and enhances agro-ecosystem health…It emphasizes the use of management practices in preference to the use of off-farm inputs, taking into account that regional conditions require locally adapted systems. This is accomplished by using, where possible, agronomic, biological, and mechanical methods, as opposed to using synthetic materials, to fulfil any specific function within the system' (Codex Alimentarus Commission 2013, 2).

Furthermore, businesses can get their organic products certified as USDA Organic under the NOP (7 C.F.R. § 205.203).

Since the NOP regulates organic farming practices, the standards specify what compost is acceptable in organic systems. The NOP specifies that compost cannot contribute to contamination of the soil, water or crops, must meet processing requirements and cannot contain any synthetic substances not approved for organic farming as delineated within the National List of Allowed and Prohibited Substances (7 C.F.R. § 205.600). Biodegradable plastic is synthetic and a contaminant and is therefore prohibited as compost feedstock under the NOP (Kennedy 2019). The only biodegradable plastic "allowed" for use in organic crop production are biodegradable bio-based plastic mulch films, however no commercially available films meet the criteria set by the NOP (Miles, Madrid and DeVetter 2021).

Although compost manufacturers cannot certify their compost as organic, compost can be approved for use on certified organic farms. The Organic Material Review Institute (OMRI) is a well-known organization that lists compost products acceptable for organic farms according to the NOP standards (see Figure 9) (OMRI, 2023).

Figure 9. OMRI listed seal

Source: (OMRI 2023)

The US also has national standards related to the land-use application of sewage sludge biosolids (40 C.F.R. § 503), which can include biosolids anaerobically digested or composted (EPA 2022). However, there are no national standards for compost nor digestate quality produced from non-sewage sources and meant for conventional, non-organic farming.

However, states within the US do have their own standards for compost and digestate quality. For example, the Washington State Department of Transportation (WSDOT) specifies that manufactured inert material (including plastics) must make up less than 0.5% of compost on a dry weight or volume basis (WSDOT 2023). The California Department of Transportation (Caltrans) also has compost quality requirements across chemical, biological and physical parameters. For fine compost, physical contaminants like plastic (as a % of compost dry weight) must make up less than 0.5% and 0.1% of fine and medium/coarse compost (CalRecycle 2023). Other state Departments of Transportation (DOT), such as the DOT in Colorado, Oregon, Texas, Maryland and Iowa have compost specifications across applications as well (US Composting Council 2023). California (and other states) also has minimum standards regarding pathogen reduction, metals, and physical contamination. California requires a finished compost to contain less than 0.5 percent physical contaminants (glass, metal, plastics) greater than 4 mm. Of this 0.5%, less than 20 percent can consist of film plastic. (Cal. Code Regs. Tit. 14, § 17868.3.1).

Certification programs within the US include the US Composting Council's (USCC) Seal of Testing Assurance Program (STA). To gain STA certification, composters must comply with federal and state regulations on permitting and compost quality. The compost cannot surpass EPA limits on heavy metals and pathogens (in accordance with the national standards for biosolids) and must be regularly submitted for testing (US Composting Council 2023). There is no mention of physical impurities for general STA certification, however, gaining STA certification for consumer compost use requires meeting higher standards (Figure 10). Physical contamination for all three consumer compost use certifications under STA cannot surpass 1% of compost dry weight, however, less than 0.5% contamination is preferable (US Composting Council 2023).

Figure 10. STA Seal of Testing Assurance (STA) (A) and Compost Consumer Use Program Seals (B – D)

A B C D

Source: (US Composting Council 2023)

Canada

Canada has national standards for compost quality under its Guidelines for Compost Quality (Canadian Council of Ministers of the Environment 2005). These standards also include limits on pollutants and pathogens within compost and, unlike the US national standards for biosolids, contains restrictions on the amount of "foreign matter" in compost. Foreign matter is defined as any matter resulting from human intervention with organic and inorganic components over 2 mm in dimension (e.g., plastics). The standards specify that compost cannot contain more than two pieces of foreign matter, larger than 25 mm in any dimension per 500 ml of compost. Higher quality compost (Category A) can only have one piece of foreign matter.

Provinces can have their own standards for compost quality. For example, Ontario Ministry of Environment (MOE) categorizes compost according to three quality categories (AA, A or B) which are determined by the biological, chemical and physical limits and requirements of compost. Foreign matter limitations are stricter than those set within the Guidelines for Compost Quality (MOE 2012):

- The highest quality (category AA) compost cannot have total foreign matter greater than 3 mm exceeding 1% of compost dry weight. Plastic specifically cannot exceed 0.5% dry weight of compost. Additionally, the compost cannot contain any foreign matter greater than 25 mm per 500 ml.
- Category A compost follows the same foreign matter requirements set above.
- Foreign matter in category B compost (the lowest quality) cannot exceed 2% of the dry weight of compost. However, plastic still cannot exceed the 0.5% limit. Foreign matter larger than 25mm cannot be present within the compost.

Provinces can also set their own standards when it comes to digestate quality and application on land. For example, Ontario has provincial regulations on anaerobic digestate quality which requires that digestate only be applied to land if it has a total foreign matter and total plastics content of less than 2% and less than 0.5% based on dry weight respectively (Government of Ontario 2022).

The BNQ in Quebec developed a voluntary compost quality standard for industry (CAN/BNQ 0413-200) and offers certification for businesses that comply with the standard (BNQ 2016). Compost Council of Canada also has a voluntary Quality Assurance Program (QAP) for compost and digestate quality (Figure 11). The QAP ensures that compost and digestate manufacturers comply with national and provincial regulations and is meant to provide confidence to users that the product was tested for quality (Compost Council of Canada 2023).

Figure 11. Compost Council of Canada QAP for compost and digestate

Source: (Compost Council of Canada 2023)

Like the US, Canada has national standards for organic agricultural products (e.g., organic produce) and organic agricultural production systems (i.e., organic farming) (CAN/CGSB-32.310) (Standards Council of Canada and Canadian General Standards Board 2021). Acceptable feedstocks for compost and digestate include all products listed in the List of Permitted Items (CAN/CGSB-32.311). Biodegradable plastics are largely absent from the list of permitted products for soil amendments. Like the USDA standards, bio-based biodegradable plastic mulch films are permitted in crop production. However, these mulch films must be 100% biodegradable and fully bio-based, which is not commercially available. If biodegradable plastic is within feedstock for compost, the plastic must be proven to degrade within the composting process and be absent from the compost when applied as a soil amendment (Standards Council of Canada and Canadian General Standards Board 2021).

The Canada Organic Regime (COR) regulates organic agricultural products according to these national standards. Under COR, managed by the Canadian Food Inspection Agency (CFIA), products that meet the national standards can be certified organic (Government of Canada 2022). To meet standards for organic farming, manufacturers can get their soil inputs (i.e., compost or digestate) listed by OMRI which offers product reviews based on the COR standards (OMRI 2023).

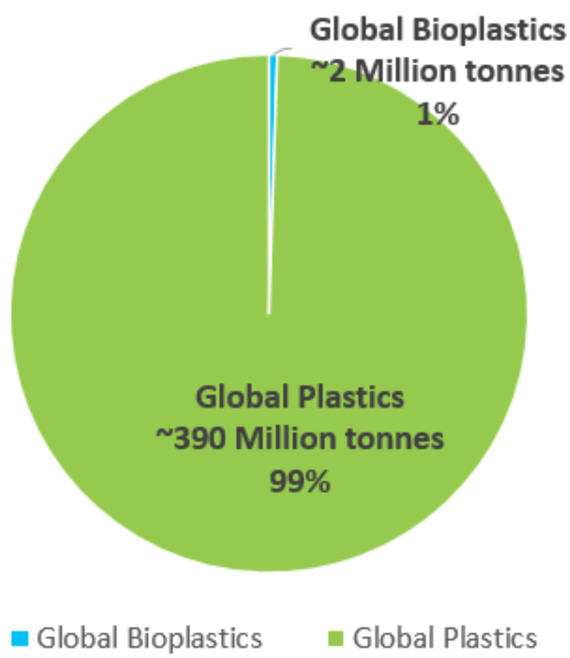
Across the US and Canada, though standards define foreign matter restrictions to maintain compost and digestate quality, they do not address microplastic pollution in the finished product. For example, Ontario MOE defines compost as the highest quality category if it does not have more than 0.5% of plastic matter greater than 3 mm in size (MOE 2012). Though this may seem like a small amount of plastic contamination, microplastics can be much smaller than 3 mm. This means that a standard is "allowing" microplastic contamination in the finished product, which can stem from conventional plastics entering facilities and even from compostable plastics that have not fully biodegraded within the treatment timeframe (see section 3.4 for information on contamination due to incomplete biodegradation). Microplastics in compost and digestate are already a problem and are incredibly difficult to remove from the finished product. Given that compost and digestate are often used to improve soils, any microplastic contamination can accumulate in the environment and potentially generate environmental and health impacts (Vithanage, et al. 2021) (Watteau, et al. 2018) (Porterfield, et al. 2023).

3 Market Overview

3.1 Bioplastics Production

Globally, the bioplastics market is relatively immature and still small-scale, comprising less than 1% of global plastics production at about 2 million tonnes (see Figure 12). Market data on bioplastics are very limited. The most well-trusted global production data available are reported annually by European Bioplastics.

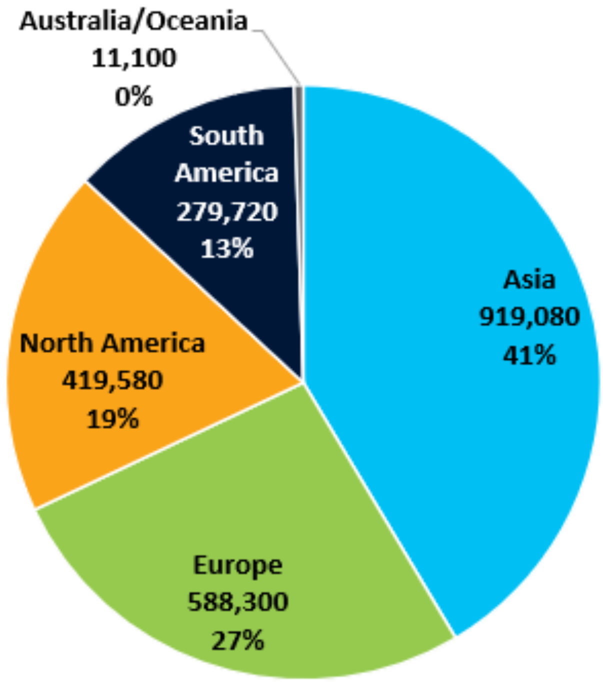
Figure 12. Global bioplastics production as a proportion of global plastics production



Source: (Statista 2023); (European Bioplastics 2022)

North America produces approximately 19% (about 420,000 tonnes) of all global bioplastics annually. As shown in Figure 13, this makes North America the third-largest producer of bioplastics after Asia (~40%) and Europe (~27%).

Figure 13. Global production capacities of bioplastics in 2022 (by region)

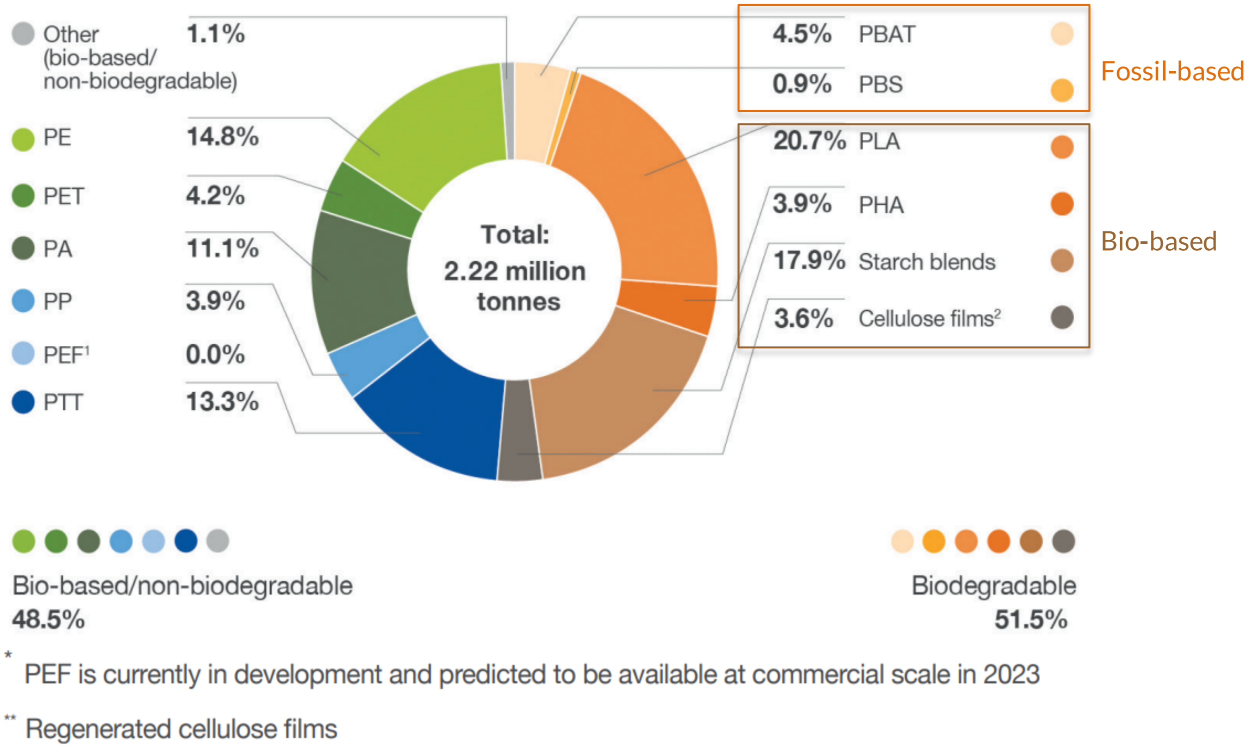


Source: Adapted from European Bioplastics (2022), https://www.european-bioplastics.org/market/

Of the ~2 million tonnes of all bioplastics produced globally each year, approximately half is designed to be biodegradable, and the other half is estimated to be bio-based but not biodegradable (European Bioplastics 2022). Figure 14 gives a more detailed breakdown of this split, showing the proportion of different material types that make up global bioplastic production. The top five bioplastics produced globally in 2022, which together made up over 75% of global bioplastics produced, were:

1. Bio-based and biodegradable PLA (approx. 21% or 460,000 tonnes) due to its particularly high use in packaging;
1. Bio-based and biodegradable plastics made from starch blends (approx. 18% or 400,000 tonnes);
2. Bio-based and non-biodegradable ("drop-in") PE (approx. 15% or 330,000 tonnes);
3. Bio-based and non-biodegradable polytrimethylene terephthalate (PTT) (approx. 13% or 290,000 tonnes); and
4. Bio-based and non-biodegradable polyamide (PA; nylon) (approx. 11% or 250,000 tonnes).

Figure 14. Global production capacities of bioplastics in 2022 by material type

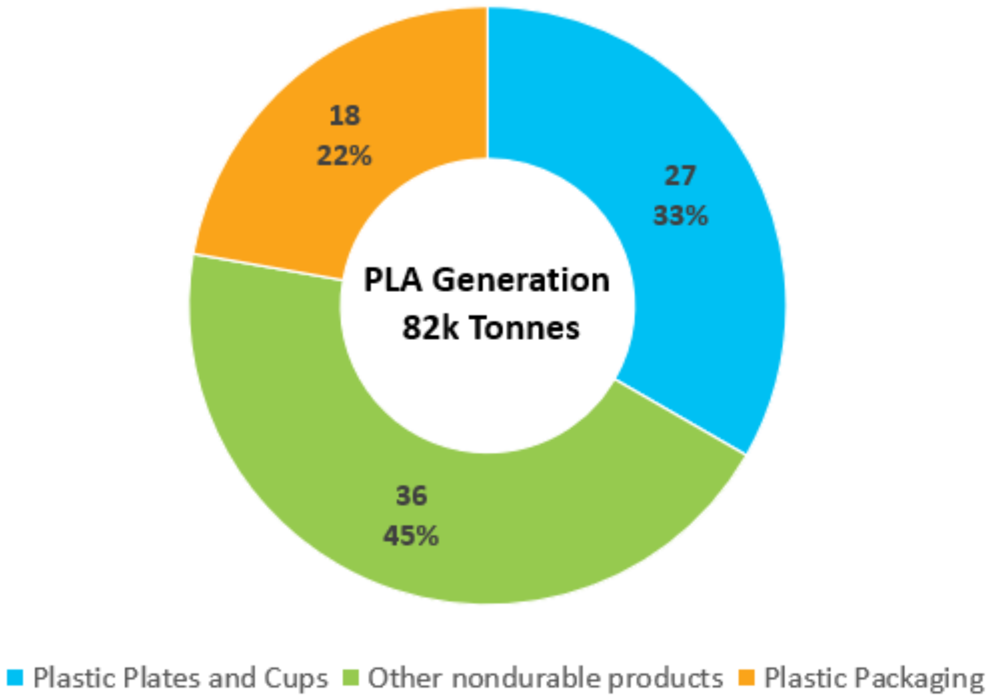


Source: Adapted from (European Bioplastics 2022).

The split of bioplastic types produced in the US and Canada is unknown. The only publicly available data on bioplastic production in the US and Canada are for PLA in the US, where an estimated 82,000 tonnes of PLA are produced annually, divided into three types of products, as shown in Figure 15:

- Packaging (18k tonnes);
- Plates, cups and cutlery (27k tonnes); and
- Other non-durable products (e.g., for use in clothing, footwear) (36k tonnes).

Figure 15: Generation of PLA in United States (in thousands of tonnes, 2018)

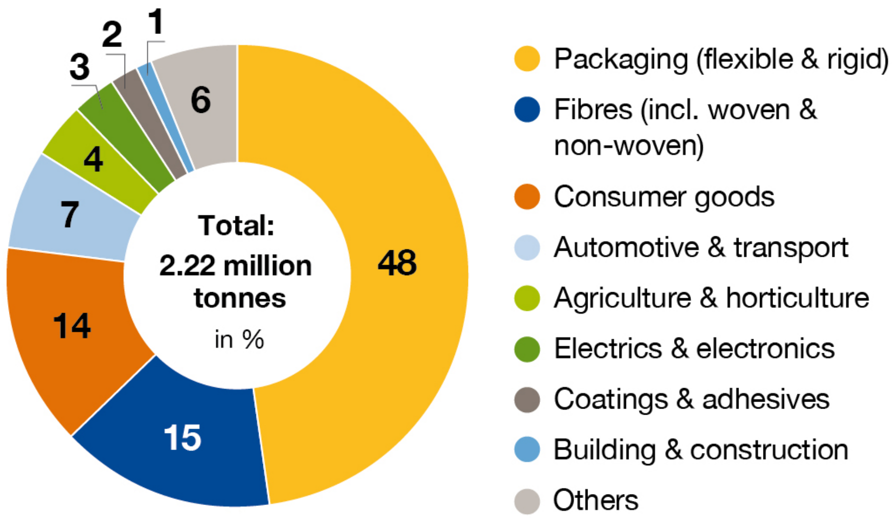


Source: (US EPA 2020).

As stated above, North America is estimated to produce roughly 420,000 tonnes of bioplastic per year. PLA generation in the US would therefore represent approximately 20% of all bioplastics generated in North America. This would indicate that the proportion of PLA generation as a percentage of all bioplastics in North America is greater than the proportion of PLA generation as a percentage of all bioplastics globally.

Despite the small market share of bio-based and/or biodegradable plastics compared to conventional plastics, they are already used for a wide range of product applications globally. These include packaging, consumer goods, textiles, agriculture, automotive, construction and electronics (see Figure 16).

Figure 16. Global production capacities of bioplastics by market segment (2022)



Source: European Bioplastics, nova-Institute (2022).
More information: **www.european-bioplastics.org/market** and **www.bio-based.eu/markets**

In the US and Canada, an even higher percentage of bioplastics are used in packaging applications, with the next most common applications being agriculture, consumer goods and textiles (Grand View Research 2022).

3.1.1 Key Bioplastic Producers and Uses

The bioplastics global market is dominated by 10 to 15 key industry players who process raw materials into bioplastics, and whose production patterns vary substantially. For instance, some global corporations are manufacturing hundreds of products, while others are manufacturing single resins in one factory. As noted above, the major players in the US and Canada are NatureWorks, Danimer Scientific, Green Dot Bioplastics, and Plant PET Tech Collaborative. These companies produce PLA, PHA, starch blends, and bioPET, respectively.

The commercialization of polyethylene furanoate (PEF), although a European venture led by Avantium in the Netherlands, is an important development, as PEF has the potential to replace PET in various applications since it has better gas and moisture barrier properties, and better strength characteristics, allowing less material to be used for a given application. While bio-based (from bioMEG, which is also used in bioPET, and FDCA, the focus of recent investment), it is only compostable over long timeframes.

Table 3 gives a global overview of different bioplastic materials, their typical bio-based carbon content, whether they meet common compostability certifications, typical feedstock used for production, market leaders in their production and where they are based, as well as the typical uses for that bioplastic material.

Table 3. Market overview of biodegradable and non-biodegradable plastic production at global level

Bioplastic Material	Typical bio-based carbon content	Common Compostability Certification	Feedstock	Market Leaders	Typical Uses
Bio-based and biodegradable					
PLA	100%	BPI Certified, OK compost industrial	Sugarcane, sugarbeet, corn, potato, wheat	NatureWorks (US), Total Corbion (Thailand)	Food service ware, bottles, bags, cups, tubs, cartons, coffee cups.
PHAs	100%	OK compost industrial & home	Sugarcane, sugarbeet, corn, potato, wheat	Danimer Scientific (formerly Meredian Holdings Group) (US), Yield10 Bioscience Inc. (formerly Metabolix) (Spain)	Food service ware, bottles, bags, packaging, medical.
Starch Blends	25-100%	Vary dependent on brand Mater-Bi: OK compost home & industrial	Varies dependent on brand e.g., corn, potatoes, wheat	Green Dot Bioplastics (US), Novamont (Italy)	Primarily compostable bin liners under Biobags brand
Bio-PBS(A)	20-100%	OK compost home & industrial	Sugarcane, sugarbeet, corn, potato, wheat	Mitsubishi Chemicals (Japan)	Films, bags, food and cosmetics packaging
Bio-based and non-biodegradable					
Bio-PET	100%	N/A	Most often sugarcane but possible with sugarbeet or starch	Indorama (Thailand, France), Plant PET Tech Collaborative (US), Braskem (Brazil)	Bottles, films, food packaging
Bio-PAs	30-100%	N/A	Sugarcane, sugarbeet, corn, potato, wheat	Arkema (France), Braskem (Brazil), DuPont (Switzerland)	Packaging, film, single-use bags
Bio-PE	100%	N/A	Sugarcane, sugarbeet, corn, potato, wheat	Avantium (Belgium), BASF (Germany), Braskem (Brazil)	bottles, textiles, food packaging, carpets, electronic materials and automotive applications

Bioplastic Material	Typical bio-based carbon content	Common Compostability Certification	Feedstock	Market Leaders	Typical Uses
PEF	100%	N/A	Sugarcane, sugarbeet, corn, potato, wheat	Avantium (Belgium)	Packaging, textiles, bottles, banknotes
Bio-PP	30%	N/A	Sugarcane, sugarbeet, corn, potato, wheat, or castor seed oil	FKuR (Germany)	Fibers, films, engineering
PTT	37%	N/A	Sugarcane, sugarbeet, corn, potato, wheat	DuPont (Switzerland)	Fibers e.g., textiles and carpets, food packaging, engineering.
Fossil-based and biodegradable					
PBAT	0 – 50%	OK compost industrial	Biomass	BASF (Germany)	Film, clingwrap, single-use bags, mulch films
PBS(A)	0 – 20%	OK compost home & industrial	Biomass	Mitsubishi Chemicals (Japan)	Films, bags, food and cosmetics packaging
PVA/PVOH	0%	N/A	None	Kuraray Europe GmbH (Germany)	Soluble containers, e.g., washing tablet, paper adhesive, thickener

Source: Adapted from (Hann, et al. 2020), (Eunomia Research & Consulting, Mepex 2019).

3.2 Quantities and Types of Bioplastics Entering Waste Streams

It is difficult to accurately determine the quantities and types of bioplastics entering specific waste streams in the US and Canada. As outlined in section 2.2.3, the two main bioplastic groups require different end-of-life management:

- Bio-based, non-biodegradable plastics are designed to be recycled alongside their conventional plastic counterparts; and
- Different bio- or fossil-based biodegradable plastics are designed to biodegrade in a variety of conditions. Those most suited to enter formal waste management are designed to be industrially composted, and in the US and Canada will most commonly be BPI certified and labelled (as explained in section 2.3 on standards and certifications).

Consequently, the quantities and types of non-biodegradable and biodegradable plastics entering waste streams are addressed separately in the following sub-sections.

3.2.1 Bio-Based, Non-Biodegradable Plastics

Bio-based non-biodegradable plastics look like their conventional plastic counterparts and should be clearly labelled for recycling, so consumers can place them in or take them to the appropriate recycling stream or drop-off center. Once in a waste stream, due to their identical appearance/chemistry to conventional plastics, and lack of targeted tracking or data collection of bio-based non-biodegradable plastics in waste streams, at a global level there are no data on, for example, what proportion of PET bottles disposed of are actually bio-PET bottles. Therefore, this study assumes that the quantities and types of bio-based non-biodegradable plastics entering waste streams are:

- The same as the quantities and types produced; and
- The quantities that are recycled versus incinerated, landfilled or lost to the environment will be in similar proportions to what happens to conventional plastics, depending on their different applications.

It is worth noting that new entrants into the market, most notably PEF, will complicate the picture, as these will need to be separated from bioPET, for example.

As outlined in the above section on bioplastic production, the majority of bio-based non-biodegradable plastics produced globally, and in the US and Canada, are used for packaging. Assuming they follow the same path through waste streams as their conventional counterparts, then of the approximately 85,000 tonnes bio-based, non-biodegradable packaging produced in North America, approximately 7,000 tonnes will be recycled. For detailed waste flows of different conventional plastics by polymer and application please refer to this study's sister publication "Milestone Study on Plastic Waste Management in the US and Canada."

3.2.2 Biodegradable Plastics

For any waste material to be treated in the most ideal way possible (i.e., at the highest possible level of the waste management hierarchy), it must be separated out from other non-target waste materials. To achieve the highest quality for recycling or composting, ideally waste material will be collected separately. If only multi-stream collection is possible then separation of target materials from non-target materials can happen at the sorting stage (e.g., in MRFs). Ideally certified compostable plastics would be collected alongside food and yard waste (organics waste) to make it to organic treatment facilities. However, neither Canada nor the US have policy or regulation that require separate collection of biodegradable or compostable plastics and there is limited or inaccessible data tracking of biodegradable plastics entering waste streams.

As discussed in more detail in section 3.3, access to organic waste collection programs that accept compostable plastics is low in the US and Canada. Additionally, biodegradable plastics that reach biological treatment facilities are often removed as discussed in more detail in section 3.4. In Canada, many food waste treatment facilities seek to remove compostable plastics because it is difficult for the pre-sorting step to discern the plastic which is compostable in the process versus the plastic which is not. As a result of this barrier, the organics facilities elect to screen out all plastic material, regardless of whether it is biodegradable or not.[3] Even when consumers place biodegradable plastics in the correct stream, it is likely that the material would be screened out at the treatment stage. This leads to the estimation that the majority of biodegradable plastic material is sent for landfilling or incineration.

No data are available on the tonnage of biodegradable plastics that enter composting streams at the national or continental level for the US and Canada.

There were a reported 1.6 million tonnes of food waste collected in the US in 2016 (BioCycle 2017). Multiplying this figure by 30% of households, with organics collection in areas that explicitly accept bioplastics, result in 502,000 tonnes of food waste collected in jurisdictions that accept bioplastics for organics treatment. Using Seattle's organics sort data, which shows that 4% of food waste in organics is compostable plastic, an estimated 19,600 tonnes of compostable plastics are sent to organics treatment facilities which accept compostable plastic material.

Combining the 19,600 tonnes of organics treated material with the estimated 7,000 tonnes of bio-based, non-biodegradable material which is sent for recycling from section 3.2.1, a total of 25,510 tonnes of bio-based and/or biodegradable plastic are estimated to be either sent for mechanical recycling, or organics treatment, although some of the latter are likely to be removed along with contaminants including conventional plastics. Based on this figure, there is likely to be a maximum recovery rate of ~6% for North America for all bioplastics.

This estimate may be overstating the recovery rate for bioplastic material, as there are poor accounting of bioplastic material flows, and this assessment assumes that treatment facilities are always processing the material they accept in the same way as other plastic/organics material. Additionally, there may be more bioplastic material entering the waste stream in the US and Canada with the addition of imported bioplastics for which there is no data.

3.3 Collection and Sorting Capacity

Bioplastics collection and sorting is dependent on local waste management policy and systems. As already stated, the three main bioplastic groups—and materials within them—have two different end-of-life requirements (other than landfill or incineration):

1. Recycling alongside conventional plastics for non-biodegradable "drop-ins," and
2. AD/industrial composting for biodegradable plastics.

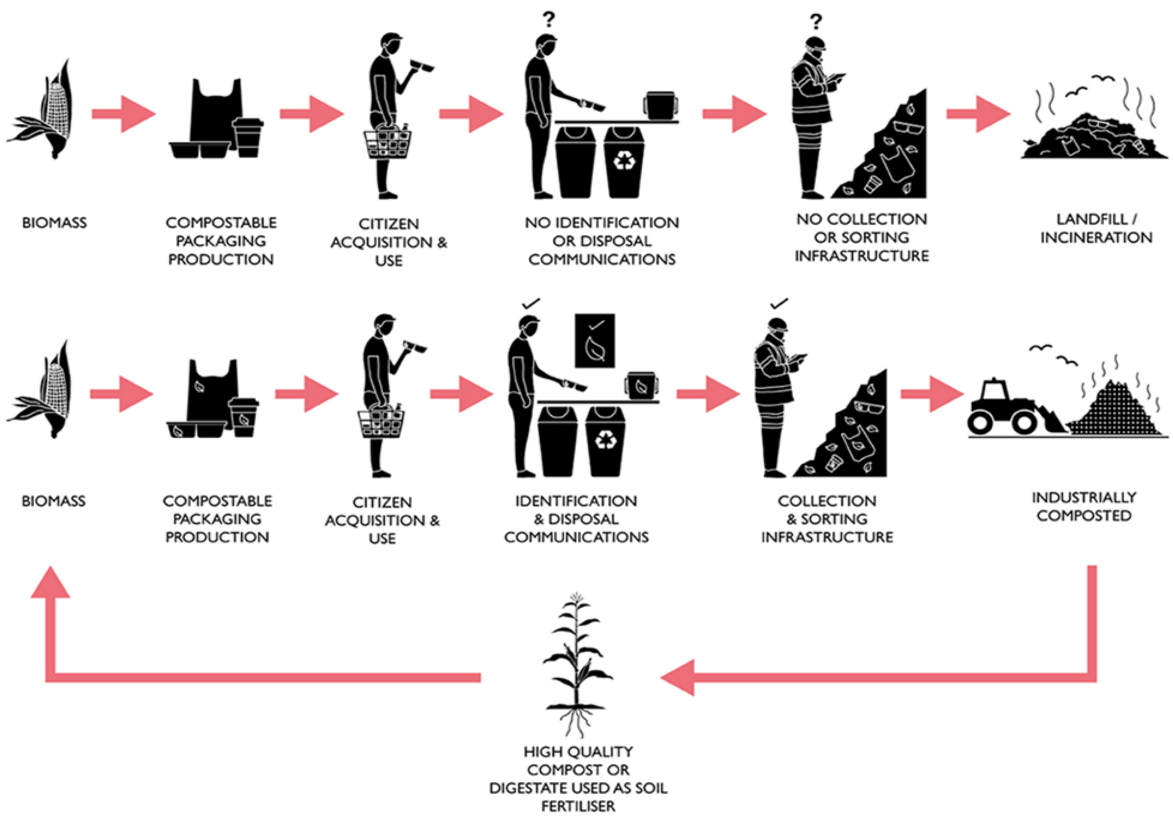
Therefore, whether they end up in the appropriate waste treatment facility relies on the below steps (illustrated in Figure 17):

1. The municipality offering the appropriate collection service or access to drop-off points (which is discussed in this section).

[3] Biodegradable and compostable packaging in Quebec: A status report. April 2021. Obtained via email correspondence with ECCC, March 3rd, 2023.

2. The consumer correctly placing the product in the appropriate waste stream.
3. The acceptance and ability of an industrial composting facility, in the case of compostable plastics, to sort and divert them to the appropriate treatment (this is discussed in section 3.4). In the case of bio-based drop-ins, material recovery facilities (MRFs) will not reject them and sort them according to how they sort chemically identical conventional polymers.
4. In the case of biodegradable plastics, the intended AD or industrial compost facility acceptance of biodegradable plastics (this is discussed in section 3.4).

Figure 17. Necessary steps for successful biological treatment of biodegradable plastics



Source: (Allison, et al. 2022)

The following sub-sections give more detail on the collection and sorting capacity for bioplastics in the US and Canada, and comments on the likelihood of the above steps being satisfied such that different bioplastic types will end up in the appropriate waste treatment facility. When these materials are not correctly managed, they may be landfilled, incinerated, or littered. While most communities in the US and Canada have access to a landfill and regular garbage collection, the additional waste infrastructure drives the ability of a product designed for recycling or composting to be collected and correctly treated. Currently, due to a lack of infrastructure that targets this type of material, or allows it in other streams such as food waste, the majority of biodegradable plastics are likely landfilled (or incinerated, although this is relatively rare in the US and Canada) (this is expanded on in section 3.4).

Furthermore, most traditional recycling is market-driven, where the products have a value. Failing this commodity value, the recycling of other items is driven more by policy and regulation. The recycling of conventional plastics, for example, is predominantly driven by recycling policy at the state or provincial level in the US and Canada. As discussed in greater detail in the CEC Plastics Waste Milestone Study, while there is intrinsic value of recovered conventional plastics (if kept relatively clean and sorted by resin type), the value might not be adequate to cover the collection and processing costs. Compostables on the other hand, do not have an intrinsic value since they do not make a positive contribution to the nutritional value of compost. As noted above, many biological treatment facilities (e.g., composting or AD facilities) are not willing to accept compostable plastic materials for reasons expanded on in section 3.4. PLA is technically recyclable but no widespread collection nor recycling systems are in place for the material because it has not yet reached economies of scale (see section 3.3.2).

3.3.1 Bio-Based, Non-Biodegradable Plastics (Drop-ins) Collection and Sorting

Drop-ins, such as bio-PET and bio-PP, are non-biodegradable, bio-based plastics that have identical mechanical properties and chemical structures to conventional, fossil-based plastics. As such, they can be processed and recycled using existing infrastructure for plastics collection, sorting and recycling. The infrastructure available for bio-based drop-ins is thus dependent on whether collection systems and sorting infrastructure exist for conventional plastics, which is dependent on provincial- and state-level policies and local practices within Canada and the US. Additionally, the existence of a collection system does not necessarily indicate that the plastics disposed of will be recycled (see the CEC Plastics Waste Milestone Study for a more detailed breakdown of difficult to recycle plastics).

Generally, the types of collection systems in place for plastics in Canada and the US are single or dual-stream curbside collection and drop-off programs. In Canada, in 2015 approximately 67% of residents had access to recycling programs that accept “all plastic containers.” Plastics with the highest access rates (over 90%) in Canada include PET, HDPE, LDPE and PP container plastics (i.e., bottles, jars, jugs, rigids). However non-container plastics such as film, bags, PS food packaging and tubs and lids have lower national access rates (CM Consulting 2016) (see CEC the Plastics Waste Milestone Study for more detail on this).

In the US, an estimated 91% of residents have access to recycling programs, although 32% of the population is estimated to only have access to drop-off programs. Multi-family dwellings are less likely to have recycling access overall, with 23% of residents not having access to any recycling programs relative to the 3% of single-family household residents. Additionally, where recycling is available, it is more likely to be a drop-off program: approximately 46% of residents in multi-family dwellings only have access to drop-off programs compared to the 26% of single-family household residents (Sustainable Packaging Coalition 2021) (see the CEC Plastics Waste Milestone Study for more detail on recycling access).

Ultimately, bio-based drop-in materials, such as bioPET and bioPE, are more likely to be collected and sorted if appropriate systems are already in place for the respective resin. For a detailed overview of the collection systems, residential access to collection, collection costs, types of accepted plastic packaging, and the available collection and sorting infrastructure in the US and Canada please refer to the CEC Plastics Waste Milestone Study.

3.3.2 Biodegradable Plastics Collection and Sorting

Many plastics can be recycled (i.e., their recycling is technically feasible), however the ability for these plastics to be successfully recycled is highly dependent on a range of waste management, economic, political and social factors, influencing their recyclability. The Ellen MacArthur Foundation (EMF), as well as the US and Canada Plastic Pacts, determines plastic packaging as recyclable if its successful collection, sorting and recycling is proven to work in practice and at scale, and whether the output has market value and can be further used as feedstock in new product. EMF suggests using a threshold postconsumer recycling rate of 30% (across multiple areas) as a criterion to "prove" recyclability in practice and at scale, though determining what criterion to use as proof is subjective (Ellen MacArthur Foundation and UN Environment Programme 2020). Though some biodegradable and compostable plastic resins can technically be recycled, none are currently successfully collected, sorted and recycled in practice and at scale in the US and Canada and are thus considered unrecyclable according to EMF's definition. Furthermore, biodegradable plastics can contaminate the conventional plastics recycling stream.

PLA is both a "technically" recyclable and compostable bio-based plastic, with the greatest market share of all bioplastic materials in the US and Canada. However, PLA cannot be recycled along with conventional plastics, requiring its own recycling stream, and is currently defined as unrecyclable (in practice and at scale) by the Association of Plastic Recyclers (APR) due to there being limited collection systems in place for PLA in the US and Canada (The Association of Plastic Recyclers 2022) (Federal Trade Commission 2012).

Given the similarity in appearance of biodegradable plastics to conventional plastics and the novelty of biodegradable polymers, biodegradable plastic is not always readily identified and sorted from conventional plastic, although in the case of PLA, existing sorting technology (e.g., optical scanners) can remove PLA from conventional plastics recycling streams (NatureWorks 2023). The low volumes of PLA placed on the market make sorting and recycling of PLA waste inefficient, expensive and financially unsustainable (Beeftink, et al. 2021). Consequently, when placed in conventional plastic recycling streams, and identified by sorting technology, PLA is sorted from conventional plastic recycling streams, and treated as residual waste (i.e., landfilled or incinerated).

Low levels of biodegradable plastic polymers already contaminate conventional plastic recycling streams. For example, PLA acts as a contaminant in PET streams at very low levels (approximately 1%) (Niaounakis 2019). Consequently, the increasing volumes of biodegradable plastics placed on the market is of concern, given that it will potentially present significant contamination challenges with existing sorting and recycling technologies. For information on sorting technologies for improving biodegradable plastics identification and sorting, see section 6.5.1.

The appropriate end-of-life treatment for most compostable plastics is biological treatment. Some certified industrially compostable plastics can be collected with organics and food waste to be treated in industrial composting facilities or in AD facilities. The following section explores current collection systems for organics waste and their accessibility to residents. Importantly, the section examines the level of acceptance and treatment feasibility of compostable plastics by the existing collection infrastructure for food waste, since the disposal route of compostable packaging is with residential food waste.

It is important to emphasize that although collection systems may accept certified industrially compostable plastics in the organics waste stream, the acceptance (and successful composting or digestion) of the materials at industrial composting or AD facilities is not guaranteed. In fact, during manual and mechanical sorting within these facilities, biodegradable plastics are often screened out along with all other plastics and non-organic contaminants as the front-end systems (from quite sophisticated de-packaging systems to simple screens with small holes, to humans with hand tools) are not able to differentiate. In the common wet AD systems, which pump a wet slurry around inside to maximize bio-gas generation, any polymeric or textile material is a real problem as it can block pipes, valves and pumps, resulting in reduced system performance and maintenance downtime. See section 3.4 for more information on the acceptance of biodegradable and compostable plastics in composting facilities.

United States

GreenBlue analyzed residential access to food waste composting programs in the largest cities in the US, representing about 40% of the US population (approximately 132 million people) (GreenBlue 2023). According to the study, collection systems for food waste composting programs in the US include municipally run and privately-run curbside and drop-off programs, where:

- Municipally run curbside programs are managed by the city or county;
- Privately-run curbside programs are run by a private composting company which collects and transports material to the nearest composting facility or composts the collected material at its own site. This type of program is often financed through a monthly subscription service and used by motivated residents; and
- Drop-off programs are municipally or privately-run and provide centers where residents can drop off their food waste.

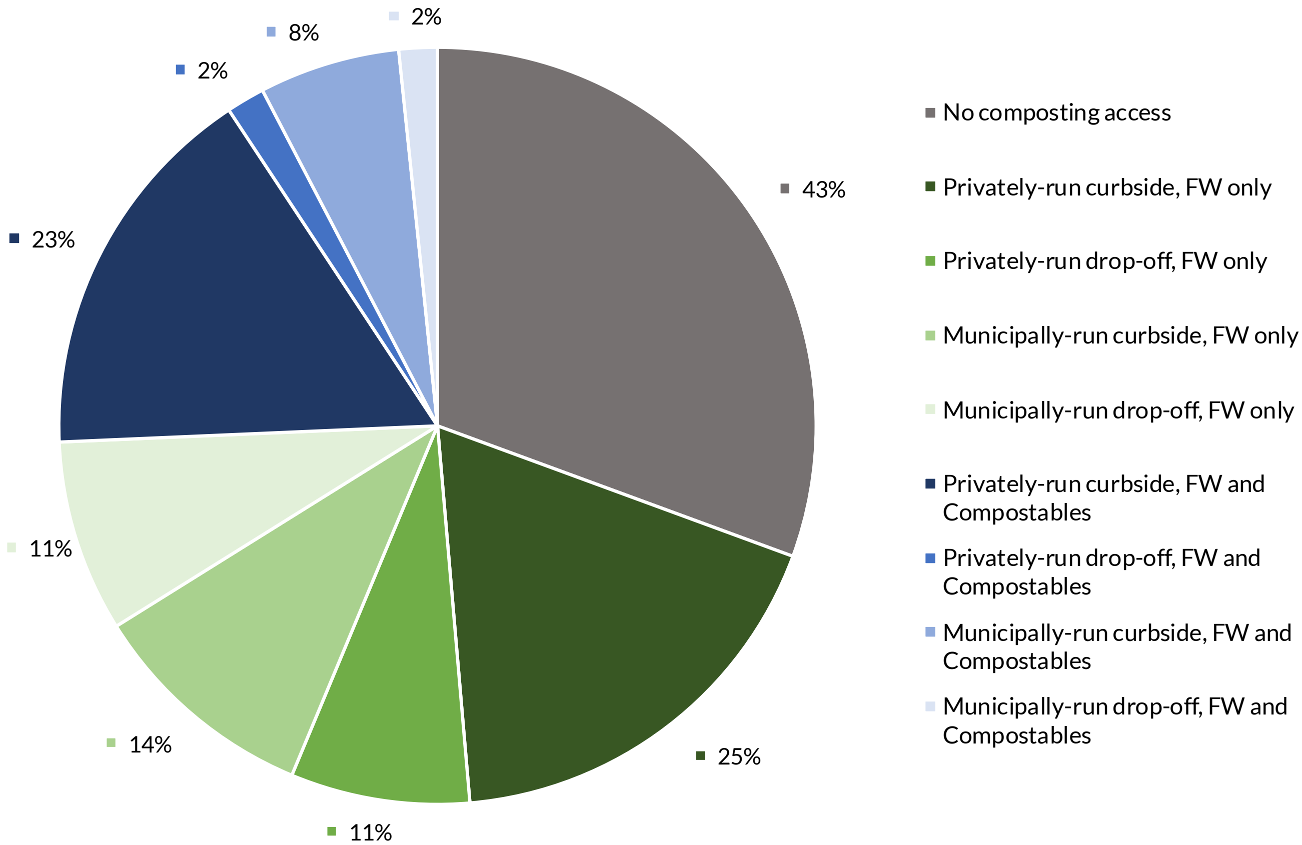
According to the GreenBlue data, which were last updated in February 2023, there are more privately run curbside collection services for food waste composting programs than municipally run curbside collection services. Of the US population analyzed with access to a food-waste-only composting program, about 25% had access to privately-run curbside collection, whilst approximately 14% had access to municipally-run curbside collection (Figure 18). This presents a barrier to engagement in food waste composting programs because it relies on highly environmentally motivated residents to seek them out and pay for their own service using a subscription. Furthermore, access to food waste composting does not equal participation in food waste collection services for composting programs.

Some cities have access to more than one composting program for food waste, potentially indicating access may be less common throughout the US (i.e., rural areas) but higher in densely populated, urban areas. Nevertheless, over 1,000 of the largest cities in the US still have relatively poor collection access for its residents. Approximately 43% of the population analyzed did not have access to composting programs of any kind in 2023 (neither private nor municipally-run) (Figure 18).[4] The data analyzed do not address differences between single-family and multi-family dwellings, which may present another accessibility challenge for composting programs (GreenBlue 2023).

GreenBlue also provides data on the number of US residents in analyzed cities with access to food waste composting programs that accept both food waste and compostable packaging. Compostable packaging in this case is inclusive of all material types (e.g., compostable fiber-based packaging), not just compostable plastic. Only approximately 8% and 2% of the population analyzed had access to municipally run curbside and municipally run drop-off programs respectively that accept any form of compostable packaging (not necessarily compostable plastic) along with food waste (Figure 18). A greater number of city residents had access to privately-run curbside collection services that accepted compostable packaging, specifically 23% of the analyzed population. However, since compostable packaging is not limited to compostable plastic, the percentage access to composting programs that accept compostable packaging does not accurately represent how acceptable compostable plastics are in these urban collection programs. Indeed, many of the large jurisdictions with organics collection programs explicitly prohibit compostable plastics.

[4] GreenBlue (2023) regularly updates the data on urban collection access to composting programs in the US (last updated on 20 February 2023 and accessed 24 April 2023). GreenBlue does not provide public access to the raw data used in the analysis. Results presented in Figure 18 should therefore be interpreted and used carefully.

Figure 18. Percentage of total US residents across over 1,000 cities with access to food waste composting programs that accept compostable packaging, across composting program type in 2023 (FW = food waste, compostables = compostable packaging) [5]



Source: Adapted from (GreenBlue 2023)

A 2021 BioCycle survey analyzed residential food waste collection access according to program type. The results, based on an analysis of 427 cities, indicate that the number of municipally run food waste collection programs has increased since 2017, with 10.04 million households in the US having access to curbside food waste collection. However, 4.2 million households have access to drop-off only programs, which are more inconvenient for residents. Additionally, only 34 (22%) of the 153 municipal programs reporting offer food waste curbside collection as part of their standard waste collection offering. The remaining 45 and 59 programs are opt-in or seasonal, further demonstrating a barrier for household participation (BioCycle 2021). Respondents for municipally run programs also reported that household participation was considered a challenge to maintain for

[5] The number of US residents with access to food waste collection may overlap across different program types. In other words, in certain cities, residents will have access to two or more programs and are therefore counted as having access to both (e.g., one person can have access to privately-run curbside and privately-run drop-off). Therefore, summing the percentage access figures will lead to a **total over 100%**. The total population of US residents in the cities analyzed was 131,551,843 when the data source was last updated in February 2023. GreenBlue's data on access collection programs for food waste composting that accept compostable packaging is likely to be an overestimate of true access.

municipally run collections and outreach and education was often necessary to boost participation (BioCycle 2021). Conversely, 96,182 households are under subscription collection services and 124 subscription programs were identified in 2021. In the survey, 12 states were identified where only privately-run collection services for food waste were available BioCycle 2021).

Relating to compostable plastics, of the total number of municipally run programs responding to the survey (265 out of 272), only 38 (14%) programs reportedly accepted compostable plastic food service items and packaging while 56 (21%) accepted food-soiled paper that had a compostable plastic coating. More commonly accepted were compostable plastic liner bags, with 115 (43%) programs reportedly accepting them (BioCycle 2021). Of the 46 subscription service curbside programs reporting, 28 (61%) accepted food soiled paper coated with compostable plastics, 26 (57%) accepted compostable plastic foodservice items and 32 (70%) accepted compostable plastic liner bags (BioCycle 2021). These results showcase the number of surveyed programs that accept compostable plastic and do not demonstrate the population access to collection services accepting these types of plastics. The survey results are also restricted to a limited number of collection programs and the proportion of programs across the US accepting compostable plastics is likely to be much lower.

In fact, an increasing number of organics collection programs across the US are explicitly banning biodegradable or compostable packaging. For example, in January 2023, the City of Los Angeles rolled out the ability of residents to commingle their residential food scraps with their existing residential yard trimmings containers. So, an additional 4 million residents now have access to a curbside organics collection program. However, it is not known how many residents take advantage of this service; and residents are explicitly told not to place products labeled “biodegradable” or “compostable” in their green bins (Table 4). Other organics collection services in the largest US cities implicitly do not accept compostable plastics within the waste stream.

Table 4. Organics collection in the ten largest cities in the US and their acceptance of biodegradable and compostable plastics

City	Partially prohibits compostable plastics			Implicitly or Explicitly Prohibits all compostable plastics
	Only accepts compostable plastic bags/bin liners	Only accepts certified industrially compostable bags	Allows compostable bags/bin liners but will treat them as contaminants	
New York (City of New York 2023)				X
Los Angeles (LA Sanitation and Environment 2023)				X
Chicago (City of Chicago 2023)				X[6]
Houston (City of Houston 2023)		X[7]		
Phoenix (City of Phoenix 2023)				X[8]
San Antonio (City of San Antonio 2023)				X
San Diego (The City of San Diego 2023)				X
Dallas (City of Dallas 2023)				X
San Jose (San Jose Recycles 2023)				X

Survey results from both municipal and privately-run collection programs indicate that the general level of acceptance of compostable plastic liner bags is much higher than any other type of biodegradable plastic product. Compostable plastic bags are assumed to improve the capture and diversion of food material from residual waste (i.e., waste that is landfilled or incinerated). For example, an LCA on end-of-life scenarios for municipal organic solid waste, completed by Nordahl et al. (2020), demonstrated that landfilling was the most GHG intensive treatment option, emitting approximately 400 kg CO_2-eq emissions per tonne of organic waste. Conversely, composting, followed by land application of compost, generated negative GHG emissions (-41 kg CO_2-eq per tonne).

By improving food waste capture, the acceptance of compostable plastic bags in collection programs and facilities, if suitable for the treatment infrastructure, can potentially improve.

[6] Chicago's program is currently yard waste only.
[7] Houston's program is leaves only but allows for two approved brands of compostable plastic bags.
[8] Phoenix's program is only yard waste and prohibits cups and fast-food containers.

However, there is a lack of US and Canadian studies that demonstrate that the use of compostable plastic bags increases residential food waste capture. Nevertheless, there is some evidence in Europe to suggest that the use of compostable plastic bio-bags helps make separate food waste disposal more acceptable for households (i.e., simpler and hygienic) whilst reducing conventional plastic contamination by replacing conventional plastic food waste bags that made their way to composting facilities (see Italy's case in section 6.6) (Eunomia Research & Consulting 2020).

Ultimately, various sources indicate that organics and food waste collection remains highly limited in the US. Collection accessibility for biodegradable plastics specifically is even more limited, given that biodegradable plastic in the organics waste stream is largely not accepted. Additionally, acceptance during collection does not mean that households will participate in separating biodegradable plastics correctly nor that biodegradable plastic waste will be accepted, nor that acceptance actually equates getting composted (or digested), at an industrial composting or an AD facility (see section 3.4).

Canada

According to a 2021 study by the Environmental Research & Education Foundation (EREF), an estimated 71% of Canadians live in an area with residential access to curbside source-separated organic waste collection programs while 91% have access to any type of organics collections program, including leaf and yard waste and drop-off programs (EREF 2021). Accessibility to source-separated organic waste collection programs was highest in provinces with source separation requirements and/or diversion requirements for organic waste, namely British Columbia, Nova Scotia, Prince Edward Island, Ontario and Quebec (Table 5). Provinces and Territories with low accessibility (under 50% of residents) to source-separated organic collection include Manitoba, Newfoundland & Labrador, Nunavut and the Northwest Territories (Table 5).

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Table 5. Residential accessibility to organic waste management programs and collection programs in Canada (2021)

Provinces / Territories	Any organics management program	Source-separated organics program		
		All	Curbside	Drop-off
Alberta	87%	74%	72%	10%
British Columbia	98%	84%	72%	68%
Manitoba	75%	7%	6%	1%
New Brunswick	56%	47%	47%	40%
Newfoundland & Labrador	49%	9%	1%	7%
Northwest Territories	47%	47%	47%	0%
Nova Scotia	99%	97%	96%	35%
Nunavut	0%	–	–	–
Ontario	98%	78%	76%	13%
Prince Edward Island	100%	100%	100%	100%
Quebec	86%	79%	79%	36%
Saskatchewan	74%	52%	48%	8%
Yukon	76%	–	–	–

Source: (EREF 2021)

Although many Canadians have access to source-separated organics waste collection, biodegradable and compostable plastics are largely rejected by organics waste collection programs, although this is currently a dynamic landscape. For example, at the time of writing, of the 12 large municipal collection programs listed in Table 6, none of them accept all forms of biodegradable plastic and many programs reject even certified industrially compostable plastics. Only four municipal programs in Table 6 accept compostable plastic bin liners or bags to help capture food waste, however these programs only accept certified industrially compostable plastics, by BPI or *Bureau de Normalisation du Québec* (BNQ). Two collection programs (cities of Edmonton and Ottawa) allow compostable plastics within the waste stream but will treat them as contaminants and landfill them regardless.

Table 6. Twelve large municipal organics waste collection programs in Canada and their acceptance of biodegradable and compostable plastic

City and Province	Partially prohibits compostable plastics		Prohibits all compostable plastics
	Only accepts certified industrially compostable bags/bin liners	Allows compostable bags/bin liners but will treat them as contaminants	
Toronto, Ontario (City of Toronto 2023)			X
Montreal, Quebec (City of Montreal 2023)			X
Vancouver, British Columbia (City of Vancouver 2023)			X
Surrey, British Columbia (City of Surrey 2023)			X
Halifax, Nova Scotia (Halifax Regional Municipality 2023)			X
Regina, Saskatchewan (City of Regina 2023)			X
Calgary, Alberta (City of Calgary 2023)	X		
Ottawa, Ontario (City of Ottawa 2023)		X	
Hamilton, Ontario (City of Hamilton 2023)	X		
Charlottetown, Prince Edward Island (Island Waste Management Corporation n.d.)	X Only BPI and BNQ certified bags are accepted		
Edmonton, Alberta (City of Edmonton 2023)		X	
Saskatoon, Saskatchewan (City of Saskatoon 2023)	X Only BPI certified while other bags/bin liners are treated as contaminants		

3.4 Recycling and Composting Infrastructure and Technology

Infrastructure for composting and recycling bioplastics is still developing across the US and Canada and not all communities have access to composting or recycling facilities that can process bioplastics. In addition, the lack of standardized labeling and sorting systems for the identification of bioplastics can make it difficult for consumers and waste management systems to effectively sort and thereby process these materials.

As discussed throughout the report thus far, bio-based, non-biodegradable plastics (bio-based drop-ins) can be processed in existing recycling infrastructure for conventional plastics and will not act as contaminants (see section 2.2.3). If collection systems successfully capture non-biodegradable bio-based plastics along with conventional plastic waste, bio-based drop-ins will be accepted across existing recycling facilities. In the US and Canada, two forms of recycling exist to process conventional plastics: mechanical and chemical recycling. Mechanical recycling uses physical processes to shred, grind, and crush plastic before melting it into granulate to make new plastic products. Chemical recycling, most commonly pyrolysis, uses chemical processes to convert plastic back into the liquid or gaseous hydrocarbons it was made from, e.g. crude oil, natural gas. Where collection systems and recycling infrastructure are limited to certain conventional plastic resins (e.g., PET bottles), other respective bio-based drop-ins (like bio-PE) will be sent to incineration or landfill with their conventional counterparts.

In the US and Canada, there are many mechanical recycling facilities and some chemical recycling plants, although the latter technology remains largely in its infancy. Some of the largest mechanical recycling facilities in the US have capacities ranging from 15,000 to 170,000 tonnes annually (see the CEC Plastics Waste Milestone Study on recycling capacity). However, these capacities are not representative of all types of conventional plastic products. The recyclability, and therefore acceptance, of conventional plastic waste types varies across technologies and facilities and can depend on resin, product application and product design (e.g., shape, size, label constructions). See the CEC Plastics Waste Milestone Study for more detailed information on US and Canadian recyclers' acceptance of resins and on difficult to recycle conventional plastics in the US and Canada.

Given that bio-based drop-ins can be processed with conventional plastic waste, the following section will examine the recycling and composting infrastructure available in the US and Canada for biodegradable plastics.

Although some biodegradable plastics (both bio- and fossil-based) are "technically recyclable," i.e., they can be sorted in MRFs and reprocessed back into the original material (e.g., PLA), the economics do not warrant their separation (small volumes make it inefficient), and there is consequently no available recycling capacity for biodegradable resins. Unlike bio-based non-biodegradable plastics, biodegradable plastics cannot be recycled along with conventional plastics (e.g., PLA with PET) as this would reduce the quality of the resulting recycled material (e.g., predominantly PET, with a low level of PLA).

The composting and AD of compostable plastics is also limited. The available composting and AD infrastructure within the US and Canada varies widely between states and provinces. In many areas, the presence and number of available facilities depends on population density, but state and provincial policies also play a dominant role in promoting the development of infrastructure.

While some facilities may be technically able to treat biodegradable and certified industrially compostable plastics, the reality is that most are not willing to do so for the following reasons:

- Consumers' inability to differentiate compostable from conventional plastics leads to confusion and highly contaminated feedstocks for compost and AD facilities (Mistry, et al. 2018) (US EPA 2021). Removing contaminants can be costly and contribute to a lower quality end product. Of particular concern is microplastic pollution from non-degradable conventional plastics and the transfer of hazardous chemicals from conventional plastics (e.g., DEHP) into the finished product; this can transfer into and build up in soil after land application (Scopetani, et al. 2022) (Braun, et al. 2023).
- Direct evidence of ecological improvement from compostable plastics is sparse and inconclusive and there appears to be consensus around the lack of nutritional benefit in resulting digestate or compost (Eunomia Research & Consulting 2020).
- Composters that sell compost approved for certified organic agriculture (see section 2.3.4) will have issues selling their product if it contains biodegradable plastics (deemed synthetic and a contaminant).
- Concern over incomplete biodegradation of the plastic due to system configurations and material type, leading to macro- and microplastic contamination in the finished product (compost or digestate) (Goldstein and Coker 2021) (Bläsing and Amelung 2018), which can transfer into and build up in soils after land applications (Scopetani, et al. 2022) (Braun, et al. 2023). In this case, compost and digestate quality may not meet mandatory national, state, or provincial standards; even if they do meet these standards, visible impurities reduce the product value and make it harder for organic recyclers to sell their products (Sustainable Packaging Coalition 2021). Contamination from incomplete biodegradation of plastic can even mean that voluntary standards are not met, which impact the ability of organics recyclers to sell their finished products to consumers (see section 2.3.4 for more information on compost and digestate quality standards). Once biodegradable plastic is accepted at a facility, it is almost impossible to remove this contamination later (A1 Organics 2023) (Oregon Composters 2019).
- Concern with contamination from hazardous chemicals in the biodegradable plastic that can leach into the finished product. For example, chemicals such as per- and polyfluoroalkyl substances (PFAS) are present in food contact packaging and have been detected in compostable packaging as well as non-compostable. Additionally, PFAS from compostable products can leach into compost (US EPA 2021) (Choi, et al. 2019).
- Practical problems associated with the handling of film and bag materials, in particular, which can block pumps and valves etc. (based on Eunomia discussions with wet AD operators).

As a result, most facilities remove any material that looks like plastic, including biodegradable plastics. This is done through relatively sophisticated de-packaging equipment and simpler screens at the front end and through human sorters using hand tools. The reality is that most biodegradable plastics end up in landfill (or incinerators) along with other materials considered to be "contaminated" by composting and AD facilities.

To understand the biological treatment capacity in the US and Canada for biodegradable plastics, below we evaluate the available composting infrastructure in the two countries, along with their acceptance of biodegradable and compostable plastics.

3.4.1 United States

The EPA mapped opportunities to manage, through composting and AD facilities, excess food waste stemming from industrial, institutional and commercial sectors, known as the ICI sector (i.e., non-residential). The map demonstrates that there are over 3,000 and 1,000 composting and AD facilities respectively within the US that could potentially accept excess food. However, not all mapped facilities currently accept food waste as feedstock nor food waste from residential streams. Additionally, the data do not indicate whether compostable plastics are accepted as feedstock across treatment facilities (EPA 2023).

There are a limited number of AD facilities that treat non-industrial and non-commercial streams of food waste in the US. Of the total food waste processed in 2019 across AD facilities surveyed by the EPA, less than 1% was waste sourced from residential streams, currently the common disposal route for compostable plastic packaging (Schroeder 2023).

BioCycle conducted a study on the state of organics recycling in 2017 and found that there were 4,713 composting facilities across the US. Most composting facilities (57%) only composted yard trimmings. Overall, the amount of food waste that was processed across composting and AD facilities in 2015 to 2016 was only 8.7% of the total feedstock processed (19,171,580.5 tonnes per year), which includes other organic waste such as yard trimmings or biosolids. Windrow and static piles were the most common type of composting facility, across all feedstock types, making up about 63% and 29% of all facilities respectively.

The above 2017 data do not provide information on whether biodegradable plastics were accepted at facilities (BioCycle 2017). Nevertheless, according to a 2018 BioCycle study, there were approximately 185 full-scale food waste composting facilities in 2018. Of 103 facilities that responded to the survey, approximately 49 facilities stated that they accepted compostable plastic products (Goldstein 2018). The study does not provide detailed information on the type of compostable plastic product accepted by facilities. However, it is likely that a limited range of certified compostable plastics are accepted at each facility. It is also highly likely that these facilities have changed their policy on compostable plastics since 2018.

Using GreenBlue data on composting infrastructure in the US, SPC approximated that in 2021 53.5% and 30.7% of facilities with composting infrastructure accepted green waste only and food waste only respectively. Only 15.8% of composting facilities analyzed accepted "some compostable packaging" in addition to food waste (Sustainable Packaging Coalition 2021). In 2023, the percentage of facilities accepting green waste, food waste and compostable products, including but not limited to "biodegradable plastics," is estimated to be 12% (124 out of 1,029 facilities) based on GreenBlue data (Green Blue 2023) (Figure 19).

Figure 19. Composting facilities in the US that accept food waste, green waste and compostable products including "bioplastics" (2023)

Source: (Green Blue 2023)

As mentioned in section 2.3.3, to improve the acceptance of certified industrially compostable plastics across the US, the Compost Manufacturing Alliance (CMA) created a certification program where products certified compostable in lab tests are field tested across a range of composting technologies against ASTM D6400 and D6868 standards (Rolnick 2022). There are currently only 25 affiliate facilities that accept certain CMA certified compostable materials. However, given that each item is certified compostable for certain technologies, rarely do facilities accept all CMA approved items (only one facility reportedly doing so in Puerto Rico). In fact, none of the bio-based, biodegradable products that have been certified compostable by CMA are accepted across all the 25 affiliate facilities (Compost Manufacturing Alliance (CMA) 2022).

In the US, composters that sell compost approved for certified organic growers cannot sell the product if it contains biodegradable plastics as set out by USDA's NOP (Goldstein and Coker 2021). The ability to sell to certified organic markets is important to many composters and approval for certified organic use can be seen as an indicator of compost quality, thereby increasing product value (USDA Agricultural Marketing Service 2016).

The US composting industry has been raising public concern about the suitability of biodegradable and compostable plastics in the organics waste stream. For example, a joint statement from Oregon composters in early 2019 lays out a list of reasons why compostable packaging poses a risk to facilities, including contamination, lowering resale value of compost, negligible benefits to the environment, and increasing costs, among others (Oregon Composters 2019). Another example is Colorado's largest organics recycler's changing their accepted materials list, restricting the compostable packaging accepted to only four CMA approved compostable 3-gallon plastic bags (A1 Organics 2023).

Organics composters are looking for ways to reduce contamination and installing technology to reduce packaging entering compost. Technologies such as the new depackager recently installed at the City of Phoenix compost facility, which is able to pull packaging and wrappers from food waste (City of Phoenix 2023), will not be able to identify the difference between non-biodegradable and biodegradable plastic packaging. Mechanical de-packagers, deployed at the front-end of a compost or AD facility, strive to remove all non-food material. They can be highly effective at removing most plastic packaging, including bags. The machines do not distinguish by material type—compostable and non-compostable plastics are removed equally. These machines, an adaptation from food manufacturing, are increasingly used at large composting and AD facilities. It is unclear how many of these machines are presently in use in the US and Canada, but the number is growing.

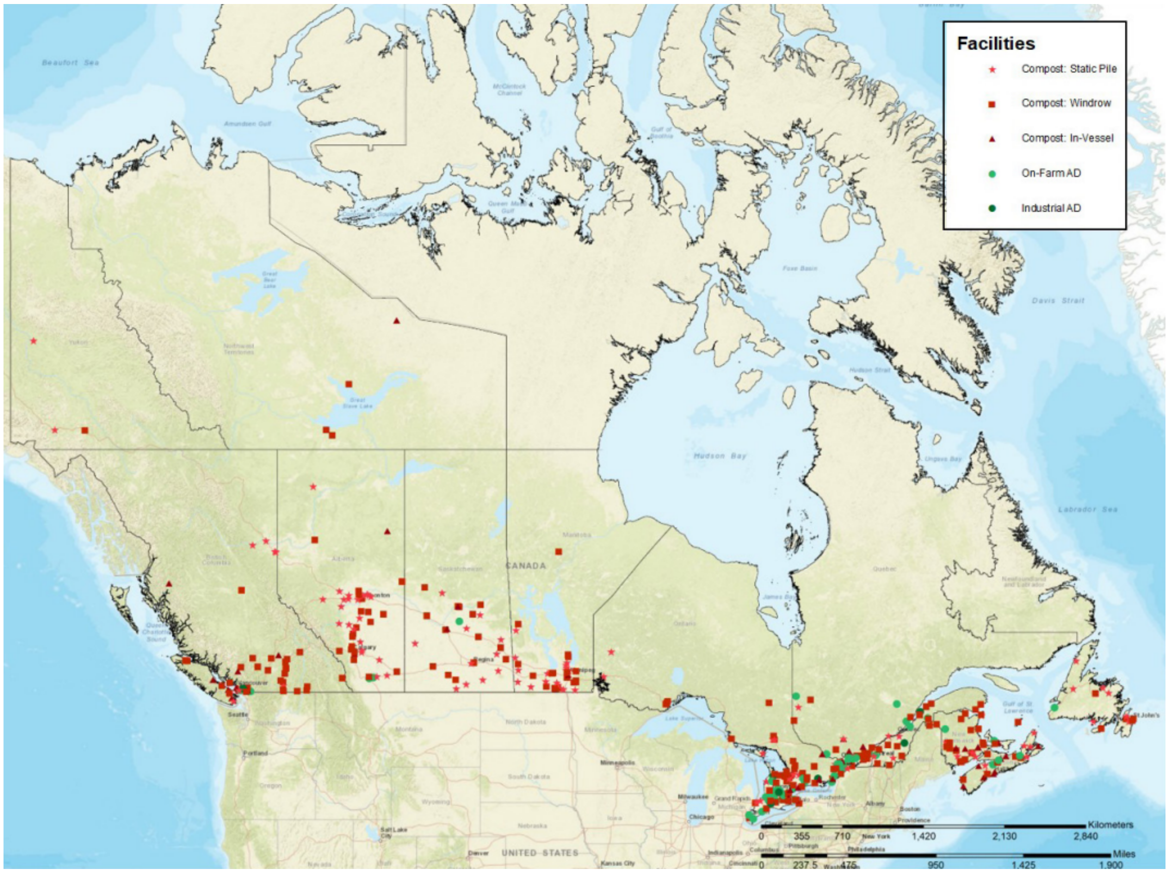
Even if barriers associated with treating compostable plastics were resolved, and the material was collected and accepted across composting and AD facilities, there is a limit in total processing capacity to treat annual organics waste generation. Only 3.7% of residential food waste in 2019 was composted, compared to the 45% of food manufacturing and processing waste managed by composting and AD combined (EPA 2023). It is therefore worth noting that there is insufficient capacity to treat any increase in compostable plastics associated with the organics waste stream, especially considering their lack of nutritional benefit to compost and digestate.

3.4.2 Canada

A 2021 study from the EREF found there were 328 compositing and 59 AD facilities in Canada. An estimated total of 4.8 million tonnes of organic waste was processed in 2019 and approximately 2.5 million tonnes of digestate and compost was produced. Of all organic waste processed in 2019, about 72% was processed through compost facilities, indicating that AD is somewhat less commonly used to treat organics waste in Canada.

There was large regional variation in the number of facilities (Figure 20) and the organics processing capacity across provinces. For example, Ontario had 107 composting and AD facilities alone, comprising 28% of all facilities in Canada and treating 38% of the total processed organic waste in 2019 (EREF 2021).

Figure 20. Map of operational organic waste management facilities in Canada (2021)



Source: (EREF 2021)

EREF estimates that Canada's present total processing capacity is approximately 5.7 million tonnes per year (excluding Quebec), with the bulk of organic waste processing capacity (47%) accounted for by Ontario. The combined capacity of IVC with AD, which can process a greater range of organic waste such as food waste, was estimated to be about 3.1 million tonnes per year. This combined capacity is slightly larger than the estimated 2.7 million tonnes per year associated with ASP and windrow composting, technologies which are largely limited to composting more 'basic degradable materials' like leaf and yard waste (EREF 2021).

In terms of the treatment capacity for compostable plastics, compostable rigid plastics are not widely accepted in organics treatment facilities across Canada. As discussed in section 3.3.2 on collection programs in Canada, there are residential food waste collection programs that permit certified compostable plastics bin liners to be used to capture food waste. However, though a collection program may permit certified compostable plastic film bags, the facility where the feedstock is taken might remove and discard the bags as contamination at the beginning of the process, while other facilities will shred the bags and contents and remove remaining film fragments through a screening process at the end. According to GreenBlue's data (Green Blue 2022), only one facility (Compost Winnipeg) in Canada accepts compostable plastic packaging, namely BPI-certified compostable dishware and bags (Compost Winnipeg 2023). However, this is mainly for educational purposes, and Compost Winnipeg generally removes compostable plastics from their treatment process. Consultation with stakeholders suggests that GreenBlue's data may not capture all facilities that accept and process compostable plastic products and packaging in Canada, however at the time of writing no other current and comprehensive dataset is publicly available. On 28 September 2023, the ECCC published a report, *The Role, Management, and Impacts of Plastics in Organic Waste Diversion Programs in Canada*, that provides an updated picture of source-separated organics programs that accept certain types of certified industrially compostable plastics (Giroux Environmental Consulting, Kelleher Environmental, and Isabelle Faucher Consultancy 2023). In general, any potential future increases in the volumes of compostable plastics may become more problematic and result in facilities reassessing their acceptance of these materials.

It is worth noting that in future, even if composters were to have a more favorable outlook on compostable plastics and were more willing to treat them, Canada's composting capacity is currently insufficient to deal with the total amount of organic waste generated annually. EREF estimate (based on 2016 organic waste data) that an additional 1.1 million tonnes of total processing capacity would be needed to process all organic waste generated in Canada. Based on the same data, EREF found that capacity (at AD and IVC facilities) to process larger volumes of 'complicated' organic materials such as source-separated organic waste (which contains food waste) was at a shortfall of an estimated 3.7 million tonnes (EREF 2021). Therefore, there is currently also an insufficient capacity to treat any increase in compostable plastic waste, which provides no nutritional benefit to compost nor digestate. Nevertheless, as discussed in section 3.3.2, the lack of acceptance of a wide range of compostable plastics in large municipal organics collection programs (Table 6) reflects the current reality: that treatment facilities generally do not want to process the material due to unresolved contamination challenges.

3.5 Quantity and Value of Bioplastic Waste Trade

Determining both the quantity and value of bioplastic waste materials traded on an international scale are challenging. International trade statistics are publicly available through the United Nations' Comtrade database (UN Comtrade Database 2023). Within this database, each product type is classified by a Harmonized System (HS) code, which enables each product type to be uniquely identified. However, no such HS code exists for bioplastic waste or organic waste. As such, it is not possible to determine the quantity, or value, of bioplastic wastes that are traded internationally from this data source.

Bio-based, non-biodegradable plastics ("drop-ins"), e.g., bio-PET, can be co-collected with other recyclable plastics, where plastics are collected for recycling. As described in the CEC Plastics Milestone Study, due to its inherent value, and the presence of a global market, recyclable plastic waste is traded internationally. A proportion of each plastic bale traded could contain bio-based, non-biodegradable plastics. However, this proportion is likely to be insignificant since bioplastics constitute only 1% of the global plastics industry.

Biodegradable plastics, either fossil-based or bio-based, can be collected via organic collection systems and therefore enter the organic treatment value chain. In general, due to the high haulage costs of organic waste, attributable to its high density, the treatment of organic waste is reasonably local to the point of collection. This means that the trade of organic waste, and any co-collected compostable plastics, is likely to be negligible.

Where collection systems for either recyclable plastics or organic waste are not available, or where residents do not participate in these systems, waste bioplastics will end up in residual waste. This residual waste could be disposed of by landfill or incineration domestically or traded for disposal in another country. In the instance that residual waste is imported or exported, a proportion of the traded residual could contain bioplastics. However, the proportion is likely to be insignificant; as noted earlier, bioplastics constitute only 1% of the global conventional plastics industry, and plastic packaging and single-use products constitute approximately 16% of residual municipal solid waste in the US (US EPA 2020), and 13% in Canada (Environment and Climate Change Canada 2020).

In summary, it is difficult to determine the quantity and value of the trade of bioplastics waste at present. First, the trade of bioplastics waste is not currently tracked within international trade databases. Second, it is likely that bioplastics will make up a negligible proportion of traded conventional recyclable plastic and residual wastes. Without further analyses of composition it is difficult to determine the exact proportions. Based on this, it has been assumed that the quantity and value of traded bioplastic waste is likely to be insignificant.

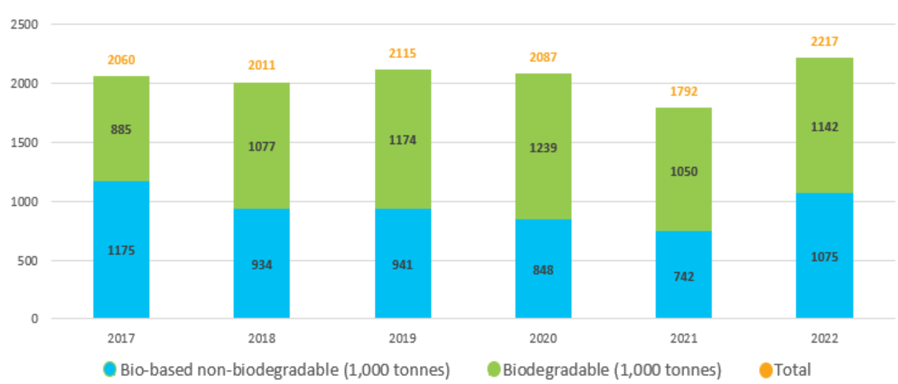
4 Market Trends

4.1 Growth Rates of Bioplastic Production

Looking at historic bioplastic global market production data for the last six years, between 2017 and 2023, do not give a clear indication of the market trajectory (see Figure 21) (European Bioplastics 2022) (European Bioplastics 2021) (European Bioplastics 2019) (European Bioplastics 2018). From 2017 to 2018, the global market shrank slightly (by 2%) overall and saw a ~20% decrease in bio-based non-biodegradable production, but a ~20% increase in biodegradable production. 2019 saw 5% total market growth, mainly coming from an increase in biodegradable plastic production. The years impacted by the COVID-19 pandemic (2020 and 2021) had negative growth. However, this was counteracted by 24% total market growth in 2022, and a reversal of the 2017—2020 trend that had seen more biodegradable plastic production and a decrease in bio-based plastic production: in 2022, bio-based non-biodegradable plastic production increased by 45% and biodegradable plastic production increased by 9%.

Overall, between 2017 and 2022, the bio-based market decreased in size year on year by an average of ~2%, while the biodegradable plastics market increased in size year on year by an average of ~5%.[9] This has resulted in a shift from bio-based non-biodegradable plastics representing the majority of bioplastic production (~60% in 2017) to a ~50% split between bio-based non-biodegradable and biodegradable production in 2022 (as mentioned in section 3.1). By comparison, the PET bottle market within the US alone increased year on year by an average of 3.3% between 2017 and 2022.[10] Globally, conventional, fossil-based plastics production increased by approximately 4% between 2020 and 2021 (Plastics Europe 2022).

Figure 21. Global bioplastics production 2017–2021



Source: Created using data from (European Bioplastics 2022); (European Bioplastics 2021); (European Bioplastics 2019); (European Bioplastics 2018)

[9] Based on calculations using production figures from the following sources: (European Bioplastics 2022); (European Bioplastics 2021); (European Bioplastics 2019); and (European Bioplastics 2018).
[10] Based on calculations using US PET bottle resin sales from the following sources: (Stina Inc. 2023); (Stina Inc. 2022); (Stina Inc. 2021); and (APR and ACC 2019).

It is unclear whether this trend will continue and result in biodegradable plastics becoming the majority segment in future, or whether the major increase (45%) in bio-based non-biodegradable plastic production seen in 2022 will continue, causing that market segment to become dominant again. This seems possible considering that increasingly manufacturers are looking to explore bio-based non-biodegradable "drop-in" plastics in their products and packaging to reduce use of virgin conventional plastic, and as an alternative to the use of recycled content. For example, Coca-Cola now has a 100% bio-PET bottle, and Avantium in Europe is in the process of commercializing PEF for various packaging and textile markets. These dynamics are discussed more in section 4.2 on demand for bioplastics.

Most predictions estimate that the US and Canadian bioplastics market will reflect the global bioplastics market and grow at a compound annual growth rate of approximately 10% up to 2030 (Fortune Business Insights 2021) (Grand View Research 2022) (Research and Markets 2021). European Bioplastics' projections of global bioplastics production capacities estimate there will be an increase from 2.2 million tonnes produced in 2022 to 6.3 million tonnes in 2027 (European Bioplastics 2022). Predictions are unreliable, of course, and may not describe how the future market will develop; European Bioplastics and others have consistently overestimated the bioplastic market growth rate in the past.

Production is expected to continue to be focused in and grow most in Asia for both biodegradable and non-biodegradable materials. Much of the growth in Asia is a result of local single-use conventional plastics bans in China and India (mostly for bags and e-commerce packaging), which have led to an increased focus on bioplastics manufacturing in these countries (Dadhaniya 2022). In China, there are more than 30 companies with biodegradable plastic production plants under construction or proposed for construction; it is expected that these would add ~4 million tonnes of production capacity (Future Markets, Inc. 2022). However, the Korean chemical company LG Chem announced in 2022 that it would start construction on a facility to produce 75,000 tonnes PLA annually in Illinois, USA, in 2023, due for completion in 2025 (The Korea Herald 2022). This capacity is far less than the proposed biodegradable plastic production plants in the pipeline in China, and just one example, but shows that production of biodegradable plastics could continue to grow in the US and Canada as well.

Policymakers and waste management facility operators in the European, US and Canadian markets are increasingly recognizing the difficulties with end-of-life management particularly of biodegradable plastics and putting in place restrictions on their use or acceptance. Hence production of biodegradable plastics in these regions is not expected to increase at the same rate as in Asia.

4.2 Demand for Bioplastics

There are many potential factors driving the demand for bioplastics. For example, increased pressure from consumers for products to be "environmentally friendly," policy measures and voluntary agreements, including the Plastic Pacts that exist in both Canada and the US. Studies of public attitudes towards biodegradable plastic have found that people commonly perceive biodegradable plastic to be "better for the environment than normal plastic" and a "positive solution for the planet" (Dilkes-Hoffman, et al. 2019). These opinions are often based on a misunderstanding of the science and seem to stem from the idea that "natural" materials and processes are inherently good, even when they may create high-intensity global warming gases like methane when disposed of in landfills, or result in very little benefit to compost.

Many companies are setting targets to reduce virgin fossil-based plastic in their products and packaging, and many are seeking to use bio-based plastic to do this as an alternative to increasing recycled content, particularly where supply of appropriate recyclables is limited and/or costly. Setting targets in this way gives flexibility in supply chains, and generally involves use of drop-in bio-based polymers such as bio-PE and bio-PP, which can be particularly helpful where food contact applications do not allow recycled content.

Biodegradable plastics are also being considered by some brands as a possible sustainable alternative where plastics cannot be eliminated, particularly where the packaging may be littered (e.g., snack packaging). Compostability is included as an option within the Ellen MacArthur Foundation's New Plastics Economy commitment, which has over 500 brand signatories, and both the US and Canada Plastics Pact commitments as part of the Ellen MacArthur Foundation's Plastics Pact network.

4.2.1 Applications and Material Types

Bioplastic alternatives exist for almost every conventional plastic material and corresponding application (European Bioplastics 2022). Again, with the caveat that predictions are unreliable, Figure 22 indicates the market share of different bioplastic materials in 2022, and how they could change by 2027. Although exact tonnages and percentage market share are unlikely to be accurate, there are some trends that seem likely, expanded on below. Overall, packaging and food service ware are expected to continue to be the main applications.

Biodegradable Plastics

The market shares of fossil-based biodegradable plastics, e.g., PBAT and PBS, are expected to decrease in line with global trends to reduce using fossil fuel feedstocks to make plastic.

PLA is expected to continue to be the dominant bioplastic material type—globally and in the US and Canada—since NatureWorks, headquartered in the US, currently has the highest production capacity for PLA (as stated in section 3.1). PLA is relatively low cost compared to many other bio-based and biodegradable plastics, and is approved for food contact applications, making it suitable for many different types of packaging. It is also transparent, making it particularly desirable for packaging, which requires the consumer to be able to view the product. The material is breathable, thus an ideal packaging for food products that require oxygen, for example salad leaves, and for textiles (another market application for which PLA is popular) (Eunomia Research & Consulting 2020).

In 2022, starch blends production was almost equal with PLA production and the second-most produced bioplastic material type. The most common starch blend on the market is Mater-Bi (produced by Novamont in Italy); Green Dot Bioplastics in the US are also leading producers of starch blends. Starch blends are most often used as household food waste bin liner bags; they are also used as mulch film in agriculture. Although European Bioplastics predicts that global starch blends production will represent a smaller proportion of the global bioplastic market by 2027, this use of biodegradable plastic for food waste bin liner bags is one of the most environmentally beneficial uses of biodegradable plastic, as discussed in section 6.

PHA production is not expected to increase greatly, as, despite PHA having good barrier properties similar to those of conventional plastics PET and PP, it is relatively expensive (production costs can be as much as 5–10 times higher than conventional plastics) and can be brittle compared to other plastics (Eunomia Research & Consulting 2020).

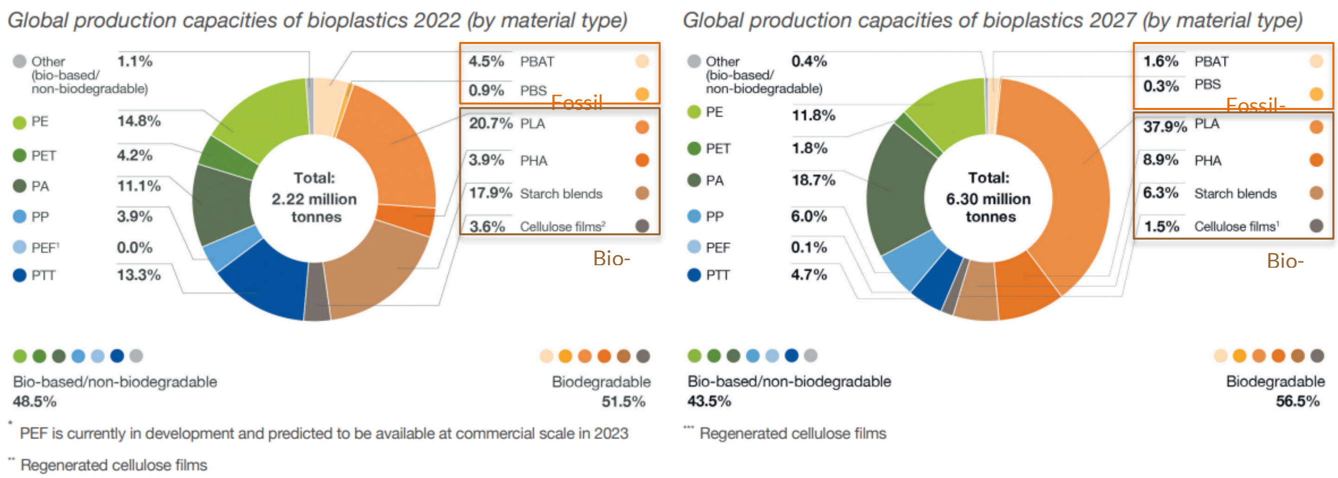
Bio-based non-biodegradable plastics

Bio-PET, bio-PP, bio-PE and bio-PA are expected to continue to be in demand as bio-based alternatives to their conventional plastic counterparts. However, bio-PET could have competition from PEF in the future (as explained in the next paragraph), and bio-PE is expensive to produce compared to conventional PE, so not much growth in production is expected unless those costs can be decreased (Eunomia Research & Consulting 2020). Currently Coca-Cola is the market leader in the bio-PET market with their plant bottle (Coca-Cola 2021). The automotive industry is the main source of demand for bio-PAs (or Nylons): it is often used to reduce vehicle weight as a lightweight but strong alternative to fiberglass (Eunomia Research & Consulting 2020).

PEF is currently in development and expected to be commercially available in 2024. It is a recyclable, bio-based plastic made by converting plant-based sugars into the chemical building block FDCA (2,5-Furandicarboxylic acid) (de Jong E 2022). There is much excitement around this bio-based, non-biodegradable plastic as a potential replacement for conventional plastic PET, due to it being reportedly much cheaper to produce than bio-PET and having better CO_2, oxygen and water properties than PET (Barrett 2013). It also has reportedly better mechanical properties, such as a 60% higher tensile modulus, meaning that there are opportunities to lightweight packaging using PEF (Omnexus 2023). Avantium's pilot plant in the Netherlands was the world's first factory to produce FDCA on a commercial scale and the company aims to accelerate the commercialization of PEF through the development of its full-scale Flagship Plant, which was under construction in 2023 (Avantium 2021).

Production of PTT is not expected to increase substantially. It is used solely in carpet fibres and preferred to conventional polyester as being more durable, resilient and softer, as well as cheaper than nylon and hydrophobic, therefore, stain resistant (Simmons 2019). However, it can cause contamination issues for recyclers if mixed with the recycling steam from conventional PP carpet (Eunomia Research & Consulting 2020).

Figure 22. Global production capacities of bioplastics in 2022 and predicted for 2027 (by material type)

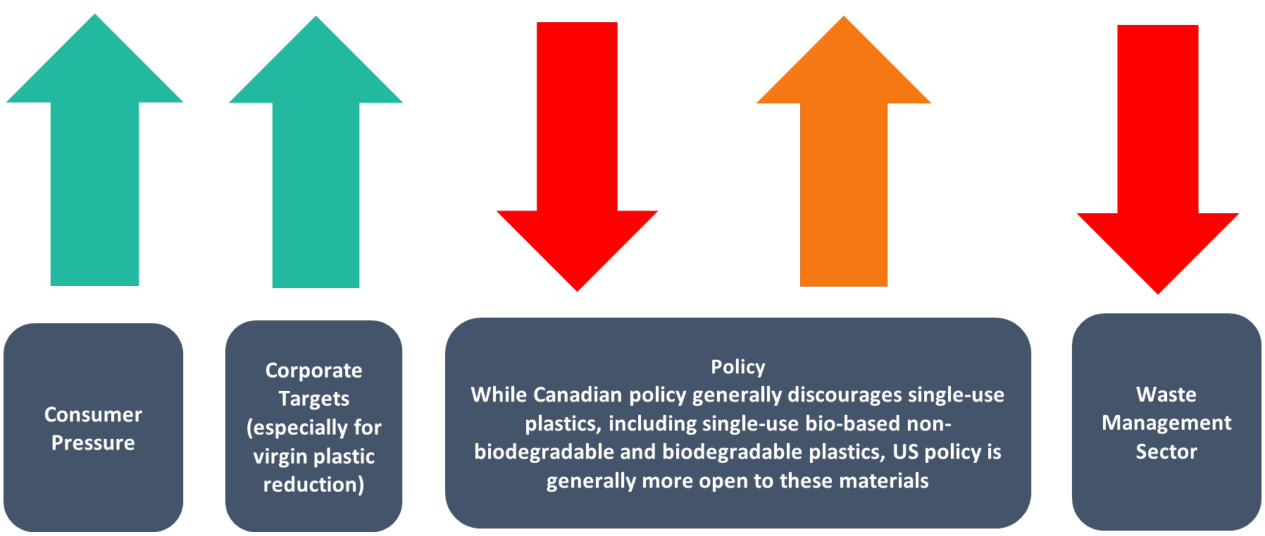


Source: Adapted from (European Bioplastics 2022)

4.3 Summary

There are market and policy drivers that favor, or discourage, the growth of bioplastics in the US and Canada, as summarized in Figure 23.

Figure 23. Drivers of demand for bioplastics in the US and Canada



Source: Eunomia Research & Consulting.

Consumers seem to intuitively believe that biodegradable materials are inherently good, while waste management operators do not favor these materials, for reasons explained in section 3.4. As will be outlined in section 5 on policy and regulatory frameworks in the US and Canada, in Canada the Single-use Plastics Prohibition Regulations (SUPPR) ban certain single-use, bio-based and/or biodegradable plastics, along with single-use conventional plastics (see also the CEC Plastic Milestone Study for further detail). Attitudes about biodegradable plastics in the US are less negative, generally being viewed thought of as an “up and coming” technology that can be a useful alternative to single-use conventional plastics, particularly in comparison to things that are not easily recycled, like plastic films.

While compostable plastics are one option that is “allowed” under the plastic pacts and the Ellen MacArthur Foundation commitments, most brands are more focused around the use of bio-based polymers as supplements to recycled plastic content, providing flexibility around commitments to move away from fossil-based plastics. Consequently, there is significant interest and investment in the bio-based “drop-in” polymers, including bio-PET and alternative, bio-based polymers, notably PEF. It is also important to note that the US Government supports such materials in the USDA’s BioPreferred Program, which encourages federal agencies to purchase goods made from bio-based plastics. Additionally, President Biden recently signed an executive order to advance the biomanufacturing industry (Executive Order 14081) and his administration has set a goal of deploying recyclable, bio-based polymers over the next 20 years that can displace over 90% of conventional plastics at scale (The White House Office of Science and Technology Policy 2023) (see section 5.1).

It seems likely that compostable polymers will remain in niche applications, for example where they fit well into food waste collection programs (e.g., as bio-bags for food waste collection in kitchen containers, tea bags, fruit stickers), and where they can play a part in reducing the impact of littering, although this would require nature degradability. Bio-based, non-biodegradable, but recyclable polymers are likely to overtake compostable polymers in production and use terms, due to their lower carbon impact and, in some cases, superior performance characteristics.

5 Policy and Regulatory Frameworks

Government policies and regulations are put in place to mitigate the negative impact that the production and mismanagement of waste can have on the environment, human health, and the economy. Policies and regulations are key to changing waste and recycling practices so that waste moves up the waste hierarchy and increases material circularity, as part of the transition to a circular economy.

This section gives an overview of the different policies the US and Canada have each implemented to manage bioplastic waste. Overall, there is currently no uniform approach to policy for managing bioplastic waste across the US and Canada.

5.1 United States

The United States does not have federal legislation that directly regulates the manufacturing, sale, use, or waste management of bioplastics. In the US, waste management is largely handled at the state level. The Resource Conservation and Recovery Act (RCRA) sets minimum standards for hazardous and non-hazardous waste, including criteria for solid waste landfills and prohibiting open dumping of solid waste (40 C.F.R. § 1.239-282 1998). Recycling and composting are not federally managed, but regulations exist on an individual state level. Table 7 summarizes state regulations related to composting and compostable plastics. Almost all US states have some form of composting regulation (except for Alaska and South Dakota).

Recently, the C.O.M.P.O.S.T Act (Cultivating Organic Matter through the Promotion Of Sustainable Techniques Act) was introduced as a federal bill to incentivize and prioritize the growth of composting programs and infrastructures across the US. The Act would designate composting as a conservation practice for the US Department of Agriculture (USDA), meaning that projects producing or using compost could qualify for federal funding. The Bill allows grants of up to US$5 million and loans of up to US$5 million to be awarded for projects to expand composting infrastructure, including facility construction, acquisition of equipment (including de-packagers), and construction of on-site composting (including home composting programs). The grants and loans would be sourced from a US$200 million annual fund that would be available for 10 years. Funding would only be granted to composting programs for source-separated organics, which includes materials certified to meet ASTM D6400 and D6868 but excludes mixed solid waste (COMPOST Act, S.179, 118th Congress, 2023-2024). The Zero Waste Food Act was introduced simultaneously to establish a grant program that funds research, policies and programs that divert food from landfill. Grants, sourced from a 10-year, US$650 million annual fund, could be awarded to AD facility expansion projects (Zero Waste Food Act, S.177, 118th Congress, 2023–2024).

As described in section 2.3, the US has established national certification standards for bio-based and/or compostable plastics. However, these ASTM standards are not legally enforceable. This means that not all items sold in the US which claim to be “bio-based,” “biodegradable” or “compostable” will actually meet the ASTM standards’ requirements—only those with the associated labels—have actually met the certification standards. This has caused significant concerns around greenwashing and the increased pressure it places on consumers to understand the differences between misleading sustainability claims in marketing and the truth (Zhu and Wang 2020). The US Federal Trade Commission (FTC) issued its first Green Guides in 1992 and amended over the years to include specific recommendations for marketing biodegradable and/or compostable products and help marketers avoid making misleading environmental claims (US Composting Council 2021). The 1998 revision notes that “marketers should possess competent and reliable scientific evidence" showing that “all the materials in the product or package will break down into, or otherwise become a part of, usable compost (e.g., soil conditioning material, mulch) in a safe and timely manner in an appropriate composting program or facility, or in a home compost pile or device.” A revision in 2012 clarified that “timely manner” means “in approximately the same time as the materials with which it is composted” (Federal Trade Commission (FTC) 2012).

The FTC requires that all claims of “Compostable” be qualified to indicate whether the item is Commercially Compostable, Home Compostable, or both. Items that are “Commercially Compostable Only” must explicitly state this limitation and also make clear that consumers may not have access to commercial composting facilities. However, the requirements within the Green Guides are not agency rules nor regulations, but instead are specific environmental claims which the FTC may or may not find deceptive under Section 5 of the FTC Act. Although the Green Guides are not legally enforceable, they can be used in cases in court. In 2013, the FTC announced enforcement actions against six companies that claimed to be producing biodegradable plastic packaging, with one civil penalty totaling US$450,000 (FTC 2013). This was the first time the FTC filed a complaint against companies making unsubstantiated claims about alternative plastic packaging and indicates the willingness of the US government to make progress on the labeling and sale of these materials.

As mentioned in section 2.3.4, composters play an important role in the acceptance of compostable materials at their facilities. In the US, some composters seek out organic certification to allow their compost to be made available to organic farms and as a marketing tool when selling compost to conventional growers. The USDA currently views compostable plastics as synthetic and while the use of compostable plastics in compost is not expressly prohibited, many certifiers will not approve a compost that contains compostable plastic, unless it can be demonstrated that the plastic materials are screened out and removed (Rynk, et al. 2022). This issue is discussed further in sections 2.5.4 and 4.4.

Overall, when it comes to biodegradable plastics, US state legislation is more focused on the labeling of biodegradable plastic products and packaging rather than the banning of the material. For example, California, Washington, and Maryland, among others, have developed legislation that specifies the certification and terminology of compostable plastics to better integrate them into composting systems.

In terms of SUP bans, state and local policies still tend to vary significantly, with some states including biodegradable plastics under their bans and others encouraging their use as an alternative to single-use conventional plastics. For example, Hawaii, has variations in county policy on SUPs. Four counties, Maui, Kauai, Hawaii, and Honolulu, which represent the majority of the state’s population, have enacted SUP bag bans. These bans include a ban on compostable plastic bags.[11] The same four counties have enacted SUP food serviceware bans; however, the counties of Maui (Ordinance 5084), Kauai (Ordinance 1079), and Hawaii (Ordinance 17-63 and 19-85) allow compostable plastic alternatives as long as they meet ASTM standards.

Although not banned in federal legislation (unlike in the EU), oxo-degradable additives to plastics were included in the US Plastics Pact list (published in January 2022) of "problematic and unnecessary" plastic materials to be phased out by 2025. The US Plastics Pact is a voluntary initiative representing 33% of the US plastic market, so it has significant influence.

In contrast to these somewhat unclear national approaches to biodegradable and oxo-degradable plastics, there is clear support for recyclable bio-based non-biodegradable plastics. Under the USDA's BioPreferred Program created by the 2002 Farm Bill, which has the aim of increasing the purchase and use of bio-based products, the US Government and its contractors are required by law to give procurement preference to bio-based products. To help with this, the USDA maintains a list of certified categories and products. The current list includes 139 product categories, all with minimum bio-based requirements, depending on the product type, and a "USDA Certified BioBased Product" label, which verifies the bio-based content of each product (see section 2.3.1) (USDA 2023). The current administration continues to promote the development of the bio-based industry: in September 2022, President Biden signed an "Executive Order on Advancing Biotechnology and Biomanufacturing Innovation for a Sustainable, Safe, and Secure American Bioeconomy" (The White House 2022). And in March 2023, the Biden administration set the goal of replacing 90% of conventional plastics with bio-based alternatives in the next 20 years (Toloken 2023).

Table 7. Bans and regulations of compostable packaging in the United States

State	Policies favorable to food waste composting[12]	State regulatory language specific to compostable packaging	Allow composting facilities to decide if they accept compostable packaging	Have organic waste landfill bans and/or recycling laws	Have legislation on labeling and marketing of compostable packaging	Ban SUP bags, including compostable bags	No policy on compostable packaging (including bans) nor favorable to food waste composting
Alabama							X
Alaska							X
Arizona							X
Arkansas	X						

[11] Kaua'i County accepts 100% bio-based, nature-biodegradable plastic bags if approved through a written application (Ordinance 885). However, no plastic bags currently exist that are nature-biodegradable in reasonable timeframes and that are 100% bio-based.
[12] Favorable policies include policies, such as food waste landfill bans, food waste collection mandates, compost feedstock definitions that include food waste, and exemptions that make it easier for small-scale composters to establish themselves.

State	Policies favorable to food waste composting[12]	State regulatory language specific to compostabl e packaging	Allow composting facilities to decide if they accept compostable packaging	Have organic waste landfill bans and/or recycling laws	Have legislation on labeling and marketing of compostable packaging	Ban SUP bags, including compostable bags	No policy on compostable packaging (including bans) nor favorable to food waste composting
California	X	X	X	X	X		
Colorado	X	X		X	X		
Connecticut	X			X		X	
Delaware						X	
Florida							X
Georgia							X
Hawaii						X[13]	
Idaho							X
Illinois							X
Indiana							X
Iowa	X	X	X		X		
Kansas							X
Kentucky							X
Louisiana	X						
Maine	X					X	
Maryland	X	X		X	X		
Massachusetts	X	X		X	X		
Michigan							X
Minnesota					X		
Mississippi	X						
Missouri							X
Montana	X						
Nebraska							X
Nevada							X

[13] Not a state ban but a de-facto ban. Four out of the five counties in Hawaii, representing most of Hawaii's population, have implemented a SUP bag ban. Only Kalawao County has not implemented a plastic bag ban; however, Kalawao has a population of only about 82 people (US Census Bureau 2022).

State	Policies favorable to food waste composting[12]	State regulatory language specific to compostable packaging	Allow composting facilities to decide if they accept compostable packaging	Have organic waste landfill bans and/or recycling laws	Have legislation on labeling and marketing of compostable packaging	Ban SUP bags, including compostable bags	No policy on compostable packaging (including bans) nor favorable to food waste composting
New Hampshire	X						
New Jersey				X			
New Mexico							X
New York	X	X		X		X	
North Carolina	X						
North Dakota							X
Ohio	X	X			X		
Oklahoma							X
Oregon	X						
Pennsylvania							X
Rhode Island	X			X			
South Carolina	X						
South Dakota							X
Tennessee							X
Texas	X						
Utah							X
Vermont	X	X	X	X		X	
Virginia	X						
Washington	X	X	X	X	X		
West Virginia							X
Wisconsin							X
Wyoming							X

Source: Compiled from (Waste Management Consulting LLC 2023), (US Composting Council n.d.), (ReFED 2023) and (GreenBlue 2022).

5.2 Canada

In Canada, waste and recycling regulations are primarily established by individual provinces and territories, while management is led by municipal authorities. The Government of Canada has authority under the Canadian Environmental Protection Act (CEPA) of 1999 when there is the potential for pollution from waste into the air, land, or water. The federal government is also responsible for waste management activities on federal land, as well as interprovincial and international movement of hazardous waste and hazardous recyclable materials. In its efforts to tackle the growing issue of plastic pollution, from both conventional and bio-based and/or biodegradable plastics, the federal government has enacted the Single-use Plastics Prohibition Regulations (SUPPR) (Government of Canada 2022). Furthermore, the Government of Canada is drafting regulations for recycled content and labeling rules for plastics (for recyclability and compostability) and is developing a federal plastics registry (Government of Canada 2023).

Single-use Plastics Prohibition Regulations (SUPPR)[14]

The SUPPR is the first piece of federal legislation in Canada under the government's plan to reduce plastic pollution and move towards a circular economy. The SUPPR bans the manufacturing, sale, and importation/exportation of six categories of SUPs (checkout bags, cutlery, foodservice ware, stir sticks, straws, and ring carriers). The SUPPR was passed under the Canadian Environmental Protection Act of 1999 after the ministers of Environment and Health made recommendations to add "plastic manufactured items" to Schedule 1 to the Act, based on the findings of the *Science Assessment of Plastic Pollution* (Government of Canada 2021). This addition allows the Government of Canada to propose risk management measures on plastic manufactured items to manage the potential ecological risks associated with those items becoming plastic pollution (Government of Canada 2021). The government's decision to add plastic manufactured items to Schedule 1 and to ban certain SUPs is currently being challenged in Federal Court by an industry group, The Responsible Plastic Use Coalition (Thurton 2023).

The SUPPR is supported by the *Science Assessment of Plastic Pollution*, published by the federal government in October 2020, which examines the potential impacts of plastic pollution on human health and the environment (Environment and Climate Change Canada & Health Canada 2020). With regards to biodegradable, compostable, bio-based, and oxo-degradable plastics, the report finds that there is "a lack of significant evidence that biodegradable, compostable, bio-based, and oxo-degradable plastics will fully degrade in natural environments" (UNEP 2015) (European Commission 2018) (European Commission, Directorate-General for Research and Innovation 2019).

The Regulatory Impact Analysis Statement that accompanies the SUPPR states that it treats single-use items made from "non-conventional" plastics (i.e., bio-based, compostable and biodegradable plastics) in the same way as "their conventional plastic counterparts." As such, single-use checkout bags, ring carriers, cutlery, straws, and stir sticks made from conventional or non-conventional plastics (i.e., bio-based, compostable and biodegradable plastics) are banned outright by the SUPPR. Non-checkout bags are not prohibited, meaning that single-use conventional or non-conventional plastic non-checkout bags can still be sold. For example, industrially compostable plastic bags

[14] See also the CEC Milestone Study on Plastic Waste Management in the US and Canada for further details.

designed to hold organic waste can be sold (e.g., in supermarkets), however a checkout bag itself cannot be designed or sold for this purpose (Government of Canada 2023) (Nay 2023).

Furthermore, the SUPPR bans SUP cutlery and straws if they contain polyethylene (PE) or polystyrene (PS) or if they change their "physical properties after being run through an electrically operated household dishwasher 100 times" (Government of Canada 2022). Therefore, bio-based and biodegradable and compostable plastic straws and cutlery that fit the latter criterion are also banned (Drost 2023). However, for example, certain bio-based, non-biodegradable plastic forks (e.g., bio-PP) that can withstand 100 wash cycles can still be placed on the market.

For foodservice ware (a term the SUPPR uses to refer to food take-away packaging), only items made from the following materials are banned: expanded polystyrene foam, extruded polystyrene foam, polyvinyl chloride, carbon black, and oxo-degradable plastic. Non-conventional plastics (including bio-based and/or biodegradable plastics e.g., compostable plastics like PLA) are not listed as prohibited plastics and therefore can be used for foodservice ware.

The SUPPR's supporting document "Guidance for selecting alternatives," offers compostable alternatives to SUP foodservice ware but recognizes that compostable alternatives require viable collection treatment pathways:

> Some alternatives can be plant-based or fiber-based, and if certified compostable, could reduce the quantity of plastic sent to landfill. It is important to remember that in some areas, the company collecting products for recycling or composting, and the company responsible for the recycling or composting process are not the same. Businesses should therefore verify that their products are accepted by local recycling or organics collections programs, otherwise these items will end up being discarded (Environment and Climate Change Canada 2022).

By banning single-use plastic checkout bags, cutlery, ring carriers, stir sticks and straws made from both conventional and "non-conventional plastics," the approach taken in the SUPPR fits within the overall Government of Canada's communicated plan to reduce plastic pollution and move toward a circular economy. By allowing "non-conventional" plastic in single-use foodservice ware, the approach aims to recognize ongoing government and industry efforts to improve the value recovery of compostable plastics through improved standards, labeling, and innovation.

To aid businesses in selecting the most sustainable alternatives to SUP foodservice ware while adhering to the bans under the SUPPR, the recommendations section of this report suggests the development of detailed procurement guidelines. These guidelines would be a development of the existing guidance for selecting alternatives,[15] which has little text on using bio-based plastic and/or compostable plastic alternatives, and include guidance on selecting the most appropriate/sustainable bioplastics as alternatives for specific product applications, including those banned under the SUPPR. This would reduce the burden of the current requirement for businesses to read and understand the regulation, technical guidelines, and the RIAS, where "non-

[15] Found at this web address (accessed November 1, 2023): https://www.canada.ca/en/environment-climate-change/services/managing-reducing-waste/reduce-plastic-waste/single-use-plastic-guidance.html

conventional" plastics are defined, and would reduce the burden of understanding the several materials and end-of-life management nuances that determine the sustainability of bioplastic alternatives. Additional recommendations are also made regarding use of compostable plastics for foodservice ware.

In addition to the SUPPR, some provinces are also adopting measures that specifically address SUPs, which in some cases have included banning single-use biodegradable packaging in product applications not covered by the SUPPR. For example, British Columbia has developed a Single-Use Plastics Action Plan, which proposes to ban a range of common plastic packaging items, including compostable and oxo-degradable plastic items. The items being considered for a ban are all oxo-degradable packaging, checkout bags, disposable foodservice ware (e.g., cutlery, straws, stir sticks) and problematic foodservice packaging (i.e., problematic to recycle).

Recent changes to British Columbia's community charter now allow local municipalities to pass their own legislation on banning SUPs without provincial approval. This suggests that bans of SUPs—including products made of compostable or oxo-biodegradable plastic—will become more widespread within British Columbia: as of 2021, more than 20 municipalities in the province developed by-laws banning these materials.

Beyond British Columbia, Table 8 provides an overview of the bans and regulations specifically addressing SUPs, including biodegradable plastics, across provinces and territories in Canada. Overall, provinces and municipalities within Canada have largely chosen to include biodegradable plastics within broader SUP bans.

Table 8. Bans and regulations in the provinces and territories of Canada

Province/Territory	Ban on single-use checkout bags	Ban on oxo-degradable plastics	Ban on compostable SUPs	Municipalities can independently ban materials
Alberta				
British Columbia **(under consideration)**	X	X*	X* Single-use checkout bags and problematic foodservice packaging**	X
Manitoba				
New Brunswick				
Newfoundland and Labrador	X		X SUP bags	
Nova Scotia	X		X SUP checkout bags	
Northwest Territories				
Nunavut				
Ontario				

Province/Territory	Ban on single-use checkout bags	Ban on oxo-degradable plastics	Ban on compostable SUPs	Municipalities can independently ban materials
Prince Edward Island	X		X SUP bags	
Quebec				
Saskatchewan				
Yukon	X		X***	

* Based on the Intentions Paper detailing a proposed regulation for plastic waste prevention which has not been enacted. The regulation may not pass but has been included in this report to indicate the ongoing discussions in this area and to highlight the fluidity around regulation of biodegradable plastic materials.

** As outlined in the above Intentions Paper, exemptions from the proposed ban of problematic plastic foodservice packaging (including compostable plastic) include materials that could be processed in most of British Columbia's composting facilities.

*** Policy does not explicitly ban compostable SUP bags but states that all SUP bags are banned (with exemptions) and only reusable bags can be provided.

Proposed Recycled Content and Labeling Rules for Plastics and the Federal Plastics Registry

The Government of Canada recently published a regulatory framework paper in April 2023, concerning recycled content and labeling of plastic packaging and SUPs, including labeling rules for recyclability, biodegradability and compostability (Government of Canada 2023). The proposed regulatory framework has not been adopted into regulation; however, if implemented, producers of certain plastic packaging and single-use plastic items would be:

- Required to include at least 30% to 60% recycled content in their products, depending on plastic packaging category and product type, by 2030.
- Required to meet rules for labeling plastics as "compostable" or "recyclable."
- Conducting recyclability assessments set out by the regulation, using QR codes in recyclable labels, using labels that differentiate the recyclability of different components.
- Prohibited from using green colored labeling, tinting, or striping on non-compostable plastic items associated with organics waste.
- Prohibited from using the terms "biodegradable," "degradable," or similar terms implying nature-biodegradability, and from using the terms "home" or "backyard" compostable.

The regulatory framework paper recognizes that bio-based plastic packaging would also be required to meet labeling and recycled content targets. For recyclable plastics to be labeled "recyclable," including bio-based drop-ins, the product would need to pass a recyclability assessment based on collection, sorting, and processing criteria. For plastics to be labeled "compostable," products must become third-party certified to ASTM, ISO standards for industrial compostability, undergo field testing, and demonstrate that the product is associated with organic waste. Additionally, the draft regulations specify that plastics labeled "compostable" must simultaneously be labeled "non-recyclable" and that PLU's produce stickers would be required to be compostable (Government of Canada 2023).

Though the above-proposed regulatory framework has not been enacted into regulation, the framework demonstrates that the government recognizes the benefits of compostable plastic in niche applications (e.g., produce stickers). Furthermore, the draft regulatory framework sets strict criteria to place certain plastic items labeled as compostable on the market, demonstrating that the government likely recognizes the challenges associated with collecting and processing compostable plastic and wishes to limit its use to more specific product applications.

Furthermore, the government is developing a plastics registry that would require producers to report data on the plastic products that they place on the Canadian market. Though the federal registry is still under development, the technical paper states that producers would be required to report data on the plastics placed on the market, collected for diversion, and treated through several end-of-life routes. The technical paper recognizes that, as part of the calculations for "plastics successfully recycled," producers would be required to report the amount of "plant-based plastic-like materials" collected for diversion and treated by composting and digestion to produce soil amendments (Government of Canada 2023), likely referring to bio-based industrially compostable plastics.

6 Best Practice and Additional Considerations and Challenges

As the preceding sections show, the bioplastics market in the US and Canada, and in general globally, is still relatively small and constantly evolving. The desirability of introducing these new materials into the market, and its waste streams, and the truth regarding the environmental benefits and dis-benefits they can bring, remain contested topics. This section builds on the assessment of bioplastics recycling and composting practices in the US and Canada outlined in the above sections and identifies key challenges and successes specific to bioplastic waste management.

6.1 Does Using Bio-based and/or Compostable Plastic Bring Environmental Benefits?

Research into overall ecological improvement of certified compostable plastics in compost is generally sparse and uncertain, with most studies focusing on ecotoxicity instead. There appears to be widespread consensus that compostable plastics generally provide little to no nutritional benefit to compost and/or soils. In addition, there is limited evidence of compostable plastics contributing to the assimilation of carbon into compost. In fact, research demonstrates that at least half of the carbon in compostable packaging is lost to CO_2 emissions released during the processes of decomposition, whiles the remaining carbon is incorporated into compost biomass.

Consequently, there is insufficient evidence to determine whether compostable plastics bring any net ecological benefits to compost or soil, and research currently demonstrates that recycling plastics may provide greater benefits than composting plastic (Eunomia Research & Consulting 2020). For example, SYSTEMIQ and the Pew Trusts found that the greenhouse gas emissions, from mechanically recycling conventional plastics into products with 100% and 25% recycled content, emit 2.1 and 3.5 tCO_2e per metric tonne of plastic utility. Conversely, industrially compostable PLA in current (global) system configurations emits the third-highest quantity of 5.2 tCO_2e per metric ton of utility, followed by incineration without energy recovery and open burning (The Pew Charitable Trusts; SYSTEMIQ 2020).

Lifecycle assessments (LCAs), comparing conventional plastics to bio-based and/or compostable plastics, show wide-ranging results, demonstrating that environmental impact is highly dependent on LCA system boundaries, scope, data availability and assumptions (e.g., feedstock, plastic polymer, end-of-life treatment, biodegradation rates) (Walker and Rothman 2020). This variation makes it difficult to recommend the use of one bio-based and/or compostable plastic polymer over another, or over conventional plastic polymers (Van Roijen and Miller 2022).

There is also a general conception that bio-based plastics are preferable to conventional plastics since they contain inert, biogenic carbon from renewable feedstock (Eunomia Research & Consulting 2020). In an analysis comparing US cradle-to-grave greenhouse gas (GHG) emissions of bio-based PE, industrially compostable PLA (also bio-based) and conventional plastics HDPE and LDPE, fossil-based plastics had the highest and bio-PE the lowest GHG emissions overall. This result is largely due to the renewable feedstock used to produce bio-PE, which captures carbon and remains inert in the product, unlike PLA, which biodegrades and releases the captured carbon (Benavides, Lee and Zarè-Mehrjerdi 2020). However, this result depends on many factors, including feedstock source and type of processing. In some cases, PLA is indicated as having a high carbon footprint, for example, in the Industrial Design & Engineering Materials Database (Idemat) (Idemat 2023).

Indeed, results begin to vary when various biodegradation and end-of-life scenarios, energy mix, and production processes are considered. For PLA, GHG emissions varied significantly (16% to 163%) due to changes in biodegradation behavior and end-of-life treatments. PLA emissions were 27% and 40% higher than HDPE (15% and 26% for LDPE) in scenarios where PLA is composted and landfilled, respectively (with 60% biodegradation rates). Landfill gas collection efficiency, which varies across landfills, also influenced PLA GHG emissions. Anaerobic conditions at the landfill mean that higher quantities of methane are emitted in landfill gas when PLA biodegrades, compared to compost facilities, where biogas released during biodegradation has lower methane content (~5% compared to ~50% composition). Additionally, production of PLA made up the majority of its GHG emissions, due to energy-intensive conversion processes, which generate higher GHG emissions compared to bio-PE, HDPE and LDPE. However, PLA production emissions are dependent on the electricity mix (i.e., the share of renewables), unlike bio-PE and conventional plastics processes which primarily depend on natural gas, further complicating assessments of overall polymer-specific GHG impact (Benavides, Lee and Zarè-Mehrjerdi 2020).

Other environmental impact considerations of bio-based and/or biodegradable plastics besides GHG emissions include likelihood of littering due to public perception of what “biodegradable” entails, direct and indirect land-use change (e.g., impacts of sourcing renewable feedstock for bio-based plastic) and chemical pollution from additives. Similarly, concerns related to compostable plastic reducing compost value include introducing pollutants into compost (i.e., chemical additives leaching), incomplete biodegradation of plastics in facilities and potential increase in non-compostable plastic contamination within composting infrastructure due to consumer confusion (Sustainable Packaging Coalition 2021). Conversely, lack of guidance on correct disposal can also introduce biodegradable plastics as contaminants in conventional plastic recycling streams, generating process inefficiencies (Eunomia Research & Consulting 2020).

The evidence suggests that bio-based and biodegradable plastics are extremely diverse and behave differently across national and local contexts. Generalized and simplified environmental impact statements that favor bio-based or biodegradable plastics over conventional (and vice-versa) can be detrimental to environmental targets and circularity goals and should be carefully assessed. Full LCAs (cradle to grave) should be considered before claiming that all bio-based plastic generates less of an environmental impact, be it climate or otherwise, compared to conventional plastic (Benavides, Lee and Zarè-Mehrjerdi 2020). Table 9 below demonstrates an overview of the methane and carbon impact of plastic types across end-of-life scenarios across plastic types (Eunomia Research & Consulting 2020).

Table 9. Carbon and methane impact of plastic types across end-of-life scenarios

<table>
<tr><th>Material</th><th>Landfill</th><th>Incineration</th><th>Composting</th><th>Anaerobic Digestion</th></tr>
<tr><td>Bio-based biodegradable</td><td rowspan="2">Mixed evidence, but likely to release at least a small amount of methane</td><td>Releases biogenic CO_2; offsets energy generation</td><td>Releases biogenic CO_2; ~1/3 is converted to biomass</td><td>Mass released as ~1/4 mostly methane which is captured and offsets energy generation; ~1/3 is converted to biomass, the remaining is biogenic CO_2*</td></tr>
<tr><td>Fossil-based biodegradable</td><td>Releases fossil CO_2; offsets energy generation</td><td>Releases fossil CO_2 ~1/3 is converted to biomass</td><td>Mass released as ~1/4 mostly methane which is captured and offsets energy generation; ~1/3 is converted to biomass, the remaining is fossil CO_2*</td></tr>
<tr><td>Bio-based non-biodegradable</td><td rowspan="2">Inert</td><td>Releases biogenic CO_2</td><td rowspan="2">Not viable waste disposal route (inert but unwanted contamination)</td><td rowspan="2">Not viable waste disposal route (inert but unwanted contamination)</td></tr>
<tr><td>Conventional</td><td>Releases fossil CO_2</td></tr>
</table>

Source: (Eunomia Research & Consulting 2020)

Note: Green = most favorable environmental scenarios; Amber = mixed or uncertain scenarios; Red = least favorable environmental scenarios.

*It is unclear exactly which proportions are converted to methane, CO_2 or biomass. This will largely depend on the resident time and whether there is a subsequent composting stage – the latter is assumed in this instance.

6.2 Product Design to Improve Recyclability or Compostability

The circularity potential of all products can be determined at the design stage. Designing products with their end-of-life in mind is important, to ensure repairability, recyclability and/or compostability and extend the product's lifetime to ensure maximum value is extracted from the raw materials and ultimately reduce overall virgin raw material extraction from the earth.

Designing for Recyclability

After determining in which applications bio-based, biodegradable, or compostable plastic would bring added value over conventional plastic in the product design (Table 9), the next consideration is how likely it is that the product is disposed of and treated effectively.

Since recycling brings greater environmental benefits over composting, designing products for recyclability is considered best practice, where possible (Markevičiūtė and Varžinskas 2022). Using bio-based, non-biodegradable plastics that can "drop-in" to existing collection and recycling infrastructure are more likely to be successfully recycled, compared to bio-based and/or biodegradable plastics that need new collection or processing infrastructure (e.g., PLA). Product design for bio-based non-biodegradable plastics should largely follow the same best practice product design principles for conventional plastics, given their suitability for standard recycling equipment and ability to be recycled with their fossil-based counterparts (Markevičiūtė and Varžinskas 2022). The product design principles outlined in the CEC Plastics Waste Milestone Study "Difficult to Recycle Plastics" section apply to drop-in bioplastics (e.g., bio-PP, bio-PET, bio-PE). Generally, product design across product applications should focus on (see the CEC Plastics Waste Milestone Study for more detailed design principles):

- Keeping products mono-material rather than multi-material;
- Designing for ease of separation for multi-component or multi-layer products;
- Avoiding the use of problematic labeling constructions that disrupt sorting; and
- Avoiding contaminants such as certain adhesives, inks, pigments and additives that may contaminate recycled material.

Regarding PLA, a compostable and bio-based plastic, although the resin is technically recyclable, the plastic is not recycled at scale within the US and Canada due to financial feasibility issues. Thus PLA should be used to capture organic waste instead. Nevertheless, the APR published guidelines for recycling PLA which can be used as product design guidance for recyclability should the share of PLA packaging continue to grow in the market (Markevičiūtė and Varžinskas 2022).

Designing for Improved Compostability, Soil Quality and Environmental Qualities

As explained in more detail in section 3.4, the primary concerns for composters regarding compostable plastic are:

- Contamination from non-compostables, due to sorting confusion and product lookalikes, and
- Contamination from compostables, when compostable products do not fully biodegrade within the necessary timeframe or contain chemical additives that are deemed harmful.

Compostable products are not feedstock and bring no nutritional value to compost. Modifying compostable plastic carbon and nitrogen ratios has the potential to improve compost quality, however, this is not a commercially mature product design innovation (Moreira, et al. 2018). Instead, compostable plastics are seen as tools to capture more organic waste and therefore it is important to design compostable plastics that will completely biodegrade within realistic timeframes.

The rate of biodegradation differs across composting methods, environment (e.g., microbial activity) and material, demonstrating the importance of field testing in ensuring products fully decompose (Van Roijen and Miller 2022). Thickness might matter in improving compostability, since size reduction can help increase surface area for biological degradation, though again this is dependent on material type (Van Roijen and Miller 2022). Including certain additives and feedstocks in compostable plastics can reduce their biodegradability. For example, polyhydroxybutyrate (PHB) is usually mixed with plasticizers to improve its mechanical properties, consequently reducing its biodegradation rates (Van Roijen and Miller 2022).

Conversely, it is also possible to modify the molecular structure of a compostable plastic to improve biodegradability, although research is still evolving and none of these innovations are market-ready. For example, research areas related to accelerating compostable plastic disintegration and biodegradation include bioaugmentation (i.e., adding certain microbial strains) (Castro-Aguirre, et al. 2018), incorporating fillers (e.g., zinc oxide compounds) (del Campo, et al. 2021) and embedding enzymes. For example, one study found that embedding enzymes into PLA and polycaprolactone (PCL) led to accelerated biodegradation rates, and almost complete degradation within two to six days in industrial composting temperatures (DelRe, et al. 2021). PCL is a synthetic polymer made from fossil-based source.

Though improving compostability through modification at the molecular level can be worthwhile, it is important to consider the impacts of introducing synthetic polymers (e.g., PCL) to compost and what impacts that may have. Even bio-based compostable plastics may have an impact on compost and/or digestate, for example by causing changes in compost fungal communities (Karamanlioglu and Alkan 2021) or by acidifying compost, thus affecting seed germination (Bandini, et al. 2020).

6.3 Contamination, Identification and Labeling

As outlined in section 3.4, contamination of feedstock and products from biological treatment routes (composting or AD) with conventional plastics and biodegradable plastics that have not adequately biodegraded is quite properly a major concern. Identification and sorting of biodegradable plastics, versus conventional plastics, by consumers and treatment facilities, remains the greatest problem for these materials.

As mentioned throughout the report, confusion during disposal, lack of awareness and misleading marketing all contribute toward the disposal of material in inappropriate waste streams (e.g., conventional plastic in organics waste or biodegradable plastics in recyclable waste). Education and awareness raising for both consumers and businesses can be important to develop appropriate disposal habits. Furthermore, education can further demonstrate where biodegradable and compostable plastics potentially provide limited, if any, additional environmental benefits over conventional plastic counterparts.

Regarding labeling and marketing, using generic terms such as “biodegradable” or “decomposable” (or variations of these) is not transparent and can confuse consumers as well as lead to green washing (Competition Bureau Canada 2021) (Federal Trade Commission (FTC) 2012). Best practice involves using third-party testing and certification to ensure that a product will fully biodegrade within reasonable timeframes before claiming it is compostable (see section 2.3.3).

Once a product has been certified compostable, an appropriate collection stream must exist, and consumers need clear instructions on how to dispose of a product in the right bin. Ideally acceptance of materials in collection programs and treatment facilities across the US and Canada would be the same, and so instructions on how to dispose of products could be the same across the two countries (in English, French, and/or Spanish as required).

How2Compost and How2Recycle labels in the US and Canada, which attempt to clarify things for consumers, can be used side-by-side for products made from multiple materials. Figure 24 shows how different potentially compostable products should be labeled. The left-hand label is for paper plates, the middle label for conventional plastic or bio-based and non-biodegradable plastic bags, and the right-hand label could be for cups made from bio-based and compostable PLA. The aim of appropriate labeling is to minimize the chance that consumers unintentionally contaminate the recycling stream and increase the successful disposal of compostable items, either to a compost bin, if available, or to a trash bin, if no composting bin is accessible (Sustainable Packaging Coalition 2021). Spatial limitations (i.e., having a large label) can be overcome by embossing and tinting products to aid rapid identification (BPI 2020).

Figure 24. Examples of the How2Compost and How2Recycle labels for different products

Source: (How2Compost 2023)

However, it is easy to see how consumers may continue to be confused by and/or overlook these labels, especially with the number of caveats still necessary, e.g., “composting programs for this plate may not exist in your area.” Consumers are more likely to identify products based on familiarity with the material, e.g., paper and cardboard products are clearly distinct from plastic products (whether conventional, bio-based or biodegradable), and dispose of them in the most commonly associated bin. Once the idea that biodegradable plastics can be disposed of with organics is introduced, the risk of confusion with conventional plastics and subsequent contamination increases. Even acceptance of fiber-based packaging and food service ware in compost or AD facilities is complicated by the possibility of paper products being lined with plastic as a moisture or grease barrier.

Generally, the simplest solution favored by composting and AD facilities is to screen out all packaging and materials other than food or garden waste. For example, A1 Organics, the largest composter in Colorado, US, announced that it would no longer accept anything other than food scraps and yard trimmings after April 1, 2023. This includes traditionally accepted fiber materials, like paper towels and coffee filters, as well as packaging or foodservice ware, even if labeled "compostable." The aim of these restrictions is to reduce the amount of material (currently 10%) A1 Organics receives that is too contaminated to process, while maintaining output compost product quality standards (Pyzyk 2023). More detail on facilities' acceptance of biodegradable plastics is covered in section 3.4.

It has to be concluded, therefore, that while labeling may direct more compostable material into a genuinely compostable stream, contamination will never fully be eliminated, and many composting and AD facilities will generally still have to screen out this compostable material for fear of other non-compostable contaminants being present—one being indistinguishable from the other, and physically impossible to separate from each other in the mixed organic stream. Better labeling, therefore, may not necessarily mean that more compostable material is actually composted. Measures other than labeling, captured in this report's final recommendations, are more likely to ensure biodegradable plastics are used and disposed of in a way that truly contributes to a circular economy.

6.4 Closed-Loop Systems

Closed loop systems for biodegradable and compostable plastics refer to systems, usually a building, site, or an event, where only selected food packaging materials are sold (e.g., compostable coffee cups) and all materials consumed on/within the premises are recovered for proper end-of-life treatment, in this case organics recycling. Theoretically, if all food and beverage packaging, sold, consumed and disposed of within a closed loop system, is industrially compostable, then food waste contamination should also decrease, thereby improving organics recycling. In reality, however, (and this has been the experience in Europe as well as the US,) there are neither restrictive boundaries keeping all non-compostable packaging out—i.e., people attending a site or event can often bring their own packaged items in and hence mix conventional plastic with compostable plastic. Additionally, collecting compostable plastic packaging within a venue or an event does not guarantee that the recovered waste will be accepted at an industrial composting facility, as noted earlier.

There are several examples in the US and Canada of closed loop systems for compostable plastic packaging. Stadiums and arenas in the US such as PNC Park in Pittsburgh (NatureWorks n.d.), Beaver Stadium at Penn State University, Target Field in Minneapolis (Green Sports Alliance 2022) and the MODA Center in Portland (NatureWorks n.d.) have previously launched compostable food service ware initiatives with US PLA producer NatureWorks. However, waste diversion estimates following program implementation are often vague and non-transparent, out of date (some older than five years) and are often published by vested stakeholders.

Restaurants and fast-food chains have also begun initiatives to replace single-use disposable food service ware with compostable plastic. The City of Seattle requires all food businesses to provide recyclable or compostable packaging versions of disposable items and requires businesses to subscribe to a composting service to process their compostable waste (Ordinance 123307). Compostable products must be approved by the two contracted organics recycling facilities, Cedar Grove and Lenz (City of Seattle 2023). In response to Seattle's 2010 Waste Ordinance, Taco Time, a quick-service restaurant chain based in the State of Washington, replaced all its conventional disposable food packaging with compostable packaging approved by Cedar Grove, an industrial composter responsible for the transport and treatment of collected packaging and food waste.

Taco Time piloted the program in 2010 using a three-bin system (one bin for residual, recycling and organic waste) and found that 90% of compost and recycling bags were contaminated, generating waste and financial losses. Despite instituting new solutions, namely editing signage and providing explanatory tray liners and table talkers to improve consumer awareness, the contamination did not stop. Ultimately, the chain found that switching all disposable products to compostable packaging and limiting sorting during disposal by using only one bin, was the best solution to reduce contamination. Converting all products to compostable materials was expensive and a lengthy process, with the last non-compostable item being replaced in 2018 (Benson n.d.). During this lengthy transition period, conventional plastic packaging (and other non-compostable materials) was being sold alongside compostable plastic packaging. If even a single bin was provided throughout this period, contamination of the food waste stream still occurred during disposal, likely requiring labor-intensive sorting to remove non-compostable packaging from the waste stream.

According to NatureWorks, Taco Time diverted between 70% to 75% of waste from landfill by 2017 (NatureWorks n.d.). Since then, no updated diversion rates have been published nor any statistics on the amount of compost produced from diverted food waste. Additionally, according to a 2019 interview with Wes Benson, Sustainability Manager, about 70% of sales stemmed from drive-through or to-go services (Jennings 2019), ultimately devaluing the closed loop system concept. Customers who buy compostable single-use food packaging on-the-go may not have ready access to an organics program that accepts compostable packaging or may not engage in pro-composting behavior nor properly dispose of products. Although Seattle's policies have led to increased participation in food waste composting (Kurtz and Fong 2022), non-compostable plastic waste makes up the majority of waste contamination by organics, according to the most recent 2016 waste composition data. For multi-family residential and commercial organics waste streams, where compostable plastics made up a larger share of waste compared to single family residential streams, non-compostable plastics comprised over 35% (multi-family residential), and over 40% (commercial) of contaminants, respectively (Cascadia Consulting Group 2018).

6.5 Innovative and Emerging Sorting, Recycling and Composting Technologies

The following section explores innovative and emerging composting, sorting and recycling technologies for compostable and/or bio-based plastics.

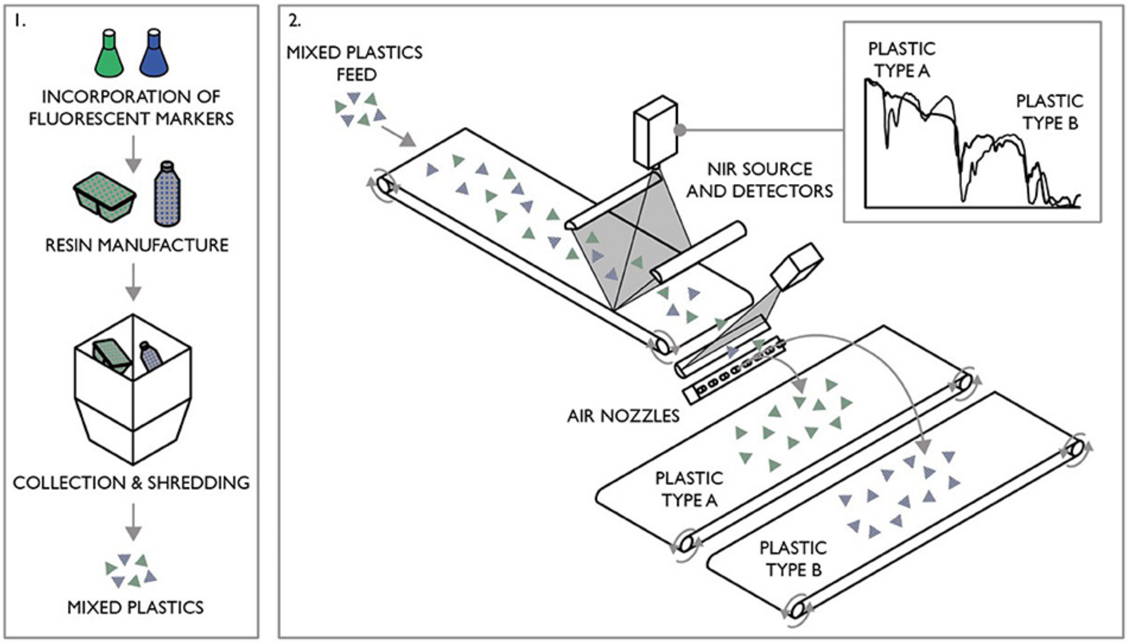
6.5.1 Sorting Technologies to Improve Biodegradable Plastics Recycling

Challenges with recycling biodegradable plastics (e.g., PLA) primarily exist due to manual and automated sorting lines being unable to differentiate between biodegradable and conventional, non-biodegradable plastics. Sorting technologies that can be used to sort biodegradable plastics include gravity-based, centrifugal, air tabling, triboelectric, and tracer-based sorting. Since gravity-based, centrifugal and air tabling sorting methods separate plastics based on their density differences, these technologies will have difficulty separating plastics with similar densities, such as PET and PLA (Taneepanichskul, Purkiss and Miodownik 2022).

Conversely, triboelectric sorting is based on charging plastics, which will then move depending on their charges, toward either a positive or negative electrode (Taneepanichskul, Purkiss and Miodownik 2022). The charges of the plastics differ according to their surface properties and can be used successfully to sort both conventional (GmbH 2021) and biodegradable plastics (Żenkiewicz, Żuk and Markiewicz 2015). However, the technology is highly dependent on material size and often requires a shredding or flaking pretreatment (Taneepanichskul, Purkiss and Miodownik 2022). An example of a highly efficient technology that employs this concept is the hamos EKS. Manufactured by the German company Hamos, the hamos EKS is an electrostatic separator that employs triboelectric sorting to separate mixed plastic waste (hamos 2023).

Tracer-based sorting utilizes a tracer within the material rather than relying on material properties to separate plastic resins. It can be highly effective at sorting biodegradable plastics from conventional, regardless of how "unidentifiable" the plastic may be due to deformation, color or contamination (Figure 25). Tracer-based sorting can utilize UV fluorescent markers that can be incorporated at the lowest possible concentrations during resin manufacturing. High concentrations of fluorescent markers in plastic products (both conventional and bio-based/compostable) can generate mechanical property alterations and impact visual appearance, though at low concentrations they do not contaminate recycling streams (Taneepanichskul, Purkiss and Miodownik 2022). Another limitation is that products containing fluorescent markers should avoid exposure to high temperatures or UV radiation (Taneepanichskul, Purkiss and Miodownik 2022). PolyPRISM markers have been successfully utilized for PP sorting in NEXTLOOPP trials, using TOMRA's sorting equipment, where sorting purities of over 99% were reached (Packaging Europe 2021). Another market-ready marker includes ErgisGroup's ErgisMark® (ErgisGroup 2023).

Figure 25. Concept behind sorting of plastic products using a fluorescent marker



Source: (Taneepanichskul, Purkiss and Miodownik 2022)

Finally, digital watermarks, imperceptible barcodes or QR codes on compostable plastic products, can be used for material identification during sorting. The technology relies on the "invisible" watermark being printed on labels, which are decoded by a high-resolution camera on a sorting line (Taneepanichskul, Purkiss and Miodownik 2022). Watermarks can also be scanned and read by smartphones, giving accessible information to consumers that can help them identify the best way to dispose of their product (Packaging Europe 2018). However, for a digital watermark system to work, it requires global standardization and access to databases. An ongoing EU pilot project, HolyGrail 2.0, is testing the feasibility of using these watermarks at commercial scales (AIM European Brands Association 2021). Digimarc Recycle is a market-ready digital watermark, available internationally and in the US and Canada, that provides a consumer engagement platform (accessible to consumers via scanning) with recycling instructions and information on product sustainability claims (Digimarc 2023).

Figure 26. Holy Grail 2.0 Digital Watermarks on printed packaging

Source: (AIM 2021)

These technologies could help improve material sorting, however, there is a consideration to be made on whether or not to invest in the high cost of the equipment. This decision-making is dependent on the market share of bioplastics: namely biodegradable plastics like PLA, which is currently rare and not significantly impacting the recycling of the conventional plastic waste stream. Once this market share increases, the costs of investing will likely be higher than the cost of not investing, and issues associated with increased contamination.

6.5.2 Lack of Innovative Composting Technologies

There are currently no innovative composting technologies that can improve compostable plastic biodegradation. Any composting technologies that reportedly have shorter retention times than traditional composting methods are unlikely to be able to biodegrade compostable plastics.

6.5.3 Chemical Recycling for Biodegradable and Non-Biodegradable Plastics

Chemical recycling through thermal depolymerization (pyrolysis and gasification), chemical depolymerization and solvent purification has been proposed as an option for managing bioplastic waste (European Bioplastics 2021). Non-biodegradable, bio-based plastics (drop-ins) could be used in chemical recycling processes, as with conventional plastics. For biodegradable plastics that cannot be integrated into mechanical recycling streams, chemical recycling may be an alternative disposal solution if they cannot be broken down in composting streams. This has not been tested in significant volumes, however, so it is unclear if chemical recycling will be a potential option for managing bioplastic waste.

Hydrolysis is a chemical depolymerization method that can recover valuable bio-based and/or compostable feedstock for aliphatic polyesters (e.g., PLA). Unlike mechanical recycling, chemical recycling does not degrade material properties with each recycling cycle and can tolerate minor contamination with conventional plastics. The hydrolysis process involves decomposition of PLA directly into lactic acid within water-based solutions. Another primary benefit of this process is that lactic acid can be directly used as feedstock in a new PLA product, avoiding the need to ferment sugars in order to generate lactic acid (McKeown and Jones 2020). However, successful chemical recycling of PLA would require a dedicated and reliant collection system for the material.

TotalEnergies Corbion utilizes hydrolysis to recycle PLA at their Luminy® PLA recycling plant in Thailand, which uses the feedstock to generate Luminy® recycled mass balance PLA grades, containing 20% recycled content (Total Energies-Corbion 2021). The importance of using the mass balance approach to measure and disclose recycled content is discussed in the CEC Plastics Milestone Study.

It should be noted that chemical recycling is not a silver bullet solution for mixed polymer waste streams, i.e., most chemical recycling processes cannot tolerate all types of mixed polymer feedstocks. Sensitivities to inputs still exist and therefore there are still requirements for segregating and sorting PLA waste to successfully break down the plastic into its monomers.

6.6 Good Practice Policy Case Study: Italy and France

Since the materials are relatively new and have a low market share compared to conventional plastics, there are no policy case studies within the US and Canada that demonstrate success in improving the composting of compostable plastics. As an alternative, northern Italy's case, where compostable plastics are used to improve food waste capture and circularity, and are largely accepted across biological treatment facilities, is evaluated below, along with the French anti-waste law.

6.6.1 Ensuring Biodegradable Plastic Enhances Food Waste Diversion

Italy's organics waste collection and treatment system is mature with long-standing policy for separate collection and food waste diversion. The country has the highest capture rate for food waste in the EU: a 2020 study estimated that in 2017–2018, Italy collected about 61 kg of food waste per capita, the highest rate, followed by Norway at 35 kg per capita (Zero Waste Europe 2020).[16]

To reduce plastics contamination, food waste is required to be collected using reusable containers or with certified, compostable plastic liners (according to the EN13432 standard). Italy banned SUP checkout bags along with fruit and vegetable (i.e., produce) bags in 2011 and 2018 respectively; however, certified industrially compostable bags were still allowed to be placed on the market and consumers are encouraged to use these bags as food waste liners (Newman 2020).

High separate collection rates are partly attributed to the use of compostable bags, which are seen to improve consumer participation (Ricci 2020) and reduce contamination of conventional plastics in composting and AD facilities (Zero Waste Europe 2022). Organic waste treatment facilities widely accept compostable plastic liners, which are reportedly deemed "compatible" with existing infrastructure (a mix of dry and wet AD). Italy requires a minimum of 90 days for compost to mature (in line with EN 13432) (Eunomia Research & Consulting 2020), reducing the likelihood that any compostable plastics will be left behind as contaminants. Additionally, Italy requires that AD digestate is also composted in a further stage (along with garden waste), to ensure a good quality final product that has the right carbon:nitrogen balance and is relatively contaminant-free (Eunomia Research & Consulting 2020).

A 2019–2020 monitoring study by the Italian Composting & Biogas Association (*Consorzio Italiano Compostatori*—CIC) indicated that conventional plastics (not limited to packaging) were making up an average 3.1% of the collected food waste stream. This level of conventional plastic contamination remains unchanged from 2016–2017 values (from a similar monitoring study), despite the conventional plastic bag ban had commenced in 2011 (Table 10). Unfortunately, CIC also estimates that in absolute terms conventional plastics in food waste increased by 23% between

[16] Northern Italy is far more active in terms of its separate waste and organic waste collection and treatment, with southern Italy in particular lagging some way behind (Newman 2010) (Agovino, Ferraro and Musella 2021).

the 2019–2020 monitoring study and the previous 2016–2017 study, a similar figure to the growth of treated food waste (Centemero 2020).

Table 10. Contamination rates in 27 Italian industrial composting and AD facilities

	% food waste treated in monitored plants	% compostable plastic in food waste	% contaminants (non-compostable materials) in food waste	% conventional plastic in food waste	% of contaminants fraction made of conventional plastic
2016–2017	75.5%	1.4%	4.9%	3.1%	62.4%
2019–2020	80.4%	3.7%	5.2%	3.1%	59.6%

Source: (Centermero 2017) and (Centemero 2020)

While 3.1% sounds like a low contamination rate, any amount of conventional plastic entering facilities can cause serious microplastic pollution in the resulting compost or digestate and affect final product quality, due to difficulties in removing microplastic contamination (see section 2.3.4). Approximately 80% of compost produced by Italian composting plants is used in agriculture and gardening (CIC, 2020), presenting a risk of microplastic accumulation.

As discussed in section 3.4, the key issue of contamination is of major concern and why several US and Canadian composting and AD facilities are often unwilling to accept, and thus screen out, compostable plastics (Oregon Composters 2019). Even a seemingly low percentage of contamination can generate significant economic losses. CIC estimated that the separation and disposal of contaminants inside organic waste costs about €52 million per year, which does not include the opportunity lost for processing organic waste feedstock that has now been disposed alongside impurities (i.e., organic waste that has been carried over into disposal alongside contaminants) (CIC 2020).

The conventional plastic contamination rate of 3.1% is comparable to the rates in a couple of spot examples in the US. King County (excluding Seattle) and the City of Seattle, Washington, have an estimated 2.8% and 2.2% plastic contamination rate for their collected commercial and residential food waste streams, respectively, though the EPA recognizes that these contamination rates are likely underestimated (US EPA 2021). In addition, these examples are more representative of collection programs operating within a smaller area and with a smaller population size than that of Italy.

Northern Italy's case ultimately demonstrates that biodegradable plastic bin liners can effectively be deployed to increase food waste capture across a whole country. However, conventional plastic contamination can still remain a challenge.

6.6.2 EPR for "Bioplastics": Biorepack, CONAI and COREPLA

Italy has an Extended Producer Responsibility (EPR) system in place for packaging where producers have shared responsibilities with local authorities to finance and operate waste collection and treatment. The Ronchi Decree (Legislative Decree No 22/97) mandated that the National Packaging Consortium (CONAI) oversee packaging recovery and recycling across Italy and ensure that recycling targets are met. CONAI consists of both packaging producers and users (businesses) who pay the CONAI Environmental Contribution (CAC), which varies according to material type, to cover collection and treatment costs for packaging (CONAI n.d.). The activities of six material Consortia are directed by CONAI, two of which are for plastic (Corepla) and "bioplastic" material (Biorepack). Using the CAC paid by producers, CONAI distributes the fees to the Material Consortia based on the share of packaging placed on the market by each material type. The Consortia are then responsible for the treatment of waste at end-of-life. However, municipalities are responsible in their operations for material collections. Based on agreements between CONAI and Italian municipalities (ANCI-CONAI Agreement), the Material Consortia pay a fee to help municipalities cover some of the costs related to waste collection (CONAI 2021).

Biorepack, the material Consortium for bioplastic material, was approved to be a part of the CONAI system by the end of 2020, making Italy the first European country to have an EPR system for compostable plastics that are collected and composted together along with food waste. Fees collected by CONAI will now be distributed to Biorepack to help municipalities pay for separate collection of food waste and enable improved treatment of compostable plastics (CONAI 2021).

Biorepack only covers EN 13432 certified compostable plastic packaging and is meant to bridge a waste treatment gap within Corepla (the plastic Consortium) which only deals with collecting and recycling conventional plastic. Before the introduction of Biorepack, Corepla charged higher compostable plastics material fees in 2019 (either €436/tonne or €546/tonne), due to the exclusion of composting facilities as a viable treatment pathway (Vetere 2020). The newly approved CAC was set at €294/tonne (315.63 US$/tonne) of packaging placed on the market but was recently reduced to €170/tonne for 2023 (185.48 US$/tonne) (Biorepack 2023). Biorepack has also introduced the following minimum biological "recycling" targets by weight:

- 50% of compostable plastics placed on the market by 31 December 2025, and
- 55% of compostable plastics placed on the market by 31 December 2030.

The Consortium reported that in 2022, 60.8% of certified compostable plastic packaging placed on market was composted, meeting their 2030 target (Biorepack 2023).

To reduce contamination within food waste, Biorepack pays higher collection fees to municipalities that have a lower fraction of impurities in collected food waste. Nevertheless, the consortium reported that contaminants in food waste were still a major challenge. In 2022, around 14% of compostable plastics were removed from treatment facilities due to contaminants (including conventional plastics) being disposed along with household food waste (Biorepack 2023).

Though the Consortium has reportedly achieved its 2030 target, contamination issues are still reported as major challenges for food waste treatment. And the long-term success of Biorepack in improving collection and biological treatment of compostable plastic is still undetermined, considering that Biorepack only began operations in 2021. However, Biorepack can serve as a case study for future evaluations into the effectiveness of EPR for certified compostable plastic used in the separate collection of food waste.

6.6.3 The French Anti-Waste Law

France has adopted policies that acknowledge the role that bio-based and biodegradable plastic can play in capturing food waste. In 2020, the French Government adopted the *Loi relative à la lutte contre le gaspillage et à l'économie circulaire*, known as the Anti-waste Law in short, which outlined multiple measures to reduce waste and improve material circularity (Loi n˚ 2020-105 du 10 février 2020).

The Anti-waste Law builds on previous laws, including the 2015 Energy Transition Law for Green Growth (Loi n˚2015-992 du 17 août 2015), which banned SUP bags and produce bags thinner than 50 microns, in 2016 and 2017, respectively. Due to a recognition of their role in capturing food waste, bio-based, home-compostable plastic produce bags were exempt, so long as they met home-composting requirements, of NF T51-800 (Décret n° 2016-379 du 30 mars 2016), the National French Standard for home-composting of plastic products, which is covered by the DIN CERTCO Home Compostable Certification Scheme (see section 2.3.3). Furthermore, bio-based compostable produce bags are exempt from the ban if they can be sorted in separate collection of bio-waste while also meeting minimum, bio-based content requirements. In particular, the bags were required to have a minimum bio-based content of 30% in 2017, which increased to 40% and 50% in 2018 and 2020, respectively. By January 2025, minimum bio-based content of SUP bags will be 60% (Décret n° 2016-379 du 30 mars 2016). The law also stipulated that by 2020, all SUP cups, glasses and kitchen plates to be banned, except for bio-based compostable items (Loi n˚2015-992 du 17 août 2015). However, the 2020 Anti-waste Law excluded exemptions for these single-use, non-bag products, only allowing single-use, bio-based home-compostable produce bags to be placed on the market (Loi n˚ 2020-105 du 10 février 2020).

The French Agency for Ecological Transition (*Agence de la transition écologique*—ADEME) notes that while fruit and vegetable plastic bags, which are not both bio-based and compostable, are already banned (since 2016), they still can be found on every small French market (European Bioplastis 2020), with the potential risk of ongoing contamination of food waste and compost. The Anti-waste Law, therefore, prohibited the importation and manufacture of SUP bags for supply within French territory as of January 2021 (*Ministère de la Transition Écologique* 2020). In addition, any non-compliance now results in fines of up to €3,000 and €15,000 for natural and legal persons, respectively, (about US$3,273 and US$16,368) (Loi n˚ 2020-105 du 10 février 2020).

The Anti-waste Law (Loi n˚ 2020-105 du 10 février 2020) also mandates the following:

- Labels on fruits and vegetables are banned since January 2022, unless labels are home-compostable, according to the French standard and made partially or fully of bio-based material.
- Marketing a product as "biodegradable," "environmentally friendly," or any equivalent claim is prohibited and any plastic material that is only industrially compostable, and not home compostable, cannot be claimed as "compostable." Additionally, all compostable plastic products must contain a "do not dispose of in nature" label.
- As of 2023, persons producing or holding over five tonnes of bio-waste annually, are required to set up source sorting, on-site valuation, or a separate collection of bio-waste.

> Bio-waste that has been sorted at source can be collected with plastic bags that meet home-compostability standards.

There is no reporting available on the effects of the 2015 Energy Transition Law for Green Growth and 2020 Anti-waste Law on improving food waste capture, increasing consumer awareness nor on reducing contamination within compost.

In 2021, the National Agency for Food, Environmental and Occupational Health & Safety (*Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail*—ANSES) was contracted by the government to report on the environmental and health impacts of bio-based, biodegradable and compostable plastics, as required by the Anti-waste Law. According to the report, ANSES claims that the compostable plastics are not compatible with home composting conditions, highlighting that industrial composting is a more favorable end-of-life treatment for biodegradable plastics, due to more controlled conditions. ANSES recommends that standards are reviewed and regulations changed to discourage the use of biodegradable plastics in home composting. The concern for home composting of biodegradable plastics stems from the resulting introduction of environmental contamination, namely microplastics. Despite NF T51 800 criteria for heavy metals, pollutants and temperature being stricter compared to the EN 13432 (industrial composting standard), it is highly unlikely that home composting conditions will match laboratory test conditions (Anses 2022).

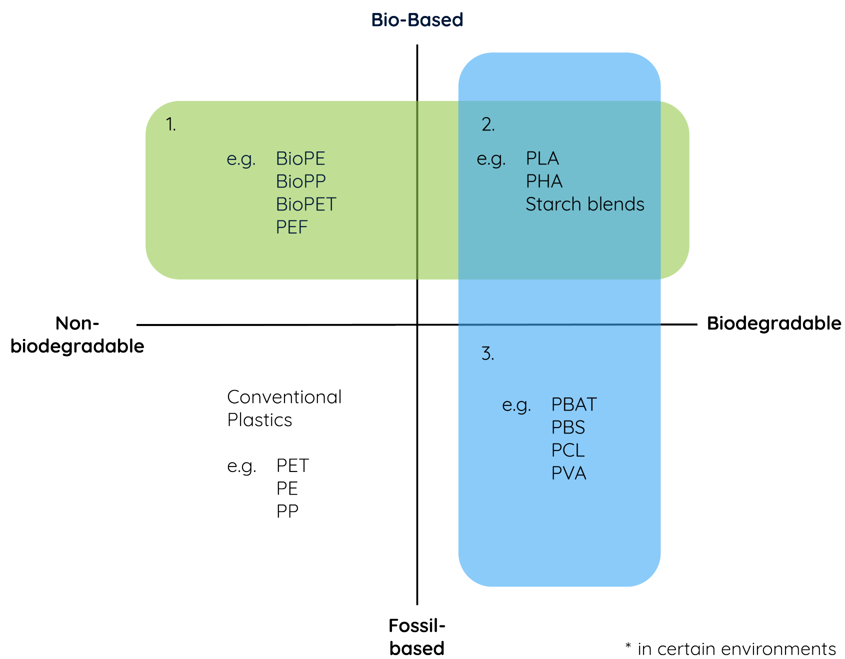
For example, a 2019 study commissioned by ADEME tested the biodegradation of home-compostable plastic produce bags under several conditions that followed the NF T51 800 requirements. According to the study, none of the plastic bags completely disintegrated within the timeframe required by NF T51 800 (180 days). Biodegradable plastic fragments up to 5 mm in size were found across all conditions—even after 12 and 18 months—and authors concluded that the current national standard does not allow for sufficient biodegradation time (ADEME, OrgaNeo, RITTMO Agroenvironnement, Microhumus 2019).

Furthermore, even if home compostable bags meet the NF T51 800 biodegradation threshold of 90% within 180 days, the residual fraction of material is still a cause of concern according to ANSES, considering that consumers may use home compost as organic amendments for produce (Anses 2022). The effects of the ANSES report, on the bio-based and home compostability requirements for produce bag exemptions under the Anti-waste Law, are yet to be seen; however, the findings may produce skepticism across consumers who home compost their food waste.

7 Findings and Recommendations

Based on the analysis of the bioplastics value chain, policy and regulatory landscapes, and best practices for improving circularity across the US and Canada given above, this section sets out, in table form, the key barriers to circularity and their possible causes, and provides recommendations for solutions, with these translated into concrete actions for policy makers.

Figure 27. Material coordinate system of different types of bioplastics



Source: Adapted from (European Bioplastics 2022)[17]

Barriers to bioplastic circularity and recommendations to overcome them are grouped by bioplastic material groups (see Figure 27) specifically by oxo-degradable plastics, bioplastics, biodegradable plastics, bio-based plastics, and recyclable, bio-based drop-ins.

The oxo-degradable plastics section (section 7.1) is applicable to plastics that fragment into microplastics and are often misclassified as biodegradable, although they do not fully biodegrade. The section recommends prohibiting or restricting their sale at the federal level.

The bioplastics section (section 7.2) encompasses all bioplastic groups (see Figure 27) and addresses barriers that affect both bio-based and biodegradable material groups, including misleading claims, lack of awareness, inappropriate application of alternatives, limited data

[17] This is the same Table featured in Figure 1 in this study.

availability, and lack of clarity and consistency in policy. Key recommendations for all bioplastics include:

- Make standards legally enforceable and develop labeling regulations.
- Issue guidance for when bioplastics are best placed as alternatives for product applications (for example, see Figure 28).
- Establish extended producer responsibility (EPR).
- Require or incentivize waste data monitoring.
- Introduce restrictions on single-use plastics and encourage reuse/refill systems.

The biodegradable plastics section (section 7.3) focuses on providing recommendations for barriers related to biodegradability and applies to both bio-based and fossil-based biodegradable plastics. Barriers include inappropriate product design, lack of home compostability standards, lack of infrastructure, low material acceptance at industrial composting facilities, and low accessibility to collection. Key recommendations for biodegradable plastics include:

- Issue guidance on designing products for appropriate applications (for example, see Figure 28).
- Adopt home compostability standards, develop more stringent industrial compostability standards, and adopt labeling regulations.
- Fund infrastructure development and expansion and introduce EPR.
- Fund R&D into improving compostability and nutritional value of compostable plastics.

Recommendations in the bio-based plastics section (section 7.4) focuses on addressing bio-based content barriers and applies to biodegradable and non-biodegradable bio-based plastics. Barriers related to sustainable feedstock production and bio-based content standards are addressed. Key recommendations for bio-based plastics include:

- Fund life cycle assessment (LCA) research on bio-based plastics.
- Develop and enforce sustainable resource production standards.
- Develop and align bio-based content standards.

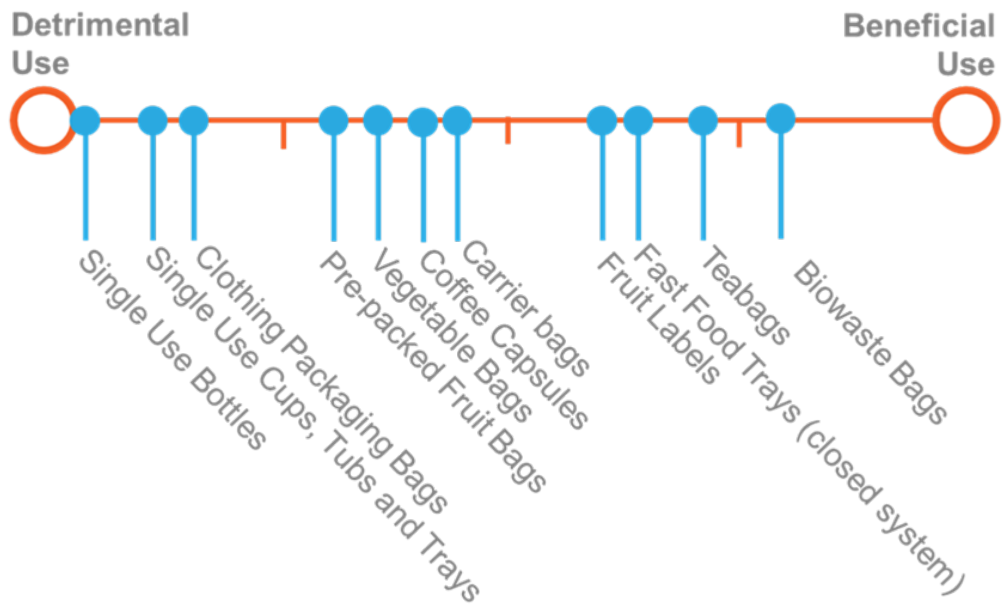
Finally, the recyclable, bio-based plastic drop-ins section (section 7.5) encompasses bio-based drop-ins that can be recycled with conventional plastic counterparts. It focuses on addressing barriers to recyclability, recycling infrastructure, market growth and recycled content demand. Key recommendations for bio-based drop-ins include:

- Increase policy signaling to stimulate their growth.
- Set maximum virgin fossil-based and minimum recycled content targets.
- Issue product design guidance and fund R&D into product design.
- Fund infrastructure expansion and improvements.
- Introduce EPR and/or deposit return schemes.

Certain bio-based recommendations (e.g., related to sustainable feedstock management) will still pertain to bio-based drop-ins. In addition, recommendations for bio-based plastic drop-ins are linked to the recommendations made within the CEC Plastics Waste Milestone Study, since drop-ins are designed to be recycled with conventional plastic counterparts and therefore rely on the same waste management systems and infrastructure.

A common recommendation is issuing guidance for designing, producing and/or using bioplastics in appropriate product applications. For example, applications may benefit from compostable plastics where: (1) the use of compostable plastic brings added environmental benefit over alternative materials under local waste management contexts, and (2) where the use of compostable plastic does not (in)directly result in compost quality reduction (e.g., contamination) (see examples in Figure 28). Appropriate product applications can be determined using LCAs that compare environmental performance between products.

Figure 28. Examples of the potential beneficial use of compostable plastics



Source: (Eunomia Research & Consulting 2020).

For some circularity barriers there are multiple possible causes, with their own corresponding suggested solutions and policy actions. In such cases, the following tables are structured, using separate cells and color-coding for clarity. The color-coding is simply red for the left two columns that outline the challenges and barriers to circularity; green for the right two columns that outline the suggested solutions. At the top of each table, the US and Canadian flags are used to indicate which of the US and Canadian nations the table applies to. It should be noted that there is some overlap and repetition in the tables below because barriers to circularity exist for multiple reasons, and policy actions may serve as solutions to overcome more than one of those barriers. For example, developing and providing guidance on the appropriate application of bio-based and/or biodegradable plastic alternatives for the best environmental/circular outcome is mentioned as a solution to barriers in procurement, product design, and in drafting single-use plastic bans.

7.1 Oxo-degradable Plastics

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
There is no circular end-of-life management pathway for oxo-degradable plastics, i.e., they cannot be reused, repaired, recycled, nor composted.	Oxo-degradable plastics do not fully biodegrade and rapidly fragment to produce microplastics: Oxo-degradable plastics, also known as oxo-biodegradable plastics, are modified conventional plastics with additives to accelerate biodegradation. Additives are commonly transition metal salts, though additives like cellulose and starch have also been used. Oxo-degradable plastics are often considered "biodegradable." However, oxo-degradable plastics do not truly biodegrade and instead fragment into microplastics. This makes oxo-degradable plastics unsuitable for composting due to contamination issues and the harm that microplastics can pose to people and the environment once the contaminated compost is spread on land. Since oxo-degradable plastics breakdown into microplastics at faster rates than conventional plastics, they are also not	Eliminate or restrict the selling and use of oxo-degradable plastics across all product applications.	Design and implement federal bans on oxo-degradable plastics and/or their additives, in the US and Canada to avoid patchwork policy at the state and local level. In the meantime, consider drafting legislation that eliminates misleading labeling and requires oxo-degradable plastics still in circulation to be labeled as not biodegradable nor compostable to ensure they are not placed in organic waste collection streams by consumers. Compost is spread onto land and any microplastics present thus accumulate in the environment, posing risks to humans and the environment. Note that oxo-degradable plastics still fragment into microplastics in landfill (which can potentially escape into the environment), so any circulation of oxo-degradable plastics on the market should ideally be eliminated. Although the SUPPR in Canada bans oxo-degradable materials from being used in

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
	recyclable alongside conventional plastics. Therefore, oxo-degradable plastics must be treated with residual waste (e.g., landfilled and/or incinerated with energy recovery), making it an unsuitable material for a circular economy.		manufacturing foodservice ware, policymakers should consider extending the ban to all product applications.
			Government procurement should establish purchasing guidelines and restrict or prohibit the purchase of oxo-degradable plastics.
	The Canadian government recently published a regulatory framework paper that proposes to prohibit the labeling of single-use plastics and plastic packaging as "oxo-degradable." Though the regulatory framework paper on labeling has not yet been adopted into regulation, publication of the draft regulation was anticipated for the end of 2023 with adoption sometime in 2024. Nevertheless, the regulatory framework paper only addresses labeling and does not address prohibiting oxo-degradable plastics from being placed on the market.	Fund awareness-raising campaigns targeting business operators that procure, use, and distribute oxo-degradable plastics.	Both federal and state/provincial level government should fund awareness-raising campaigns for consumers on the environmental impacts of oxo-degradable plastics.

7.2 Bioplastics

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
Bio-based and biodegradable plastic products contain misleading claims: Products are misleadingly marketed or labeled, both in terms of "sustainable," "eco" and/or "green" claims and in terms of disposal and treatment route (recyclable, compostable).	**Standards are not legally enforceable:** Standards for bio-based content, industrial and home compostability are not legally enforceable at a federal level, across the US and Canada. In the US, the FTC Green Guides has certain minimum requirements for labeling a product as "compostable," nevertheless, these are not agency rules nor regulations (though they can be used in court cases). Finally, the Canadian government recently published a regulatory framework paper proposing to prohibit single-use plastic products and plastic packaging from using the term "home compostable" and require plastic products labeled as "compostable" to be third-party certified against ASTM and ISO standards for industrial compostability. However, the regulatory framework on labeling has not yet been adopted into regulation and does not address bio-based content.	Make bio-based content and compostability standards legally enforceable at a federal level.	Consider making it a legal requirement for producers labeling their product as "bio-based," "industrially compostable," or "home compostable," to certify their products against a standard for bio-based content, industrial or home compostability. Standards would ideally be consistent across the US and Canada. Consider enforcing that products cannot be labelled as "biodegradable" and must be certified and tested against a standard for industrial or home compostability. If adopted, the Canadian government's regulatory framework on compostability labeling would effectively address the above action for industrially compostable plastics. However, the framework does not enforce testing against a bio-based content standard for products labeled as "bio-based."

	Misleading claims are not prohibited nor restricted: There are no national policies prohibiting or limiting the use of misleading claims (e.g., erroneously claiming biodegradability) on plastic products. The Canadian Government has recently published a regulatory framework paper for labeling single-use plastics and plastic packaging as "recyclable" or "compostable," but it has not yet been adopted into regulation and does not prohibit the use of misleading claims in the case of bio-based content.	Create federal level labeling regulations for bio-based, industrially compostable, and home compostable plastics.	Prohibit the use of misleading claims/labels other than "bio-based," "industrial compostable" and "home compostable." Consider restricting and/or prohibiting the use of "nature/soil/marine biodegradable" labels, due to the lack of international standards against which these products can reliably be tested. Additionally, based on the best available research, develop and use compostability and recyclability criteria and assessments for labeling bio-based and/or biodegradable products (as compostable or recyclable). The assessments should ideally include considerations for product design, accessibility to recycling and food waste collection, and the product's association with food waste disposal (for industrially compostable plastics which rely on this disposal route for proper treatment). Canada's regulatory framework paper on labeling addresses many of the above points for industrially compostable plastics. It sets forth rules on labeling single-use plastics and plastic packaging as compostable or recyclable and prohibits the use of misleading

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Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
			claims such as "biodegradable." However, it lacks policy addressing misleading labeling of bio-based content.
			Based on regulation, develop detailed guidance for producers on labeling bioplastics, including the definition of each material group (encompassed within bioplastics), their scope and their waste management requirements, to avoid misleading marketing. Guidance would ideally provide additional guidelines on conducting industrial/home compostability and recyclability assessments. Additionally, producers would ideally make available information that helps facilities define the appropriate process/treatment for the recyclable/ compostable product. Producers could make this information available on the labels themselves and through the publishing of technical specification sheets.

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
Businesses and consumers generating bio-based and biodegradable plastic waste are unaware and inappropriately using bioplastic products: There is a lack of clear information and guidance for businesses generating bioplastic waste (e.g., food and beverage businesses), and consumers of bioplastics, on the realities of waste management, including the material groups encompassed within bioplastics and the upstream and downstream management requirements for each material group. Businesses that use bio-based and compostable plastic products, often as alternatives to conventional plastics, often do not use these material	**Provision of guidance and awareness raising has been limited:** Current research has not been coherently summarized and effectively disseminated to users of bio-based and biodegradable plastics.	Inform consumers and businesses that generate bioplastic waste (e.g., food and beverage) of the differences between material groups, the waste management requirements of each, and the sustainability impacts of material mismanagement.	Provide best practice guidance for businesses that generate bioplastic waste (e.g., procurement guidance) and for consumers in the form of a toolkit with scenarios and applications in which bio-based and biodegradable plastics are most likely to be environmentally beneficial and where they are not. The guidance should be based on the best available research, including LCAs and analyses of upstream environmental impacts. Additionally, guidance should be a result of multi-stakeholder consultation and collaboration, including food and beverage associations.
			Fund educational and awareness raising campaigns for consumers and for businesses, with support and collaboration from the relevant trade associations (e.g., food and beverage associations) in the case of businesses.

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
groups in appropriate applications. In other words, bio-based and compostable plastics are often used for product applications that: 1. are unlikely to be recycled and composted, or 2. that cause contamination issues and other challenges within recycling and composting facilities. The added environmental benefit of using an alternative material to conventional fossil-based plastic is therefore reduced or, sometimes, entirely negated.	**No incentives to use bio-based and biodegradable plastic products in appropriate product applications:** Businesses are not incentivized to use bio-based and compostable plastic products in their appropriate product application. Even with the awareness-raising campaigns and educational tools in place (see row above), without incentives for appropriate usage (or disincentives for inappropriate usage), businesses may not be sufficiently motivated to make the most sustainable procurement choice.	Based on established guidance (see above recommendation) and on the available collection and treatment systems for bio-based and industrially/home compostable plastics, incentivize businesses using bioplastics to use respective material groups in their appropriate product application and to appropriately manage their waste at end-of-life.	There is a possible fiscal policy tool that could be explored and would need careful qualification for materials covered and materials would need to be certified to prevent unintended consequences: Consider providing tax breaks for businesses that use the bioplastic material groups in appropriate product applications, thereby also encouraging them to report on bioplastics they are using. The appropriate bioplastics are to be laid out in government procurement guidance for businesses as per a separate recommendation. Tax breaks are already being used in states within the US, for example, to incentivize the production of chemicals made from renewable resources. In Maine, there is a tax credit of US$0.07 per pound of renewable chemical produced in the state. Higher tax credits between US$0.09 and US$0.12 per pound are possible for chemicals produced from forest-derived biomass and for companies that meet criteria specified in

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Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
			legislation (LD 1698). The credit is only applicable on substances sold or used to produce chemicals, polymers, plastics, and formulated products with a minimum 95% bio-based content according to ASTM D6866 (LD 1698). In terms of providing tax breaks according to category, the UK Government provides tax relief in the form of capital allowances for certain equipment, machinery, and vehicles. For example, businesses can claim an "enhanced capital allowance" of up to 100% of the costs of purchasing certain equipment types. The list includes electric cars and zero-emissions goods vehicles, though the equipment must fulfill unique criteria to be eligible (HM Revenue & Customs 2023).
			Introduce eco-modulation under extended producer responsibility whereby businesses using bioplastic alternatives are incentivized to use them in the appropriate product application through a modulated fee structure. This would require explicit definitions of each product group

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
			encompassed within bioplastics and certification of products against standards (for bio-based content, industrial and home compostability).
Limited data availability in US and Canada: Across US and Canada, there are limited data available and/or accessible, around production, use, and end-of-life treatment of bio-based and biodegradable plastics and the processing capacities of facilities. This means there is a lack of detailed insight into tonnages of different materials in circulation, entering the waste stream, or escaping to the environment, and flows of material within waste streams, including how they are ultimately processed.	**Lack of data monitoring and reporting incentives/requirements:** Bioplastics consists of relatively novel groups of materials, making up a comparatively low fraction of waste generated. Across the US and Canada there are essentially no current requirements or incentives for data reporting.	Improve monitoring of bio-based and biodegradable plastic tonnages placed on the market and entering waste streams in US and Canada.	Collect data from MRFs to track the biodegradable plastic contaminants in conventional plastic recycling streams and collect data from industrial composting facilities on plastics of all kinds within the food waste stream. It is recommended to do this on an occasional audit basis, not continuously, to reduce the administrative burden. Data monitoring at facilities may require government support, in the form of grants or other financial support, to install appropriate sorting and identification equipment, especially considering that sorting at industrial composting facilities is largely manual.
		Develop and implement waste characterization standards.	Develop incentives/requirements and guidance for waste reporting and for performing waste characterizations, to better understand the composition of waste

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Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
			streams entering waste management facilities.
		Coordinate data reporting standards, across the US and Canada.	Use existing networks to enable collaborative discussions around data monitoring and reporting consistencies with stakeholders across the US and Canada. More consistent reporting would not only provide clarity on bioplastics production and waste management for the US and Canada but also would enable comparisons to be made across countries.
Lack of clarity on where bio-based and biodegradable plastics sit within single-use plastic bans: Policy at the local and state/provincial level can be unclear on whether bio-based and biodegradable plastics are included in SUP bans. In some cases, legislation suggests bio-based and certified compostable plastics as permitted alternatives to conventional single-use plastics. The lack of clarity and sometimes	**Lack of explicit guidance to policymakers on sustainable alternatives:** There is still confusion and/or lack of awareness among policymakers, around the end-of-life management requirements of bioplastic material groups and their current upstream and downstream management challenges and associated environmental impacts, especially for biodegradable plastics. Where LCAs on bio-based and biodegradable plastics exist for relevant product applications, they can show wide-ranging results in terms of environmental impact. Results are highly dependent on LCA system	Conduct further research into the product types and applications where bio-based and compostable plastics are feasible as conventional plastic alternatives and create the most added value throughout their lifecycle, in terms of environmental benefit, circularity, and use of materials.	Collaborate across government agencies to provide funding for research into bio-based and compostable plastic applicability and feasibility across product types. Research should take into consideration not only product requirements (e.g., product lifetime) but relevant production systems, waste management contexts, consumer behavior, and upstream and downstream environmental impact of the material group in respective product applications. Additionally, provide funding for country specific research and

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
patchwork policy at the national level can confuse businesses that use conventional single-use plastics on what alternative is considered a truly sustainable option and risks perpetuating single-use consumption.	boundaries, scope, data availability and assumptions (e.g., feedstock, end-of-life treatment, biodegradation rates) (Walker and Rothman 2020). The variation in results makes it difficult to recommend the use of one bio-based and compostable plastic over another, or of one bioplastic material group over a conventional plastic (Van Roijen and Miller 2022).		LCAs on bio-based and compostable plastic polymers, across a range of relevant product applications.
		Aggregate research on the environmental impact of bio-based and compostable plastics compared to conventional plastics, across waste management contexts.	Aggregate and summarize research on the environmental impact of bio-based and compostable plastics across relevant product applications, production scenarios, and waste management contexts, with the primary aim to create overarching report(s) defining scenarios in which bioplastics are most likely to be environmentally beneficial compared to conventional plastics (for each country). As a part of this action, gaps in current research should be identified, which can provide opportunities for further funding.
		Provide tools that equip policymakers with the knowledge necessary to incorporate bio-based and compostable plastics most effectively and least harmfully in their single-use plastic policies.	Based on research, create guidance for policymakers on different bioplastic materials, the potential environmental impact of each bioplastic material group, and the opportunities/challenges associated with their production, use and end-of-life management. This could be for states, provinces, and/or municipalities banning single-use

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			plastics and could be in the form of a hierarchical toolkit that highlights beneficial product applications according to material group. Such guidance could enable state, provincial, and local governments to suggest truly sustainable material alternatives, where reuse is not possible. Any guidance should highlight that all biodegradable plastic products must be certified compostable against a standard to be treated and processed either at industrial composting facilities or in home composting systems.
	Implementing reuse systems are still not a priority at the policy level: Many SUP bans do not promote reuse/refill systems and instead promote a transition to single-use alternatives, perpetuating single-use consumption and limiting advancements in the circular economy.	To transition to a truly circular economy, replace single-use products with reuse/refill systems where possible, through mandates or by incentivizing businesses. For many single-use plastic product applications (e.g., checkout bags), reusable alternatives are likely preferable to a single-use bioplastic material alternative. Nevertheless, LCAs should be conducted to determine which type, reusables or	US states and Canadian provinces should consider mandating reuse systems and refill quotas especially for food service ware when "sitting-in," though ideally it would be more effective to have a federal mandate which avoids patchwork policy.
			Incentivize the establishment of reuse/refill systems through pilot schemes and federal funding and/or grants. Grants can be awarded to reuse/refill projects, with support from relevant associations,

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
		single-use bioplastics, are least environmentally harmful for that product application.	such as food and beverage associations. Additionally, at the state or provincial level, consider providing tax breaks to businesses that implement reuse/refill systems. Across the US and Canada, single-use plastics are supplied by local vendors and are often consumed in shopping centers and in street markets (e.g., street food vendors) within urban areas, instead of "seated restaurants." In this case, local/state governments should consider, where viable, funding and/or piloting reusable packaging programs (e.g., for takeaway food) and incentivizing vendors/shopping centers/local suppliers, to engage in such programs.
		Raise the awareness of business owners about the benefits of implementing a reuse/refill system and provide them with accessible tools/resources to transition from a single-use to reuse/refill system.	Fund educational campaigns and training programs for businesses aiming to implement reuse/refill systems, in collaboration with relevant associations. Provide best practice guidance for businesses on setting up reuse/refill systems.

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
Single-use plastic policy remains inconsistent at a national level: Not all US states have banned or restricted the use and consumption of unnecessary single-use products, including single use conventional plastic and bio-based and biodegradable plastics. Furthermore, the promotion of alternative materials varies state-by-state, generating further confusion for businesses and consumers who generate conventional plastic and bioplastic waste. Only six states currently have single-use plastic bans in place that include a ban on compostable plastic bags as well as conventional plastic bags.	**Lack of national policy restricting or prohibiting single-use plastics:** At the national level in the US, there is no federal law prohibiting or restricting single-use plastic production and consumption.	Consider introducing federal law prohibiting and/or restricting single-use conventional plastic and bioplastic products. As recommended elsewhere, sustainable procurement choices can also be encouraged without policy through clear guidelines on appropriate product applications for different bioplastic materials, especially biodegradable plastics.	Consider introducing a federal policy that restricts or bans the use of unnecessary single-use plastics, clearly defining whether bioplastic alternatives are included in the ban and whether these vary according to product type/application. Important to consider is the single-use nature of a product, as much as the material from which it is made.
		Consider introducing national policies incentivizing businesses to transition away from single-use plastics to sustainable material alternatives (according to best practice guidance) and/or reuse/refill systems. As recommended elsewhere, sustainable procurement choices can also be encouraged without fiscal policy through clear guidelines on appropriate product applications for different bioplastic materials, especially compostable plastics.	Consider requiring states, at minimum, to implement extended producer responsibility for packaging, requiring producers of/businesses using single-use plastics to finance end-of-life management of their product. To disincentivize businesses from using SUPs or from placing SUPs on the market, consider introducing eco-modulated fees that charge higher fees for single-use plastics based on reusability, recyclability, and/or other circularity criteria. Whether bio-based and compostable alternatives are charged different fees from conventional plastics should be

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Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
			explicitly defined, including whether these fees vary according to product type. Also important to consider is the single-use nature of a product, as much as the material from which it is made.
			Consider taxing businesses that unnecessarily use SUPs when more circular alternatives are available on the market (e.g., reuse). Similarly, consider providing tax breaks, such as a tax credit, to businesses that have successfully transitioned away from using single-use plastics to reuse/refill systems and/or using more sustainable material alternatives, with consideration for the upstream and downstream management and environmental impact of said alternatives.

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7.3 Biodegradable Plastics

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
Inappropriate product design: Producers have designed and manufactured compostable plastics for product applications that are not necessarily associated with or appropriate to dispose of in the food waste stream (e.g., for food packaging in retail). Currently, industrially compostable plastics are only formally collected (e.g., by municipal or private waste collection programs) through the food waste stream. Similarly, households engaging in home composting dispose of home compostable plastics with their food waste. Evidence suggests that landfilling with compostable plastics should be avoided entirely to prevent methane emissions. Since industrial composting facilities are only likely to accept certified industrially compostable plastics, which capture more food waste, using industrially compostable plastics in	**Lack of disincentives, guidance, and awareness among producers/businesses:** Lack of disincentives and guidance for producers to manufacture compostable plastics for appropriate applications, combined with a lack of awareness or understanding of the difficulties associated with end-of-life treatment of these products and of the outright rejection of these materials by many food waste collection programs and composting facilities.	Disincentivize producers from designing compostable plastics to use for inappropriate product applications. The Canadian government recently published a regulatory framework paper which proposes that producers demonstrate their single-use plastics and plastic packaging labeled as "compostable" are associated with organic wastes, namely food scraps and yard trimmings. Additionally, the paper proposes prohibiting the use of the label "home" or "backyard" compostable. Such labeling requirements would reduce the use of misleading claims of compostability, and are also likely to reduce instances where plastics labeled "industrially compostable" are not associated with organic waste at end-of-life. The regulatory framework paper has not yet been adopted into regulation, but draft regulations for publication at the end of 2023 and adoption	Develop detailed guidance for producers on product design and appropriate product applications for compostable plastics, based on current upstream and downstream sustainability impact and waste management context. Heavily promote the guidance with large brands (e.g., food and beverage, retail, grocery), to encourage them to mandate the appropriate changes within their own supply chains. Producers will therefore be forced to change their product design, thereby generating cascading change for smaller brands/businesses that procure from those producers. Consider banning/restricting the use of compostable plastics for inappropriate product applications. Additionally, consider banning the use of biodegradable plastics that are not certified industrially or home compostable.

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
product applications not associated with food waste capture only leads to the facility rejecting and landfilling the material. Additionally, using industrially compostable plastics in non-food related product applications can generate consumer confusion on the correct disposal route (i.e., food waste) for the product, given that industrially compostable plastic is largely indistinguishable from conventional plastics.		sometime in 2024. So far, no minimum criteria have been published for producers to demonstrate their products are "associated with organic wastes."	
	Limited evidence on food waste capture: One argument for using compostable plastic for food service ware is to increase food waste capture as the packaging can be thrown away with the food waste and composted (as opposed to the food contaminating conventional plastic and preventing it from being recycled). Additionally, there is an argument that using compostable plastic as food waste bin liners helps increase food waste capture and residential engagement with food waste composting. However, there is limited evidence from the US and Canada on how, and by how much, industrially compostable plastics can improve the capture of food waste. The limited evidence of a positive relationship between industrially compostable plastic and food waste capture	Fund and conduct research into industrially compostable plastics and food waste diversion.	Fund and conduct studies within the US and Canada to understand the true impact that using industrially compostable food waste bin liners and food service ware have on food waste capture.
			Promote the use of paper/cardboard with an aqueous dispersion barrier coating (made of bio-based, compostable material) for food service ware in preference to industrially compostable plastic. In relatively closed systems like events or on campuses, this can be thrown in with food waste where separate collection exists to capture food waste and is easier to deal with in an AD plant or IVC. Aqueous dispersion barrier coating makes paper/cardboard resistant to water and grease. Unlike plastic lining glued onto the surface of a paper product, an aqueous

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
	restricts opportunities for policymakers to incentivize designing for food waste capture.		solution containing plastic particles is applied to the paper, which leaves a plastic layer when the solution is dried and contains less plastic. Though paper/cardboard with aqueous dispersion barrier coatings are largely compostable, the coatings commonly contain conventional plastic. Therefore, it is important to encourage the use and development of aqueous dispersion coatings that are bio-based, truly industrially compostable, and safe.
No home compostability standard exists in the US or Canada.	Home composting conditions are extremely variable, making it difficult to test against a standard.	Develop and/or adopt national home compostability standards, across the US and Canada.	Use existing international standards on home compostability as a basis for developing national home compostability standards and mandate that home compostable-labeled products are tested against a credible standard and certified. Begin collaborative discussions around aligning standards wherever possible, to ensure that certified home compostable products sold across markets are at least following similar standards and, therefore, treatment requirements. Use

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
			existing networks to align standards, involving relevant bodies, such as BPI, which is currently researching home compostable standards.
Lack of infrastructure to recycle recyclable compostable plastics: Infrastructure to process recyclable compostable plastics (e.g., PLA) does not exist to recycle these materials at scale, meaning they act as a contaminant to the conventional plastics recycling stream, and when they are removed from the conventional plastics recycling stream they are diverted to landfill.	**Low market volumes and economies of scale:** Low market volumes do not warrant separation and processing of these recyclable compostable plastics, and currently contamination of conventional recycling streams is not at a high enough level to cause problems (e.g., PLA acts as a contaminant in PET streams at very low levels).	As volumes of biodegradable plastics entering waste streams increase, it will be important to sort them out of the conventional plastics recycling stream. This will require installation of suitable sorting infrastructure in MRFs and may require research and investment into new sorting technologies that can identify novel biopolymers.	Where sorting technology already exists, e.g., NIR to detect PLA, provide grants and/or funding opportunities for plants to install sorting technology to remove biodegradable plastic contaminants. Conduct research or provide funding for research into sorting technology for improved sorting of novel biopolymers to reduce contamination of recycling streams. Include bioplastics under packaging extended producer responsibility, requiring them to finance end-of-life management of their product that could encourage investment into sorting and recycling infrastructure.

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
Food waste collection schemes and industrial composting facilities do not accept industrially compostable plastics: Many food waste collections and composting facilities do not accept industrially compostable plastics and discourage their disposal in organic/food waste streams. For example, in the US, Oregon composters in 2019 released a joint statement on the reasons why they do not wish to accept compostable plastics (Oregon Composters, 2019). According to GreenBlue data, an estimated 12% of composting facilities accepted compostable products. This is likely an overestimation of which facilities accept compostable plastics, considering that compostable products are not limited to compostable plastics	**Various industrial compostability standards:** There are multiple standards for industrial compostability, globally and across the US and Canada. These are criticized by compost facilities that they do not reflect real-world conditions, and the existence of many is challenging for businesses to follow, as well as to fit many labels onto their products.	Align standards for industrial compostability across the US and Canada.	Develop collaborative discussions with stakeholders in the US and Canada to understand the potential for aligning industrial composting standards across US and Canada, updated to reflect the latest scientific understanding and approaches including in-field testing. Ideally governments would develop a regional standard (used across the US and Canada) and liaise with others (e.g., the EU) to potentially develop a global standard, for example through the ISO since these materials are not only produced, used, and disposed of in the US and Canada.
	Incomplete biodegradation: Industrial composting standards do not follow realistic industrial composting conditions and testing is often completed under longer timeframes than what is operationally	Develop stricter standards and certifications for industrial compostability.	Consult the waste management industry and compost/digestate quality standards to inform biodegradation requirements under realistic operational timeframes and conditions for certified industrially compostable plastics.

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Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
and include, e.g., fiber-based materials.	necessary. Contamination from incomplete biodegradation of industrially compostable plastics reduces the product value of compost. This is especially the case for composting facilities that sell their soil amendments for use in organic agriculture, which often require the product to follow strict physical impurity standards.		Incorporate field testing (in composting facilities) into existing certification schemes, to ensure that a lab-tested and certified industrially compostable product will fully biodegrade within realistic timeframes. As part of the regulatory framework paper, the Canadian government is proposing that single-use plastics and plastic packaging labeled as "compostable" must undergo field testing within a Canadian composting facility before being labeled as such. The regulatory framework paper has not yet been adopted into legislation, although publication of draft regulations was expected by the end of 2023. Though not a mandatory part of certification, producers have field tested their industrially compostable products at facilities to ensure their acceptance. For example, in Calgary, Co-op and its supplier of compostable bags, LEAF Environmental Products Inc. collaborated with the Calgary Composting

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
			Facility to ensure Co-op's compostable checkout bags biodegrade in the city's composting process. However, the SUPPR banned the provision of single-use conventional and compostable plastic checkout bags. Therefore, the Co-op compostable bags are now banned from being provided during checkout but will still be sold in packs within the store to be used as bin liners for food waste.
			Revise standards by reducing the timeframe used to conduct biodegradation tests (i.e., requiring products to pass minimum biodegradation thresholds within shorter timeframes).
		While improving the acceptance of industrially compostable plastics within industrial composting facilities, promote innovation and improved product design.	Fund R&D and incentivize producers into improving the compostability of industrially compostable plastics, by collaborating with composters. Additionally, provide federal funding opportunities to upgrade composting infrastructure. Note that this solution is not a silver-bullet to improving the acceptance of

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
			industrially compostable plastics at facilities and measures such as the ones recommended above and below will need to be considered to improve the acceptance of these plastics at facilities.
	Contamination from conventional and other plastics: Industrially compostable plastics are largely indistinguishable from conventional plastics, home compostable plastics, and nature/marine biodegradable plastics. Consumers misidentify these plastics as industrially compostable and dispose of them in the food waste stream causing contamination at industrial composting facilities. Contamination from plastic products that do not fully biodegrade (e.g., conventional plastics), reduces product quality and value (Oregon Composters, 2019).	Develop more consistent and accurate labeling by implementing labeling regulations and improve consumer awareness around how to recognize biodegradable and certified compostable plastics and appropriately dispose of products. The Canadian government has published a regulatory framework paper on labeling single-use plastics and plastic packaging, which contains proposed requirements for labeling products as "compostable," including coloring and tinting requirements, The paper also prohibits the use of "home/backyard compostable," "biodegradable," "degradable," and the like. The regulatory framework paper is yet to be adopted into legislation, expected	Engage in collaborative discussions around labeling consistency with stakeholders in the US and Canada, to ensure that any products traded between countries are accurately recognized and disposed of.
			Consider federally mandating accurate, transparent labels for compostable plastics, including indications on whether the product is home or industrially compostable and how to dispose of the product. Any labeling scheme would need to be supported by consumer awareness-raising campaigns and by the creation and/or improvement of viable waste management infrastructure. As noted in the "suggested solution(s)" column, the Canadian government has published a regulatory framework paper proposing labeling

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
		for publication at the end of 2023 and adopted in 2024.	requirements for compostable plastic packaging and SUPs.
			Fund and conduct research into the extent to which labeling could be used to reduce consumer confusion. For example, pilot projects could install recovery containers in specific locations (e.g., waste depots/drop-offs and new locations like at event spaces and canteens) for consumers to dispose of industrially compostable plastics.
			Introduce extended producer responsibility for biodegradable plastics, with a requirement that a certain percentage of the extended producer responsibility fees (paid for by producers) goes towards awareness raising initiatives and communication campaigns on accurate identification and disposal. Additionally, fund educational and awareness-raising campaigns to educate consumers on differentiating between industrially compostable plastics, other bioplastics (e.g.,

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			bio-based drop-ins), and conventional plastics.
		In conjunction with stricter labeling regulations, reduce opportunities overall for confusion and, consequently, incorrect disposal, which causes contamination.	Introduce extended producer responsibility for biodegradable plastics and consider eco-modulating fees so that these plastics are not produced for/used in inappropriate product applications. Eco-modulation is likely to be specific to waste management context and should be aligned with national guidance on the appropriate uses for compostable plastics (as per a previous recommendation), based on the best available research.
	Compostable plastics provide no nutritional benefit to soil/compost: Compostable plastics not adding an inherent value to end-products (i.e., compost/digestate)	Promote product design and innovation.	Fund R&D into product design for industrially compostable plastics that do improve the ecological state/nutritional value of soil/compost. Note that innovation alone will not improve the acceptance of industrially compostable plastics at composting facilities. A range of policies will need to be implemented to reduce contamination at facilities and improve the acceptance of the material at facilities.

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
Low accessibility to collection schemes accepting industrially composable plastics: Low accessibility to food waste collection that accepts industrially compostable plastics, meaning that industrially compostable plastic products are likely to end up in landfill. This is still the case if consumers dispose of industrially compostable plastics in recycling streams since the material acts as a contaminant and would likely be sorted out as such.	**Separate food waste collection absent, limited, or inaccessible:** Separate food waste collection exists but is limited or inaccessible in the US. According to data on residential access to food waste composting programs in the largest US cities (representing ~40% of the US population), about 43% of residents do not have access to composting programs of any kind. Additionally, where residents do have access to composting programs, these were mostly in the form of subscription-based rather than accessible municipal programs. Furthermore, where accessible food waste collection programs do exist, there is low acceptance of compostable plastics within them. Only 8% of municipal curbside programs accept compostable packaging (not limited to compostable plastic) (GreenBlue, 2023).	Invest in a formal, effective, and accessible food waste collection and treatment. However, this solution would be for environmental goals related to emissions from food waste and capture of nutrients into compost, not for the sake of processing industrially compostable plastics.	Provide opportunities for federal funding and/or grants for expanding and upgrading infrastructure or use tax credits for new waste processing infrastructure.
			Collaborate with food waste prevention schemes and use existing networks to develop and implement organic waste management programs that are both accessible and engage residents.
		Increase producer involvement through extended producer	Develop guidance for states/provinces to implement extended producer responsibility for biodegradable

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
Limited treatment capacity for food waste, which is the only available treatment and processing route for industrially compostable plastics.	**Lack of food waste composting infrastructure or limited processing capacity for food waste:** In the US, though some infrastructure exists, facilities are less likely to process food waste, especially from residential streams. Of the total food waste processed in 2019 across EPA-surveyed AD facilities, less than 1% of the waste was sourced from residential streams (Schroeder, 2023). Similarly, BioCycle estimated that in 2015 to 2016, the amount of food waste processed across composting and AD facilities only made up 8.7% of the total feedstock processed (BioCycle, 2017).	responsibility for biodegradable plastics.	plastics and set minimum treatment targets for composting to encourage investment in infrastructure. If allowed to be placed on the market, consider using eco-modulated fees for nature/marine biodegradable plastics that cannot be reliably tested against standards and are not formally treated.
		Invest in organic and food waste treatment infrastructure.	Provide opportunities for federal funding and/or grants for infrastructure. For example, in the US, the C.O.M.P.O.S.T Act was introduced as a federal bill to incentivize the growth of composting programs and infrastructure and would have allowed grants and loans both up to US$5 million for projects expanding infrastructure.
			Improve existing access to organic waste management infrastructure by awarding federal grants for organic waste management projects on agricultural land.

7.4 Bio-based Plastics

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
Lack of policy managing sustainable feedstock production for bio-based plastics: Bio-based plastics, particularly drop-ins, can potentially provide several benefits due to their biogenic carbon. However, mismanaged feedstock production can still potentially generate environmental/sustainability impacts upstream, e.g., land-use change. Unsustainable agricultural practices (e.g., monoculture) during raw material production can generate negative environmental impacts (e.g., biodiversity loss) and indirect land-use change from competition for arable land. A 2020 study estimated that if bio-based plastics were to replace all conventional plastics in packaging globally, it would require a minimum of 61 million hectares of agricultural land and at least 389 billion cubic meters of water. Conventional plastic production uses much less water during production. When focusing on the EU only, authors found that substitution of conventional plastic packaging with bio-based plastics would require, on average, approximately 125 billion m^3 of water.	**Gaps in research:** There are gaps in research on the environmental impacts of bio-based plastics throughout their lifecycle, related to the relationship between bio-based plastic production, direct and indirect land-use change, and other unintended environmental impacts.	Improve research on the upstream impacts of bio-based plastic production and ways to improve the sustainability of bio-based feedstock production.	Provide funding for research into existing gaps in LCAs, particularly gaps related to incorporating direct/indirect land-use change in LCAs and gaps related to the relationship between direct/indirect land-use change and other cascading environmental impacts.
			Provide funding for R&D into sustainable agriculture, yield improvement and the use of second- and third-generation feedstock, which would reduce the demand for arable land.
			Conduct studies to measure current and future direct and indirect land-use change from bio-based plastic production (forecasting).
	Lack of sustainable resource management standards: Lack of enforceable national standards for	Develop and adopt national standards and guidelines for sustainable resource production and	Develop and adopt national standards and guidelines for sustainable feedstock production and management.

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
However, conventional plastic packaging would require less than 25 billion m^3 of water on average (Brizga, Hubacek and Feng 2020). Manufacturing processes can also generate environmental impacts if they are particularly resource intensive.	the sustainable management of raw materials (e.g., used in bio-based plastic production) and ensuring sustainable feedstocks are used. Canada has a relatively stringent forest governance framework that enforces a system of sustainable forest management and timber production (Government of Canada 2020). In relation to bio-based plastic production, forest management laws may currently be important in reducing instances of land-use change (e.g., forest clearing for crops). Wood cellulose (a second-generation feedstock) from timber can be used to create bio-based plastics. Nevertheless, most bio-based plastics are sourced from first-generation feedstocks (i.e., carbohydrate rich crops like corn). Standards and criteria enforcing sustainable crop management (for the bioeconomy) are still generally lacking (across the US and Canada). The US also have federal and state laws related to sustainable forest management and timber production,	management in a bioeconomy.	Incorporate direct/indirect land-use change as a measurement criterion. In developing standards, consult existing multi-stakeholder, credible certification schemes (e.g., ISCC Plus and RSB Global). Sustainable feedstock production standards may include, for example, criteria for sustainable agriculture, prohibitions on direct land-use change, and criteria to identify feedstock at high risk of generating indirect land-use change.
			Begin collaborative discussions around aligning standards and certification requirements across the US and Canada.
		Enforce sustainable resource management certification of bio-based plastic products.	Consider federally mandating that bio-based products are certified against above standards on sourcing from sustainable feedstock to be labeled as "bio-based." This would be in conjunction with additional

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
	though these are generally less stringent than those in Canada.		labeling/marketing prohibitions.
Bio-based products placed on the market are not easily comparable.	**Variation in bio-based content calculations:** Existing standards/certifications for bio-based content are based on varied calculation methods. Depending on the approach used, the calculated and certified bio-based content for the same product can vary significantly (Willemse and van der Zee 2018).	Align approaches to measure bio-based content across the US and Canada.	Begin collaborative discussions around bio-based content measures used within bio-based content standards with stakeholders from the US and Canada. Consider aligning approaches within standards, to ensure products are comparable across markets.

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
No standard for bio-based content currently exists in Canada.		Develop and/or adopt a national bio-based content standard.	Develop and/or adopt a standard based on existing standards, collaborative discussions with the US, and the best available research on the most transparent method to measure bio-based content.

7.5 Recyclable, Bio-based Drop-ins

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
Growth of bio-based drop-ins have been comparatively slow: Bio-based drop-ins (which can be recycled alongside conventional plastics) can potentially provide several benefits in a circular economy, namely in the case of achieving a net-zero trajectory. For example, bio-based plastic substitution of conventional plastic packaging (in Europe) is estimated to produce almost four times less the mean GHG emissions associated with conventional plastic packaging production (15 instead of 56 million tonnes CO_2eq) (Brizga, Hubacek and Feng 2020). However, the growth of bio-based plastic production has been slow relative to conventional plastic production (the bio-based market increased in size year on year by an average of 1% between 2017 and 2022).	**Producers are not incentivized to move away from virgin fossil-based plastic:** Lack of incentives for producers to move away from using virgin fossil fuels in plastics. Virgin fossil materials historically have been lower in price than bio-based material used in plastics (including drop-ins).	Set targets for reducing virgin fossil-based plastic content, which allows producers to incorporate recycled content and/or bio-based content (virgin or recycled) into their products.	Create national-level or state/provincial-level virgin fossil-based plastic content reduction targets or include virgin fossil-based content reduction goals as part of extended producer responsibility.
	There has been a lack of policy signaling to drive investment into the production of bio-based drop-ins.	Increase policy signaling.	Consider taxing conventional plastics based on virgin fossil content, such as was done in Spain and Italy (€450 per tonne of virgin non-recycled plastic packaging to be introduced in 2024). As an alternative, consider taxing plastics that meet a minimum virgin fossil fuel content, as in the UK (£200 tax per tonne of total packaging weight, where packaging has less than 30% recycled content, introduced in April 2022). Given that the taxes are based on virgin fossil fuel content, any certified bio-based content and recycled content within the plastics would not be taxed.
			Encourage, and consider mandating,

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
			the public sector to procure recyclable, bio-based drop-ins to increase volumes of the material produced, thereby reducing the price. The US has its own BioPreferred Program for bio-based plastics more generally (both drop-ins and biodegradable plastics). Canada could emulate the US's BioPreferred Program with a particular emphasis on recyclable bio-based drop-ins. However, such programs should be built upon, requiring the bio-based material to be certified sustainably produced/managed against standards. Additionally, a requirement should be in place to ensure that applications in which the products are being used are appropriate so that the products will be correctly managed at end-of-life. The US Government should consider including these requirements within their BioPreferred program.

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
Limited availability and use of recycled content: Bio-based drop-ins can be processed alongside conventional plastic counterparts and certain bio-based drop-ins are technically recyclable within the US and Canada due to the existence of infrastructure and a recycling market for conventional fossil-based counterparts. However, there is a limited availability and use of recycled plastic for both conventional and bio-based plastic) Though virgin bio-based drop-ins are often environmentally preferable to virgin fossil-based plastics, increasing the recycled content of bio-based drop-ins would generate circularity benefits and lead to even greater environmental savings. Additionally, like for their conventional plastic counterparts, product design can still generate recycling challenges for bio-based drop-ins and there is a lack of infrastructure to process "difficult to recycle" plastics.	**Lack of incentives for producers to incorporate recycled content into their products.**	Stimulate national demand for recyclate by ensuring an increasing demand for recycled content.	Consider mandating purchasing requirements for post-consumer resin and establishing minimum recycled content targets for manufacturers. If possible, consider applying import tariffs to virgin fossil-based materials to improve the economic viability of national recycled material.
	Lack of infrastructure available to sort and process "difficult to recycle" polymers and products, including multi-material flexibles.	Increase or improve existing recycling infrastructure to sort and process "difficult to recycle" polymers/products.	Provide grants and funding opportunities on sorting and recycling technologies to overcome challenges in recycling "difficult to recycle" products. Fund R&D into innovative technologies that overcome certain recycling challenges.
		Encourage product design principles that improve reusability and/or recyclability within the existing system.	Based on design guidelines, consider mandating design requirements for products, especially single-use products with no reusable alternatives.
			Fund R&D into designing products for reusability and recyclability and publish clear design guidelines for producers, to improve the reusability and

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
			recyclability of their products.
			Involve producers through extended producer responsibility for bio-based drop-ins and incorporate product design into an eco-modulated fee structure. Fees for products which, based on established national guidelines, do not follow minimum design principles for recyclability, are therefore higher, incentivizing producers to shift to more recyclable product designs.

Barrier to circularity	Possible cause(s)	Suggested solution(s)	Action(s) for policy makers
Inequitable access to recycling collection for plastics: Limited and unequal access to frequent, consistent recycling collections means that (as with conventional plastics), recyclable bio-based drop-ins may often end up in landfill despite being recyclable.	**Limited recycling collection access in rural areas and multi-family dwellings:** In the US, though formal collection for the recycling of plastic packaging exists in many areas across the country, access to collection is unequal. Two out of every five people in the US experience no or inequitable access to recycling collections (The Recycling Partnership 2021). About 40% of US residents only have access to drop-off recycling programs, largely multi-family dwellings and residents living in less-densely populated rural areas (Sustainable Packaging Coalition 2022).	Increase producer involvement through mandated or voluntary extended producer responsibility and/or a deposit return scheme and increase access points to plastic packaging recycling in both urban and rural communities.	Develop guidance/best practices for states to implement extended producer responsibility and/or a deposit return scheme across urban and rural areas.

Appendix

8 Circular Economy Definitions

Currently, there is no standard, internationally recognized definition of the "circular economy." Below are several definitions that were used to provide guidance and reference for carrying out this study.

8.1 Government

The Government of Canada:

The circular economy is a different way of doing business. The way our economies extract, use, then dispose of resources is putting pressure on our natural systems, communities, and public health. This is a linear economy—it moves in a straight line from resource extraction to waste disposal. In a circular economy, nothing is waste. The circular economy retains and recovers as much value as possible from resources by reusing, repairing, refurbishing, remanufacturing, repurposing, or recycling products and materials. It's about using valuable resources wisely, thinking about waste as a resource instead of a cost, and finding innovative ways to better the environment and the economy.

Source: https://www.canada.ca/en/services/environment/conservation/sustainability/circular-economy.html

The Government of the United States:

The term "circular economy" means: an economy that uses a systems-focused approach and involves industrial processes and economic activities that; are restorative or regenerative by design; enable resources used in such processes and activities to maintain their highest values for as long as possible; and aim for the elimination of waste through the superior design of materials, products, and systems (including business models).

Source: Save Our Seas 2.0 Act – United States law enacted on December 18, 2020

The European Union:

The circular economy is a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible. In this way, the life cycle of products is extended.

In practice, it implies reducing waste to a minimum. When a product reaches the end of its life, its materials are kept within the economy wherever possible, thanks to recycling. These can be productively used again and again, thereby creating further value.

This is a departure from the traditional, linear economic model, which is based on a "take-make-consume-throw away" pattern. This model relies on large quantities of cheap, easily accessible materials and energy.

Source: https://www.europarl.europa.eu/news/en/headlines/economy/20151201STO05603/circular-economy-definition-importance-and-benefits#:~:text=The%20circular%20economy%20is%20a,reducing%20waste%20to%20a%20minimum

8.2 Reports/Studies

Closed Loop Partners Report (2020)

Put simply, the circular economy eliminates the concept of waste and makes the most of materials that are already in play, much like natural systems in which nutrients are continually cycled. Resource efficiency, and the resulting opportunities for savings and profit, is at its core.

Source: The Circular Shift: Four Key Drivers of Circularity in North America Report

McCarthy et al. (part of OECD Environment Working Papers series):

There is no single commonly accepted definition of the term "circular economy," but different definitions share the basic concept of decoupling of natural resource extraction and use from economic output, i.e., increased resource efficiency as outcome. One core view of the circular economy is that it can be defined relative to a traditional linear economic system, i.e., one that focuses on closing resource loops. A second, slightly broader view of the circular economy stresses the importance of slower material flows, either within an economy with some degree of material circularity, or within one that is more linear. The third, and broadest view of the circular economy is that it involves a more efficient use of natural resources, materials, and products within an existing linear system. This broad view of the circular economy affects potentially all economic activities, not only those that have a high material use profile, and is the one applied in most modelling assessments and in this review.

Source: McCarthy, A., Dellink, R. and Bibas, R., 2018. The macroeconomics of the circular economy transition: A critical review of modelling approaches.

Circle Economy – Circularity Gap Report (2018):

At the heart of the circular economy is the idea of moving away from linear value chains that we have had in place for more than 200 years. It means breaking with the "take-make-waste" tradition and transitioning towards a circular approach that is much less heavily reliant on raw material extraction and much more focused on minimising and eliminating waste. The broader benefit of this circular model is to separate things we do want from our economic system – such as equally distributed prosperity and a bright future for the next generations – from those we do not want – like wasteful use of scarce natural resources and adverse effects on our environment and society. A circular economy is thereby a decoupling strategy aimed at growing prosperity, whilst intelligently managing resources within the boundaries of our planet.

Source: https://www.circularity-gap.world/

8.3 Organizations

Ellen MacArthur Foundation:

Systems solution framework that tackles global challenges like climate change, biodiversity loss, waste, and pollution. It is based on three principles, driven by design: eliminate waste and pollution, circulate products and materials (at their highest value), and regenerate nature. It is underpinned by a transition to renewable energy and materials. Transitioning to a circular economy entails decoupling economic activity from the consumption of finite resources. This represents a systemic shift that builds long-term resilience, generates business and economic opportunities, and provides environmental and societal benefits.

Source: https://ellenmacarthurfoundation.org/topics/circular-economy-introduction/glossary

International Resource Panel (IRP) & United Nations Environment Programme (UNEP):

The circular economy is one in which the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste is minimized. This is in contrast to a "linear economy," which is based on the "extract, make and dispose" model of production and consumption.

Source: https://www.resourcepanel.org/glossary

United Nations:

Whilst there is no universally agreed definition of a circular economy, the 2019 United Nations Environment Assembly, the UN's flagship environment conference, described it as a model in which products and materials are "designed in such a way that they can be reused, remanufactured, recycled or recovered and thus maintained in the economy for as long as possible."

Source: https://news.un.org/en/story/2021/06/1093802

8.4 Events and related communications

Sitra / World Circular Economy Forum 2021, Toronto (Canada) (WCEF):

The circular economy is not a new idea. Indigenous communities across North America and beyond have been practicing principles of circularity, including regeneration and reciprocity, since time immemorial.

Source: https://www.sitra.fi/en/publications/wcef2021-summary-report/

An economic model which does not focus on producing more and more goods, but in which consumption is based on using services—sharing, renting and recycling—instead of owning. Materials are not destroyed in the end but are used to make new products over and over again.

Source: https://www.sitra.fi/en/dictionary/the-circular-economy/

The circular economy is part of the glue that binds together the need to tackle climate change, the loss of biodiversity and the overconsumption of natural resources with an inclusive democracy, economic growth and increasing social well-being.

Source: https://www.sitra.fi/en/blogs/circular-economy-makes-business-sense-and-can-help-tackle-globalcrises/

Circular North America – Discussion Paper and Event Summary (May 2021)

The circular economy has come to the forefront as a solution for moving away from today's linear "take-make-waste" society, addressing growing environmental and social challenges and risks while generating significant economic benefits. Defining the opportunities for the US and Canada requires an understanding of where things are today, what the end goal is, and how to get there – identifying relevant natural resource industry strengths while leveraging service-based sectors and the broader innovation ecosystem.

Source: https://www.canada.ca/content/dam/eccc/documents/pdf/circular-economy/north-americapaper/WCEF-Circular-North-America_Report_2021_EN.pdf and https://circulareconomyleaders.ca/circularnorth-america/

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