CLOSED LOOP partners

Navigating Plastic Alternatives In a Circular Economy

A Closed Loop Partners Report

Table of Contents

This report has been produced by Closed Loop Ventures Group in collaboration with the Center for the Circular Economy at Closed Loop Partners.

Lead Author:

Hannah Friedman, Closed Loop Ventures Group & Internal Research Lead

Editors:

Kate Daly, Head of the Center for the Circular Economy

Danielle Joseph, Closed Loop Ventures Group

Georgia Sherwin, Director of Communications & Strategic Initiatives

Foreword

By Kate Daly

Head of the Center for the Circular Economy, Closed Loop Partners

As we imagine a waste-free future, with a truly circular economy for plastics, we must acknowledge that we're in a phase of contradiction, experimentation and trade-offs, alongside progress and advances, as we chart a new course.

Today, millions of tons of plastic waste end up in our oceans, at the tops of our tallest mountains and are even consumed, inadvertently, at our dinner tables. This waste highlights the inefficiencies of our current linear take-make-waste economy, in which we continue to extract finite raw materials, leaving the value of existing materials unrealized.

To break this cycle, a reduction in the volume of global plastics production is critical. This can be achieved in part by consciously designing systems and products to use fewer materials. By implementing circular business models, like refillable and reusable product and packaging formats, we can extend the life of materials in our economy, capturing the long-term value of resources and displacing the need for disposable, single-use items where appropriate. Rental and resale models can also help keep valuable materials circulating for multiple uses and create recurring revenue opportunities. Repair and refurbishment systems can then help prolong product life by replacing only needed pieces and preserving the integrity and use of the rest of the remaining material.

This fundamental reset of our current linear take-make-waste system won't happen overnight, and will require systemic changes in business operations, consumer behavior and policy, among other things. But there are near-term steps that take us in the right direction to address the critical failures of a linear system. In this report, we explore one approach to eliminating traditional single-use plastics that could offer the benefit of increasing the diversion of food scraps from landfill, and that is the rise of compostable packaging.

If formulated in accordance with certification standards, and captured properly after use, compostable packaging can take on another life as carbon sequestering, nutrient-rich soil to re-fertilize our lands. Compostable packaging can drive value across the system, rather than ending up wasted in a landfill, where the majority of single-use plastics end up today.

It is a tall order. Brands and packaging manufacturers will need to assess compostable materials with diligence and deploy them with restraint if we are going to get this right. Today, the organics processing infrastructure needed to recapture these materials properly after use is underdeveloped.

There is no silver bullet solution to the plastics crisis. Redesigning, reusing, repairing, recycling and composting materials are all complementary pieces of a broader puzzle. The materiality of products and packaging will always need to be evaluated according to their specific contexts—against their social, environmental and economic trade-offs—to ensure materials are kept in circulation at their highest value and best use case for as long as possible.

During this phase of experimentation, we may end up asking ourselves more questions than we answer, but that's an essential step as we transition to new approaches and systems. This report shines a light on compostable packaging as one tool in the toolbox to transition to a circular economy. This report does not define one material as environmentally superior to another, but instead, dispels some myths around this growing sector, laying the groundwork for better informed decisions on when reusable, recyclable or compostable packaging might be most appropriate. We continue to research, explore and test, and we invite you to join us on our collective journey toward a circular economy that eliminates waste and builds sustainable, inclusive systems for all.

Kate Daly

Kate Daly
Head of the Center for the Circular Economy, Closed Loop Partners

About Closed Loop Partners

We are an investment firm and innovation center building a circular economy, a new economic model focused on a profitable and sustainable future.

The firm is comprised of venture capital, growth equity, private equity, project-based finance and an innovation center. Our ecosystem connects entrepreneurs, industry experts, global consumer goods and technology companies, retailers, financial institutions and municipalities.

This report has been created by our Closed Loop Ventures Group, in collaboration with our Center for the Circular Economy.

Closed Loop Ventures Group
invests in early-stage companies developing breakthrough solutions for the circular economy, exploring leading innovations in material science, robotics, agritech, sustainable consumer products and advanced technologies that further the circular economy. The group was founded in 2017 and has made investments across four sectors: plastics and packaging, food and agriculture, fashion and beauty and supply chain logistics and technology.

The Center for the Circular Economy
is an innovation center for research, analysis and collaboration to accelerate the transition to a circular economy in which materials are shared, re-used and continuously cycled. The Center specializes in convening brands and industries to solve seemingly intractable material challenges, harnessing design, innovation and the power of collaboration to reimagine products and packaging for sustainable impact at scale, creating the systems change necessary for the advancement of the circular economy.

Our Methodology

Closed Loop Ventures Group reviews nearly 250 investment opportunities per quarter, observing trends and opportunity areas across sectors. Given the increased attention to plastic alternatives and the rising number of material innovations in our pipeline across product categories—including packaging, product formulations and apparel—we took a deep dive. We are equipped with the findings of our desk research, due diligence, interviews with thought-leaders and operators in the industry, as well as insights from across Closed Loop Partners' platforms—including a teaser of this content from our *Circular Shift Report* and our upcoming *Bringing Reusable Packaging Systems to Life Report* out of the Center for the Circular Economy. We situate plastic alternatives holistically within the circular economy.

We are uniquely positioned to synthesize the learnings across our different touchpoints in the circular economy—from pre-competitive collaborations with large multinational brands, to the convening of experts on environmental and social impact, to the operators in Closed Loop Partners' portfolio of investments. We are thrilled to share these learnings and systems-thinking approaches on plastic alternatives.

250

deals reviewed per quarter by Closed Loop Ventures Group

Executive Summary

Currently, only 9% of the world's plastic is recycled globally,[1] while 11 million metric tons of plastic waste enters our oceans every year[2] at a cost to people, the planet and business. In response, consumers and regulators are increasingly pushing companies to align their products and packaging with waste reduction and climate impact goals. This pressure has led to companies making ambitious public commitments for implementing plastic-free products, eliminating non-recyclable formats and increasing the recycled content in their packaging, in turn spurring a rapid and, at times, haphazard shift away from petroleum-based, single-use plastics that are bound for landfill.

A circular economy can provide the tools and models to guide a transition away from the current linear system. First, a circular economy is intentionally designed to use less material in the production, packaging and delivery of products. Second, in addition to reducing materials used, a circular economy aims to keep existing materials in circulation at their highest value and for their best use case for as long as possible, by reusing, repairing and recycling. As companies have begun to deploy these strategies, many are also turning to bio-based plastics, biopolymers and compostable alternatives (terms we define in this report)—resulting in a surge of innovation and a flood of new materials entering the market as plastic alternatives. Biopolymers and bio-based plastics are growing their market share, expecting to reach nearly $27.9 billion by 2025, up from $10.5 billion in 2020,[3] with over 2.8 million metric tons expected to be produced in 2025, up from 2.1 million metric tons in 2020.[4]

However, compostable alternatives are not a silver-bullet, and as they begin to enter the market at higher volumes, there is not enough recovery infrastructure to recapture their full value efficiently. Only about 185 full-scale commercial composting facilities in the United States accept food waste, and even fewer accept compostable-certified packaging.[5] With new materials already outpacing the capacity of our existing recovery infrastructure, there is a critical need to address the misalignment between production and end-of-life, to ensure even higher volumes of compostable packaging don't end up in landfill in the future.

Compostable alternatives play a very specific role as one line of defense against waste—after reduction and reuse—and should only be deployed in specific formats and contexts. It is critical that we look at biopolymer material innovations and compostable alternatives holistically within our entire system. Navigating this increasingly crowded and complex space can be challenging. What are the upstream impacts of sourcing and manufacturing these alternative materials? What are the best recovery pathways for these materials after use? What criteria should be applied to identify which packaging formats make the most sense as refillable versus recyclable versus compostable, based on the use case or product? How do we determine the contexts in which compostable packaging can play a role in diverting some of the 63 million tons of food waste—making up 21% of total solid waste[6]—going to landfills each year?

This report does not define one material for products and packaging as superior to another. Instead, it aims to demystify the landscape of bio-based plastics, biopolymers and compostable alternatives, and unpack the associated opportunities and challenges within the industry's move toward plastic alternatives. This report dispels the myths of deceptive vocabulary, lays out frameworks to navigate the challenges of contamination, highlights opportunities to drive value through the recovery system, demands rigorous testing to avoid unintended consequences and calls for more research in the space.

First, Closed Loop Partners uses vocabulary that defines materials by both their sources and their end-of-life. Regenerative by nature, a circular economy moves away from fossil fuel extraction and assesses the opportunities of bio-based feedstocks, ideally from waste sources. Circularity also requires that materials have a clear end-of-life recovery pathway that aligns with existing recycling or organics processing infrastructure, such as commercial composting or anaerobic digestion.

Second, Closed Loop Partners recognizes the business opportunity that resides in keeping materials in play as resources with a market value for as long as possible. Where reusable products and packaging are not yet at scale or are not appropriate for a given use case, clearly labeled products as either designated for recycling or for commercial composting helps avoid consumer confusion and the resulting contamination of the wrong material in the wrong place.

Avoiding contamination can be achieved, in part, by designing products in a way that drives value for their end-of-life recovery pathway. Converting easily-sorted, high-value plastics to compostable alternatives can result in lost revenue for plastics recyclers. Compostable products are suitable for small formats, such as cutlery and straws that already slip through the cracks of plastic recycling equipment, or non-recyclable formats such as multilaminate films. Critically, compostable products with high food-contact, such as plates and bowls, in the specific contexts can help increase the diversion of food scraps away from landfill and into organics processing streams.

In the transition from where we are today and where we need to go, in order to avoid replacing one problem with another, rigorous testing can demonstrate that materials add value as they flow through their end-of-life recovery pathways and do not create unintended consequences along the way. Testing ensures that products are sorted properly, that the recovered material has market value and that no residual microplastics or toxic chemicals enter the environment. Certification of compostable packaging can help avoid these externalities and communicate to consumers and recovery players where the products should go after use: avoiding landfill and our oceans. A circular economy can help funnel materials into either recycling or organics processing infrastructure.

Investment is critical to scale this underdeveloped infrastructure for the efficient recovery of materials after use. Investors, packaging producers and brands must collaborate and consider the complexities of biopolymers at end-of-life to ensure that these new materials bring value across the system.

Biopolymers and bio-based plastics can play an important role in contributing to net positive climate impacts through their potential to sequester carbon in soil, to create compost used for agriculture and to avoid the waste and greenhouse gas emissions associated with organic materials decomposing in landfill. Abiding by the tenets of the circular economy can help achieve these goals and avoid the unintended consequences of replacing one landfill-bound material with another.

Finding 1: Identify bio-based materials that use waste as a feedstock

CONSIDERATIONS: What are these materials made from? At scale, what might the social, economic and environmental consequences be? By solving one problem, could we inadvertently create another?

Finding 2: Design products and packaging that are clearly intended to be recyclable or processed in organics infrastructure

CONSIDERATIONS: What happens when products and packaging look alike but require different end-of-life recovery pathways? How do we avoid materials ending up in the wrong recovery stream and causing contamination?

Finding 3: Deploy compostable packaging to divert food scraps toward organics processing and to solve for product formats that are not successfully recycled today

CONSIDERATIONS: How do we know which product formats and packaging should be recyclable versus compostable? How can compostable packaging drive economic value to organics processing facilities? What role can it play related to food waste diversion from landfills?

Finding 4: Select materials and products that are certified compostable by industry-accepted third-parties

CONSIDERATIONS: How do we know if new compostable packaging solutions have been sufficiently tested to meet set standards and avoid negative externalities? How do we minimize confusion and move toward a shared language to navigate such a complex subject?

Finding 5: Reserve marine and soil degradable certifications for specific use cases

CONSIDERATIONS: What happens when we think beyond packaging, specifically about biopolymers used within our non-solid, consumable product formulations—in everything from the liquids in our shampoos to our laundry detergents?

Finding 6: Avoid landfills and leakage to waterways by designing for recapture within organics processing infrastructure

CONSIDERATIONS: How do we design a system to keep materials out of landfill and our oceans? What additional research is needed to fully understand the scope of plastic disintegration into microplastics?

Setting the Scene

SETTING THE SCENE

The Rise of Plastic Alternatives

At Closed Loop Partners, we envision a system in which all materials circulate at their highest value and best use case. With only 9% of the world's plastic recycled globally today and 11 million metric tons of plastic waste entering our oceans annually, single-use plastics and synthetic fibers in clothing are increasingly under scrutiny—from consumers, regulators and companies. Consumer preferences are driving the transition, supported by increasing regulatory tailwinds and against the backdrop of many companies seeking to align their products and packaging with waste reduction and climate impact goals.

Bio-based plastics, intended for recyclability, and biopolymers, among other categories of compostable alternatives, are emerging as corporate brands, manufacturers and consumers seek alternatives to traditional petroleum-based plastics.

9%

of the world's plastic is recycled

11M

metric tons of plastic waste entering our oceans

DEFINITIONS

Bio-Based Plastics

"Bio-based plastics" can be made from plant-based feedstocks but can become chemically-identical to plastics after manufacturing. If so, they are intended to be recycled alongside traditional petroleum-based plastics at end-of-life. These are distinct from what we refer to as "biopolymers."

Biopolymers

"Biopolymers" are a set of polymers that are naturally occurring or produced by biological organisms, and are intended to biodegrade within organics processing infrastructure at their end-of-life (defined on page 34). Examples of biopolymers include materials such as polyhydroxyalkanoates (PHAs) and polylactic acid (PLA).

As innovators and new discoveries bring a staggering number of new biopolymer offerings to the market, navigating this increasingly crowded and complex space can be confusing and challenging. Many questions remain about these emerging materials. What are the upstream impacts of sourcing and manufacturing these alternative materials? What are the best recovery pathways for these materials after use? What criteria should be applied to identify which packaging formats make the most sense as refillable versus recyclable versus compostable based on the use case or product? How do we determine the contexts in which compostable packaging can play a role in diverting some of the 63 million tons of food waste, making up 21% of total solid waste,[7] going to landfills each year?

The circular economy can provide a framework to help navigate this space, holding material innovations to high standards for sustainably sourcing feedstocks and building end-of-life recovery pathways that recapture material value after use.

We at Closed Loop Partners apply this holistic circular economy framework to evaluate biopolymers along two axes: feedstocks and end-of-life.

Feedstocks

Material innovations should be bio-based, and when possible, sourced from renewable feedstocks that are waste byproducts.

End-of-Life

Material innovations should be complementary to existing recycling systems and create added value in organics processing infrastructure.

SETTING THE SCENE

Building a Circular Economy for Plastics

Bio-based plastics and biopolymers are not a silver bullet to solve complex, global waste challenges. A combination of approaches will be necessary to accelerate the transition to a circular economy for plastics. First, a circular economy is consciously designed to use fewer materials in the production and delivery of products and to keep existing materials in circulation at their highest value and best use case for as long as possible. Biopolymers and compostable alternatives need to be bolstered by other solutions, including reuse models that keep products in play for longer, and other design practices intended to increase the recoverability of materials after use—such as monomateriality.

Bio-based plastics and biopolymers represent one piece in the broader circular economy. Biopolymer materials have unique benefits over hard-to-recycle and petroleum-based plastics for specific use cases, and they fill necessary gaps in the system when deployed thoughtfully. They can also facilitate the critical diversion of food scraps away from landfill and into organics process infrastructure—a primary objective of the circular economy.

This report outlines the landscape of biopolymers and compostable packaging today—distinguishing them from bio-based plastics—demystifying the space and unpacking the associated opportunities and challenges when considering scale. This report is a synthesis of secondary research to identify the key differences, challenges and benefits of bio-based plastics and biopolymers. This report offers a snapshot of the state of the system at a moment in time, but the landscape of plastic alternatives continues to evolve. Bio-based plastics and biopolymers make up a critical and complex component of the larger system, underscoring the importance of understanding these materials to fully maximize their potential in the circular economy.

Demystifying Alternative Material Innovations:

From Feedstock to End-of-Life Recovery

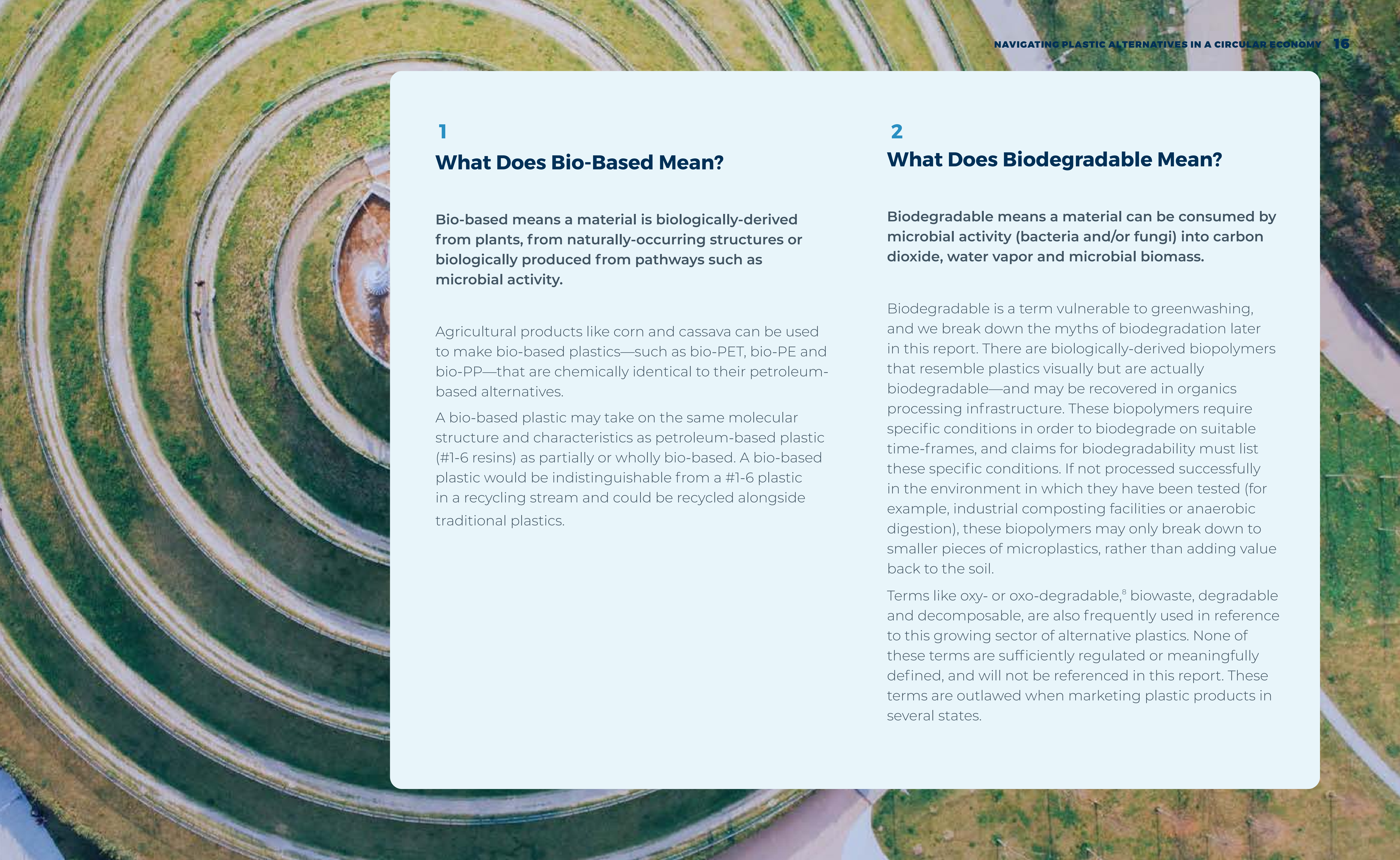
Demystifying Alternative Material Innovations

The term “bio-plastic,” frequently used to denote alternatives to traditional plastic, flattens complex nuances and does not necessarily mean a material is sustainable for its context or use case.

“Bio-plastic” can imply that the material is made of:

1) *bio*-based material feedstocks
and/or is
2) *biodegradable* at end-of-life.

These properties are not mutually exclusive, and neither are definitively sustainable. “Bio-plastic” can also refer to biopolymers—a set of polymers, distinct from traditional plastics, that are biologically-derived and biodegradable.



1

What Does Bio-Based Mean?

Bio-based means a material is biologically-derived from plants, from naturally-occurring structures or biologically produced from pathways such as microbial activity.

Agricultural products like corn and cassava can be used to make bio-based plastics—such as bio-PET, bio-PE and bio-PP—that are chemically identical to their petroleum-based alternatives.

A bio-based plastic may take on the same molecular structure and characteristics as petroleum-based plastic (#1-6 resins) as partially or wholly bio-based. A bio-based plastic would be indistinguishable from a #1-6 plastic in a recycling stream and could be recycled alongside traditional plastics.

2

What Does Biodegradable Mean?

Biodegradable means a material can be consumed by microbial activity (bacteria and/or fungi) into carbon dioxide, water vapor and microbial biomass.

Biodegradable is a term vulnerable to greenwashing, and we break down the myths of biodegradation later in this report. There are biologically-derived biopolymers that resemble plastics visually but are actually biodegradable—and may be recovered in organics processing infrastructure. These biopolymers require specific conditions in order to biodegrade on suitable time-frames, and claims for biodegradability must list these specific conditions. If not processed successfully in the environment in which they have been tested (for example, industrial composting facilities or anaerobic digestion), these biopolymers may only break down to smaller pieces of microplastics, rather than adding value back to the soil.

Terms like oxy- or oxo-degradable,[8] biowaste, degradable and decomposable, are also frequently used in reference to this growing sector of alternative plastics. None of these terms are sufficiently regulated or meaningfully defined, and will not be referenced in this report. These terms are outlawed when marketing plastic products in several states.

To remedy the vocabulary challenges of the space, we describe new materials by both the feedstock and an end-of-life pathway.

1

Feedstock: Where It's From

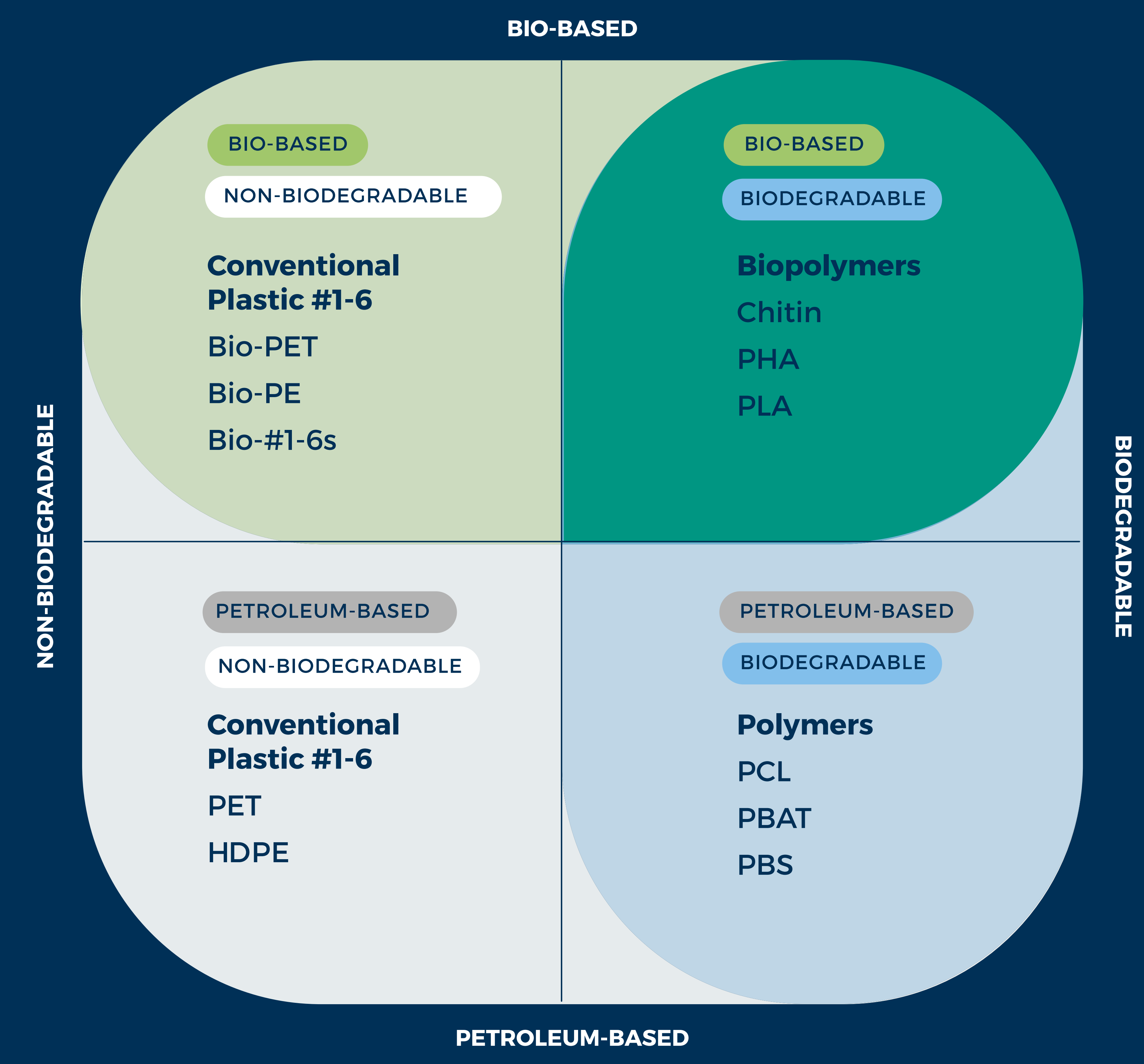
We describe new innovations as either bio-based or petroleum-based. In Figure 1, this is the y-axis.

2

End-of-Life: Where It's Going

We use the term biopolymer to refer broadly to the set of polymers, partially or wholly biologically-derived, that are biodegradable and intended for organics processing at end-of-life, distinguished from bio-based plastics which are intended for recycling streams.[9] In Figure 1, this is the x-axis.

Figure 1: Interrelationship Between Conventional, Bio-Based and Biodegradable Plastics



DEMYSTIFYING ALTERNATIVE MATERIAL INNOVATIONS

Understanding the Material Innovation Ecosystem

Within this complex and crowded landscape, we have tapped the 2,000+ innovations in Closed Loop Ventures Group's pipeline to create an outline of the emerging and established landscape of biopolymers (see Figure 2). We have compiled a variety of secondary sources to form a high-level picture of these materials, noting where possible when different grades or copolymers create variation in the performance or end-of-life pathways. This overview aims to distill a complex landscape, not to make assessments on the viability of one material over another.

Our Language Approach

We recognize the complexity of vocabulary in the evolving sector of compostable packaging. The term biopolymer is often used interchangeably with bioplastics and biodegradable polymers. Biopolymers are sometimes narrowly defined as the set of polymers that are found naturally or produced by living organisms. This narrow biopolymer definition does not encompass the petroleum-based yet equally biodegradable polymers such as polybutylene adipate terephthalate (PBAT, except where PBAT is partially bio-based).

For the sake of clarity and communication about the end-of-life intention for these polymers, we at Closed Loop Partners will honor the technical differences in Figure 1 but will colloquially refer to 1) biologically-derived biopolymers and 2) partially petroleum-based biodegradable polymers jointly as biopolymers throughout this report.

Figure 2 Mapping the End-of-Life Pathways for Plastic Alternatives

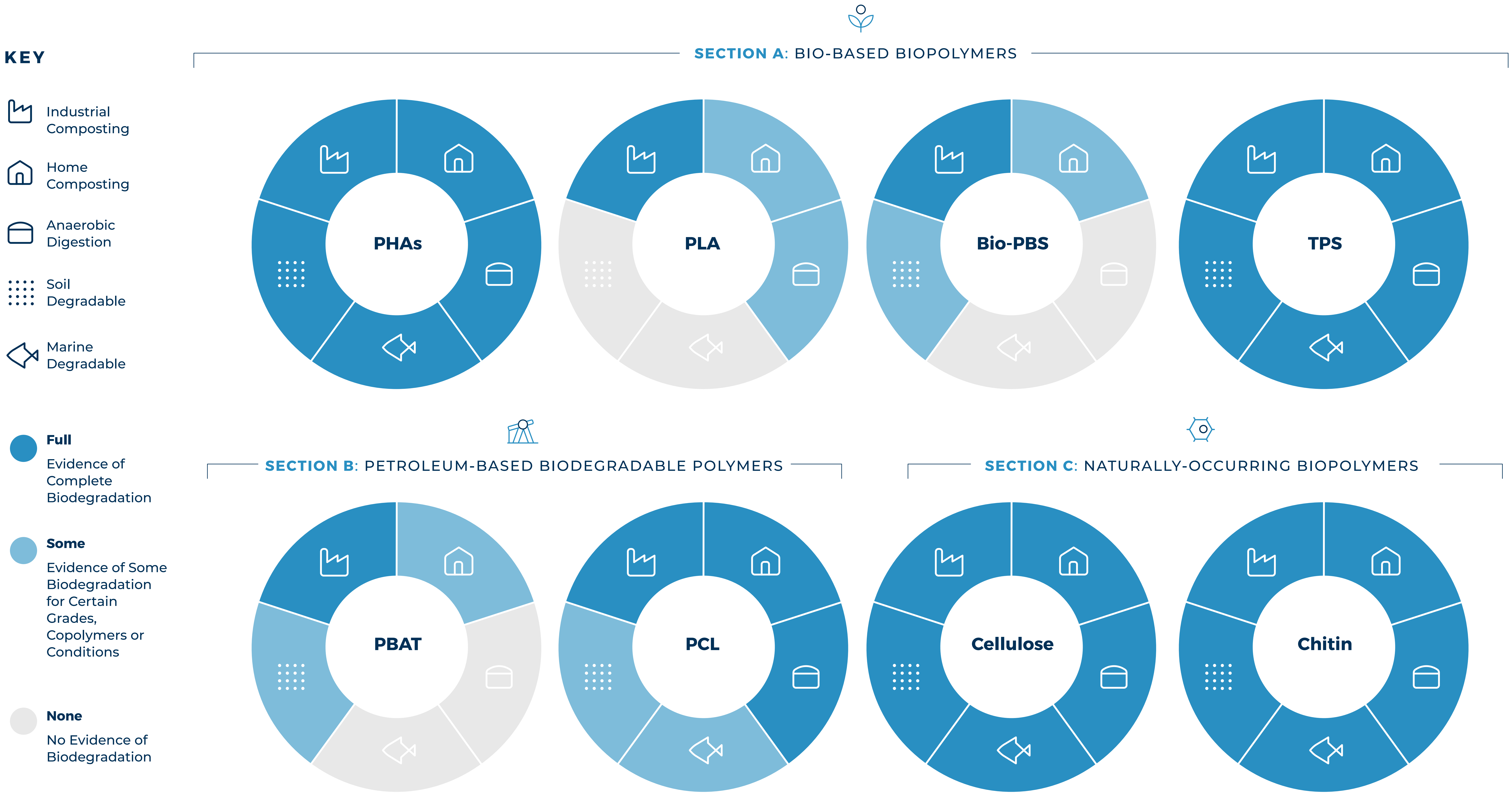
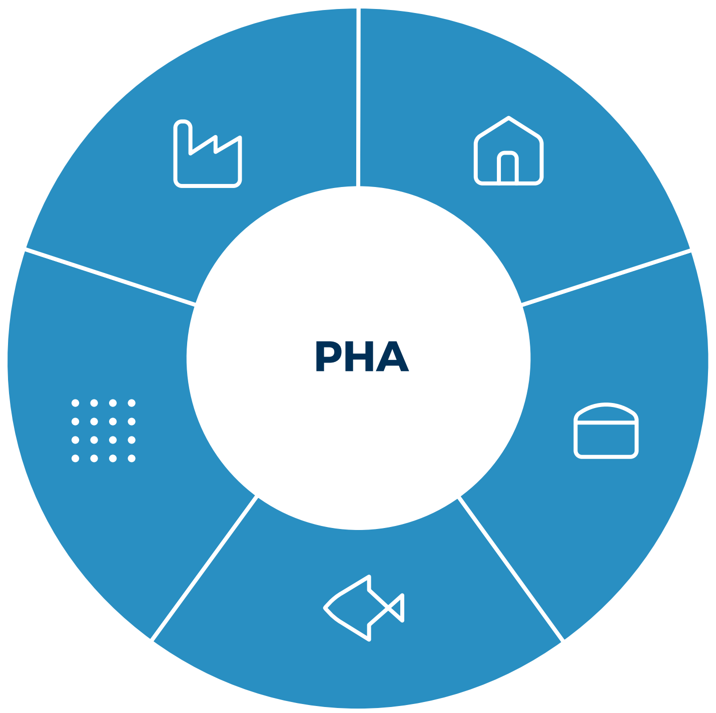


Figure 2 triangulates findings between 3 sources: OECD, 2018; The Nova Institute, 2020 (presenting research along with partners and sponsors—Kunststoff Technik Stuttgart, OWS, Inc, Marine Sciences, TÜV Rheinland and TÜV Austria); and Narancic, 2018.

SECTION A
BIO-BASED BIOPOLYMERS



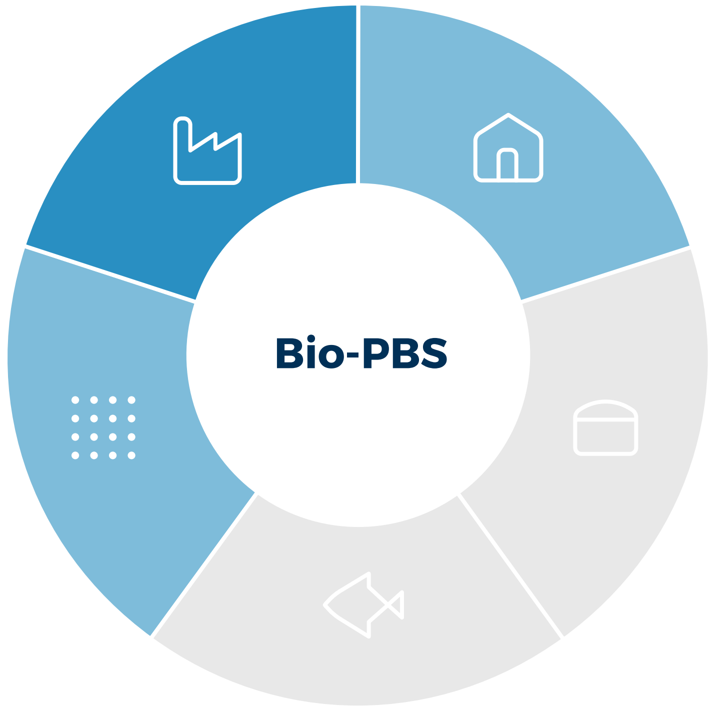
PHAs

Polyhydroxyalkanoates are another family of increasingly common biopolymers—including poly(3-hydroxybutyrate), or PHB,[10] and all its variants: PHBH, PHBV and PHBO, just to name a few.[11, 12, 13] PHAs can be made from any carbon-based feedstock; some are made using food scraps, used cooking oil, other organic waste or landfill methane. PHAs are made by microbial fermentation and are readily biodegradable in almost all environments (aerobic, anaerobic, marine and soil).[14, 15] Although this is rapidly changing, historically, there has not been enough manufacturing capacity of PHAs, and they have thus been traditionally expensive to produce.[16]

PLA

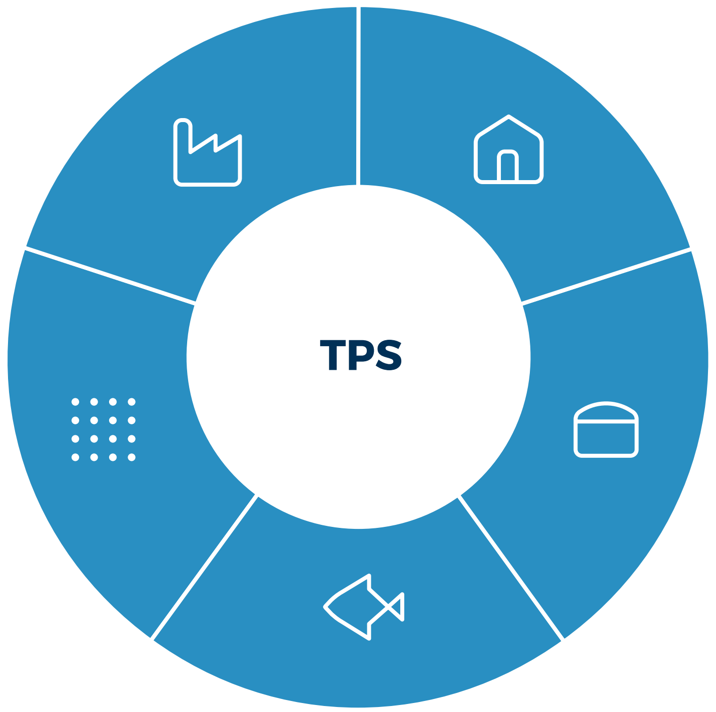
Polylactic acid[17, 18] is perhaps the best-known biopolymer family. It is typically made from corn and its byproducts, but PLA can also be made from anything with high starch content like cassava, beets and sugarcane bagasse. PLA is typically made by fermentation and the polycondensation of lactic acid.[19] Historically, PLA can be brittle, it can have poor gas barrier properties compared to polyolefins, and some grades of PLA may not hold up well to heat.[20] PLA is often blended with other materials or biopolymers to address these performance challenges.[21] PLA is typically only compostable in industrial composting conditions where criteria for temperatures, moisture, oxygen levels and nutrient ratios are met.[22, 23] While new variations are evolving to biodegrade in home composting environments,[24] most PLA-based products are not currently home compostable.[25] PLA does not biodegrade in a landfill.[26, 27]

SECTION A
BIO-BASED
BIOPOLYMERS



Bio-PBS

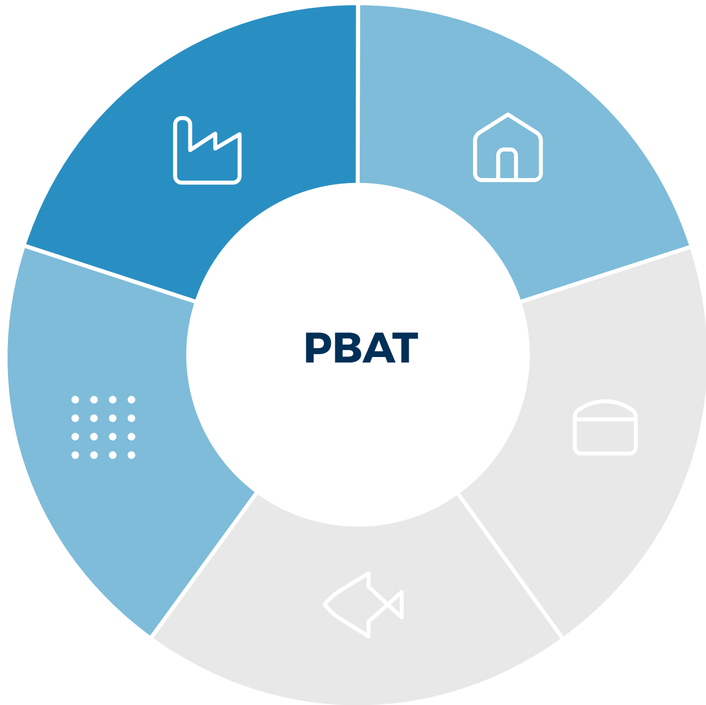
Bio-PBS has the prefix "bio" because it is chemically identical to its petroleum-based sister PBS, or polybutylene succinate.[28] Other variants include PBSA, or Polybutylene succinate adipate. PBS biopolymers are made through the condensation polymerization of succinic acid (or dimethyl succinate) and 1,4-butanediol (BDO). Most of the current grades of bio-PBS are only partially bio-based where the succinic acid is derived from renewable feedstocks (corn, sugarcane, etc.) and the butanediol (BDO) monomer is petroleum-based, though some are making bio-BDO from renewable feedstocks.[29] Both bio-PBS and petroleum-based PBS are industrially compostable;[30] some grades are home compostable[31] and soil degradable.[32, 33]



TPS

TPS, or thermoplastic starch, is a common biopolymer made by the plasticization of starch.[34] This starch can be derived from multiple bio-based, renewable sources (corn, sugarcane, cassava, etc.). TPS can have poor performance properties alone: it is brittle, sensitive to water and can be challenging to process in some applications.[35] Therefore, like PLA, TPS is often blended with other polymers to achieve better attributes in packaging applications. The compostability of TPS blends[36] are highly dependent on the accompanying biopolymer used; when blended with non-compostable polymers, these TPS blends can cause challenges for both the recycling and composting streams and are not recoverable in either.

SECTION B
PETROLEUM-BASED BIODEGRADABLE POLYMERS



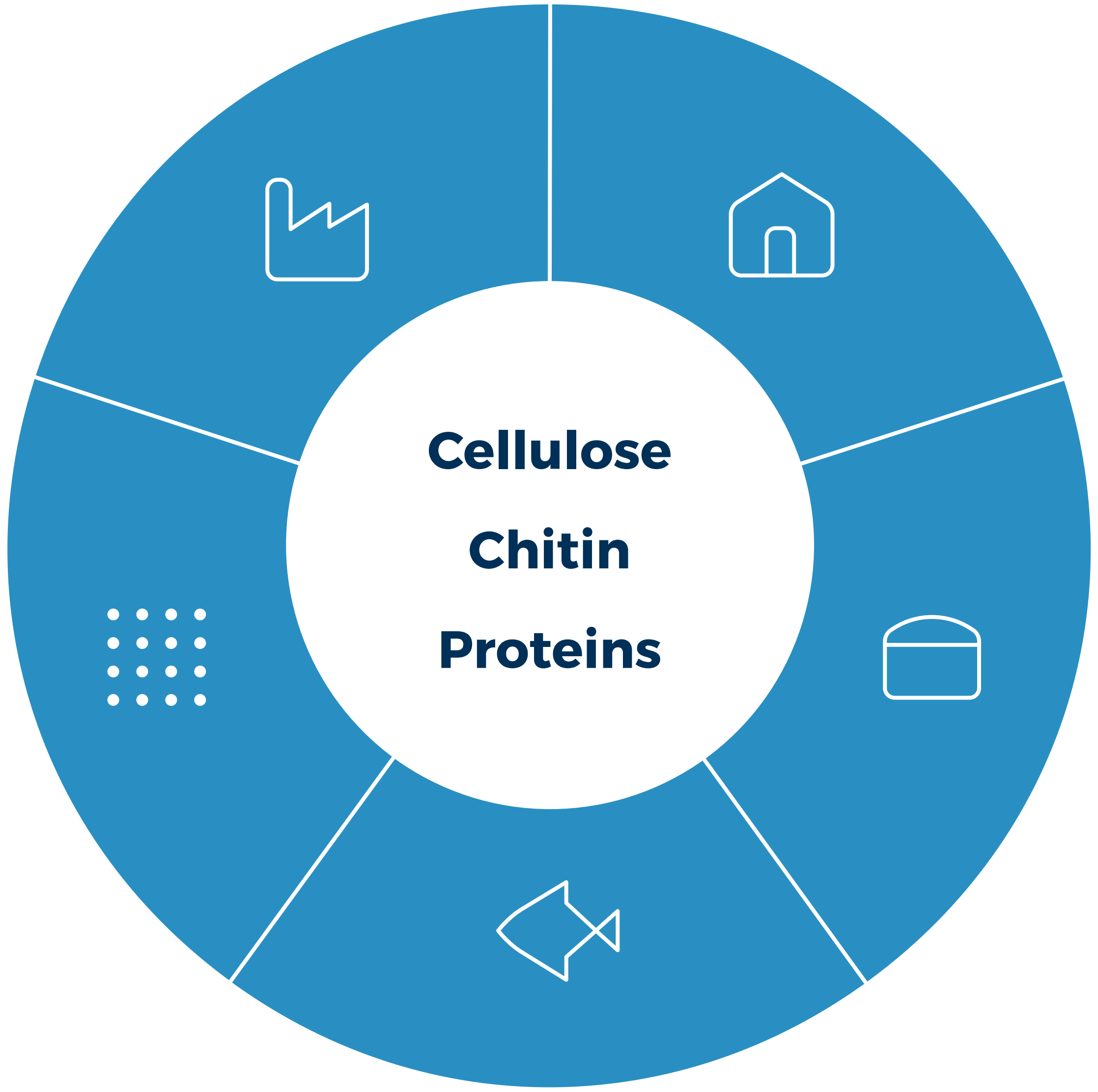
PBAT

Polybutylene adipate terephthalate is made through the polycondensation of butanediol (BDO), adipic acid (AA) and terephthalic acid (PTA).[37,38] Today, PBAT is mostly petroleum-based, though companies have started to use bio-based BDO and other inputs for a partially bio-based polymer.[39] PBAT is industrially compostable; some grades are home compostable and soil degradable.[40,41] It is generally recognized to have desirable performance properties including tensile strength and flexibility similar to those of LDPE. PBAT can be used in blended applications to increase the performance of more brittle biopolymers while retaining the biodegradability and compostability at end-of-life.

PCL

Polycaprolactone is prepared by ring opening polymerization of ε-caprolactone using a catalyst, such as stannous octanoate.[42,43] Similar to PBAT, PCL is readily biodegradable and compostable in most scenarios despite its petroleum-based feedstocks.[44,45] PCL is another example of a biopolymer often used in blends due to its ability to render other biopolymers like PLA more readily biodegradable in more environments.[46]

SECTION C
NATURALLY-OCCURRING BIOPOLYMERS



Common natural biopolymers come from a variety of bio-based feedstocks found naturally in the environment. Nature designs a number of phenomenal materials that we are still in the process of discovering.

Naturally-occuring polymers are known to biodegrade in all environments,[47] given they exist naturally in the world around us today. Compostable certification of these products and packaging is still best-practice, detailed below in the section that outlines the parameters of compostability.

Cellulose

Cellulose is a polysaccharide from nearly all plants and is often accompanied in the cell wall of plants by hemicellulose and lignin. Cellulose can also be treated chemically and spun into "manufactured" or "semi-synthetic" fibers for garments such as viscose (also known as rayon).[48]

Chitin

Chitin is an amino polysaccharide polymer found in the exoskeletons of crustaceans and insects and in the cell walls of fungi; the most well-known derivative is chitosan, created by the deacetylation of chitin.[49]

Proteins

Some companies are using naturally derived proteins; for example, those fermented by bacteria and captured from wasted milk.

SECTION D
OTHER

PVOH and PVA

PVOH and PVA are used interchangeably to describe Polyvinyl Alcohol. PVA is petroleum-based, made by hydrolysis of polyvinyl acetate.[50] PVA is most notable for its water solubility, even in kitchen sinks or as detergent pods. Due to this attribute, PVA is only applicable to specific use cases and therefore cannot entirely solve for common alternatives to single-use plastics.

PEF

PEF, or Polyethylene Furanoate, is created by the polymerization of furandicarboxylic acid (FDCA) in the presence of ethylene glycol.[51, 52] The feedstocks for FDCA can be from plant-based sugars,[53] and when using bio-based monoethylene glycol (MEG), the resulting PEF is 100% bio-based. This may not always happen in the production of PEF today. PEF has superior gas barrier properties and tensile strength to PET, among other desirable attributes. Further research and industry consensus are needed to determine whether PEF is recyclable alongside PET in the recycling stream[54]—though some claim it can be recycled “at up to 5% PEF with no effect on the recycled PET performance.”[55] PEF is not known to be biodegradable.

Navigating Plastic Alternatives in a Circular Economy

FINDING

1

Identify bio-based materials that use waste as a feedstock

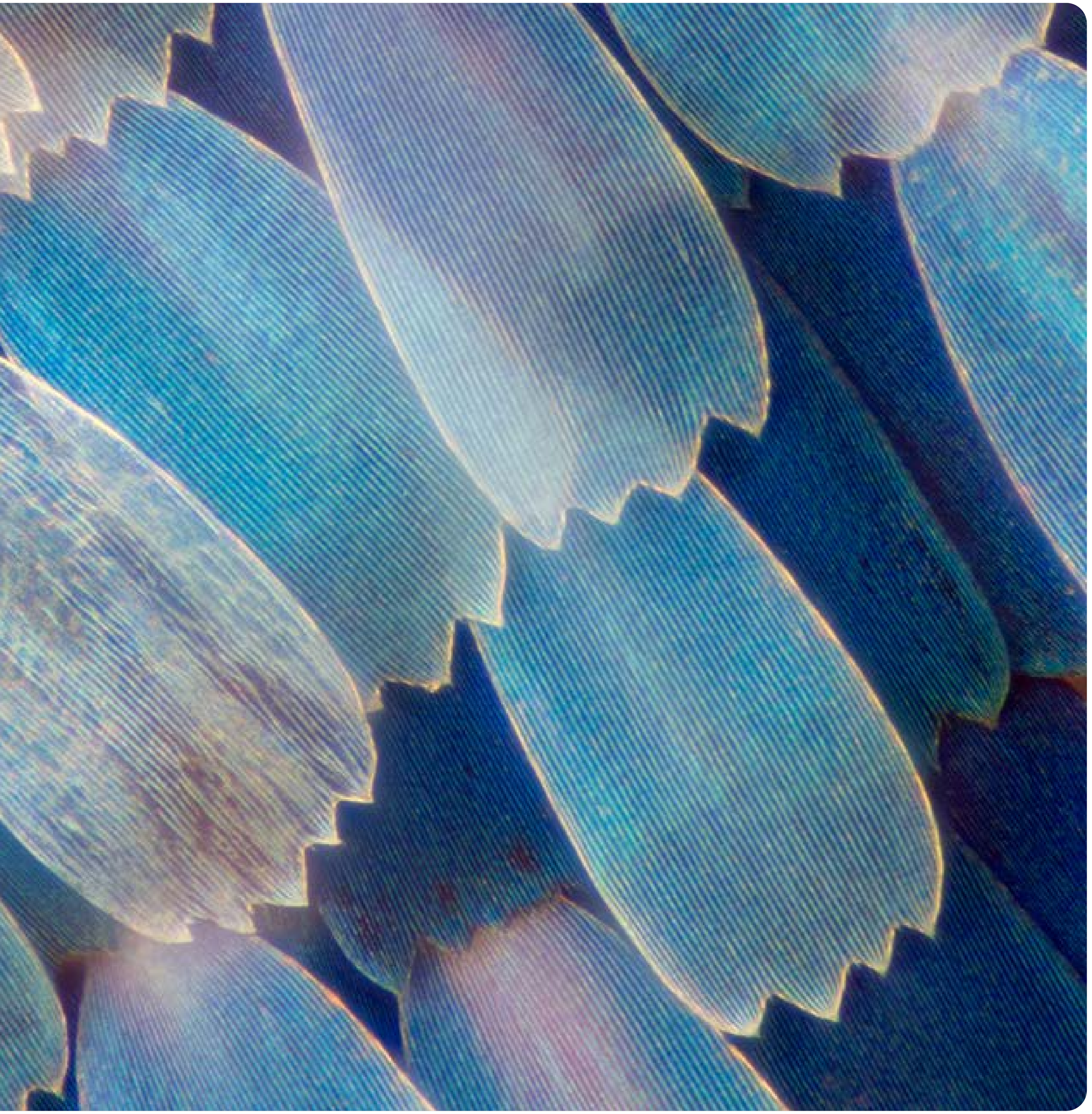
Bio-based feedstocks have potential to sequester carbon, but their environmental impacts are dependent on cradle-to-cradle assessments of a specific material or product in its regional context.

Bio-based plastics derived from agricultural products like corn and cassava (a starchy root) are "renewable" resources when compared to traditional petroleum-derived plastics, meaning their feedstocks—crops—can be regrown year after year. From a climate perspective, the agricultural sequestration of carbon in the soil in the process of growing these agricultural products is a positive climate impact. However, as corn and other commodity crop prices remain low and subsidized, new entrants to the market or incumbents expanding production of biopolymers must evaluate which feedstocks are the best choice economically and environmentally, given limited arable land.

Meanwhile, similar agricultural products such as bagasse (sugarcane residue) or rice husks—currently being landfilled or, in some cases, burned openly in the field—should be evaluated for use instead of only commodity crops like corn. Globally, estimates suggest 1.45 billion metric tons of such agricultural waste is produced annually.[56] Some innovations source cellulosic feedstocks from waste in the forestry and paper industries, and some naturally-occurring biopolymers, like chitosan, are typically derived from waste streams in the lobster, shrimp, crab and insect protein industries. These existing waste streams create opportunities as feedstocks for biopolymers and compostable packaging.

One person's agricultural waste is another's perfectly suitable biopolymer feedstock.

With any new material selection, there needs to be an alignment with the material's desired function, its achievable performance properties, the environmental goals for its context and the available capacity of the recovery infrastructure to collect, process and recapture it after use. Life Cycle Assessments (LCAs) can be one helpful analysis in the toolkit to make these decisions about environmental trade-offs. Given the inherent constraints of comparing LCA methodologies, the goal of this report is not to define one material as environmentally superior to another, but instead, to highlight the opportunity of capitalizing on existing waste feedstocks for biopolymers and compostable packaging.



COMPANY SPOTLIGHTS

Innovations in Chitosan

PACKAGING

PRODUCT FORMULATIONS

Derived from chitin, the second most abundant natural biopolymer to cellulose, chitosan is created by treating the shells of shrimp and other crustaceans with an alkaline substance, opening it to a variety of commercial and medical uses. Boasting natural antimicrobial properties, it has become an increasingly popular raw material explored by early-stage companies and sourced from waste generated by crustacean processing and fisheries. Across North America and Europe, early-stage companies are developing packaging applications for this biopolymer.

The Shellworks and **CuanTec**, two startups based in the United Kingdom, have developed early-stage technologies for chitin processing, using the polysaccharide for thin film plastic. **Cruz Foam**, a startup based in the United States, is an early-stage technology that creates protective packaging foam from chitosan. **Tidal Vision**, headquartered in Bellingham, Washington, is a commercial scale chitosan producer in North America, has chitosan extraction technology that lowers the cost of chitosan production, creates chitosan-based chemical solutions for wide-ranging use cases, including wastewater treatments and antimicrobial textile treatments.

COMPANY SPOTLIGHT

Mango Materials

TEXTILES

PACKAGING

The textile space today is ripe for disruption, with conventional polyester, a petroleum-based material, making up over 50% of global fiber production.[57] Polyhydroxyalkanoates or PHAs, produced by bacteria and other living organisms, are typically readily biodegradable in multiple environments including industrial composting facilities, home compost sites, anaerobic digestion units and most marine environments, making it an attractive alternative to petroleum-based, non-biodegradable textiles.

Mango Materials, a company located in the San Francisco Bay Area, has developed their biopolymers by transforming landfill and wastewater methane gas into PHA, specifically P3HB called YOPP PHA Pellets. Through a creative use of waste feedstocks, the company has developed fiber-grade pellets, used to melt spin the bio-based fibers into shoes, activewear, backpacks and rope. Beyond textile applications, the pellets are also used for injection molding, creating rigid objects like caps, jars and bottles that are traditionally difficult to recycle; 3D-printing, to create filament for printing; and films and sheets, to meet the needs of flexible packaging.

FINDING
2

Design products and packaging that are clearly intended to be recyclable or processed in organics infrastructure

Renewable agricultural products like corn and cassava can be used to make bio-based plastics that are chemically identical to their petroleum-based alternatives—such as bio-PET, bio-PE and bio-PP. Replicating a high-value traditional plastic like polyethylene terephthalate (PET), for example, with renewable feedstocks is not necessarily negative if the PET is identified, recaptured and recycled at end-of-life.

But, what if materials end up in the wrong recovery stream after use?

If traditional, recyclable plastic resins (#1-6) end up in the organics processing stream, shredding those traditional resins can create microplastics and fragments that are nearly impossible to separate out from the organics and therefore contaminate a composting facility's product. The same applies for bio-based plastics that are intended to be recyclable after use, yet are visually indistinguishable from biopolymer materials and certified compostable packaging that require composting after use. These products are referred to as "look-alikes" and the increased confusion in the market regarding what's what will most often result in the organics processing facility rejecting entire loads of organic waste, for fear that traditional or bio-based plastics will render their compost unusable.

Conversely, if biopolymers wind up in the plastics recycling stream, the biopolymer can act as a contaminant[a] to the reprocessing of traditional plastics if not effectively sorted out. This is costly for the recycling system and composting system respectively, reducing the output value for all actors.

Greater industry consensus, standard-setting and consistent labelling can help alleviate the challenges of contamination and drive value through the system.

a. Most biopolymers have unique molecular structures compared to conventional plastics (#1-6). Yet, their physical and mechanical properties can be similar to those of conventional plastics, and if integrated during reprocessing, can behave similarly in the final output. However, the intended use of this output dictates whether this integration is appropriate.

There are some design innovations, largely in home goods and personal care products, that convert the majority of a package to paper and retain a thin, removable plastic film liner that the consumer is expected to remove and recycle separately. These designs are intended to reduce the plastic used by volume and keep the two materials mechanically separable by hand. While thoughtfully designed, this new packaging format relies on significant consumer behavior change, which risks consumer confusion and the subsequent contamination to both paper and plastic recycling streams. Plus, the resulting thin film plastic is not easily recycled today. The Biodegradable Products Institute's (BPI) eligibility criteria dictate that a product cannot require disassembly in order to be composted.[58] It is essential that these different materials are clearly labeled to the consumer with the appropriate end-of-life action to ensure their material value is recaptured.

There are some paper coating or lining innovations, largely in food serviceware and beverage applications, where the (bio)polymer is adhered to or dispersed within the paper. Products like these may claim they are both recyclable as paper and compostable in the organics stream.

How should we evaluate claims that a paper-based food packaging product can be both recyclable and compostable?

Some paper products may make sense to recover as fibers in paper recycling mills, even when lined with biopolymers. One example would be a low food-contact use case such as the fiber cup for hot drinks, which is typically lined with polyethylene—an area that Closed Loop Partners' Center for the Circular Economy has done considerable testing with the NextGen Consortium. These products should seek repulpability and recyclability testing when aiming to be recaptured in the paper recycling stream. Testing is critical and helps ensure that mills achieve a high fiber yield, that the repulped fiber meets the grade quality needed by the mill and that the new materials avoid any operational challenges like extra equipment cleaning.

Per- and Polyfluoroalkyl Substances (PFAS)—toxic, persistent chemicals linked to causing cancer—have been a challenge for the industry in the rush to create paper-based food service products.[59] The backlash and outrage from consumers over finding PFAS in the packaging we eat from underscores the need for thorough testing through the full life cycle of these materials: beginning with feedstock, through recovery after use. Packaging producers and brands who ensure products are certified compostable benefit from BPI's screen for PFAS.[60] These challenges require greater industry attention and standardization, and New York recently joined Washington and Maine—alongside corporates like Amazon—in banning PFAS.[61, 62, 63, 64]

There will be a period of transition to ensure these two systems—recycling and organics processing—calibrate to address cross-contamination. Contamination concerns do not absolve the need for investment in these systems. Instead, greater industry collaboration and communication are required to drive toward optimal, circular outcomes.

FINDING

3

Deploy compostable packaging to divert food scraps toward organics processing and to solve for product formats that are not successfully recycled today

If a material isn't able to be composted or anaerobically digested, the goal would be for it to be recyclable. We identify these two circular economy pathways as the highest-value recapture systems for a material to (re)circulate.

But, how do we know which product formats and packaging should be recyclable versus compostable?

Biopolymers and compostable innovations may solve a real problem if they are deployed for a packaging format that is not able to be recaptured in the recycling system today. For example, solutions that provide a compostable alternative for food serviceware, like cutlery, replace a plastic format that typically is too small for the sorting and processing equipment at a recycling facility and literally falls through the cracks. Or, similarly, compostable flexible films may help keep food-contaminated and multi-laminate packaging out of the recycling system where it contaminates otherwise clean bales of recyclable materials.

Critically, compostable product formats and packaging should increase or enable the capture of food scraps, which are high-value materials for composting facilities. Food contaminated-products and packaging are a prime opportunity for a shift to compostable packaging. In fact, BPI's eligibility for compostable certification requires that an item be associated with food waste.[65]

Many businesses are also putting forward strategies that convert all the packaging and food serviceware in small, semi-closed environments, like food courts, stadiums and coffee shops, to certified compostable products. Organics processors may not find a large value to compost in terms of the nutrients (Nitrogen, Phosphorus or Potassium) from the biopolymers and compostable packaging themselves, but rather in the non-contaminated, high-nutrient-content food scraps these packages carry into the organics stream. Biopolymers and compostable packaging typically do not add additional nutrients back to the soil, but instead act as a helpful bulking agent and have not been found to affect the Carbon to Nitrogen ratios of industrial composting.[66] Organics processors will find higher value in the high-nutrient-content food scraps that these packages carry into the organics stream than in the packaging itself.

Select materials for their best use case and highest value through their end-of-life recovery pathway.

One critical component contributing to the certfication of materials as compostable is thickness. If a product's format does not enable it to meet compostability certifications, packaging manufacturers should consider whether the end-of-life pathway for the given format should instead be recycling, not organics processing. A biopolymer may be theoretically compostable, but depending on the thickness in its product application, it may not meet the time-frames needed by industrial composting facilities. Consider attempting to compost a toothpick versus a 2x4 piece of wood[67]—both are made of the same material but are not capable of being processed in the same way.

Compostability certifications are designed to be compatible with industrial composting processes. Thick biopolymer materials can cause operational challenges for a composter by slowing down their processes if they have to re-run biopolymers through their systems multiple times. Operators can, of course, individually decide whether they may want to re-run material—and some do. However, operators' willingness to do so is often contingent on whether they can be assured all materials are compostable and not a "look-alike," underscoring the need for consistent industry standardization and labelling.

COMPANY SPOTLIGHT

BioPBS PTT MCC Biochem

PACKAGING

NEXTGEN CUP CHALLENGE WINNER

To maintain integrity during use, paper cups typically have polyethylene plastic liners that prevent liquid from seeping out or soaking through the material. The difficult-to-separate paper and plastic materials are a key challenge for end-of-life processing. Biopolymer alternatives to this lining seek to solve this challenge, aiming to increase the recoverability of the entire cup.

PTT MCC Biochem, a chemical company based in Thailand, developed a cup coating using their BioPBS material, a fully bio-based and compostable alternative to plastic. These BioPBS-coated cups were one of the winning solutions in the NextGen Cup Challenge managed by Closed Loop Partners' Center for the Circular Economy, and were piloted by one of the Consortium's Founding Partners, Starbucks. The compostable liner is EN 13432 and TUV Austria OK COMPOST certified and is viable for composting at industrial facilities. The cups are also viable for recycling in the paper stream at end-of-life, where paper cups are accepted, having completed and passed lab-scale and mill-scale repulpability and paper recycling testing.

FINDING

4

Select materials and products that are certified compostable by industry-accepted third-parties

To reiterate, bio-based is distinct from biodegradable—the former referencing feedstock, the latter referencing end-of-life. In addition, there is a critical difference between biodegradable and compostable, illustrated in Figure 3.

Biodegradable describes a material that can be consumed by microbial activity (bacteria and/or fungi) into carbon dioxide, water vapor and microbial biomass.

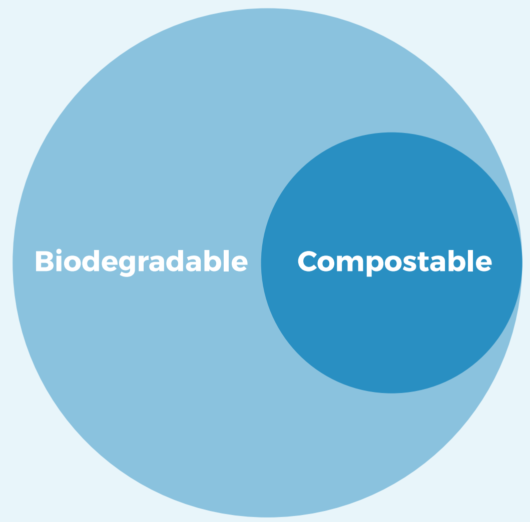
Compostable describes a material that disintegrates (breaks apart into small enough pieces) and biodegrades under specific conditions, in the specific time-frames needed by composters at their facilities (home or industrial) and does not release any harmful chemicals, toxic components or heavy metals into the environment or soil amendment being created—detailed in Figure 4.

.

Biodegradable does not always mean compostable, but everything that's compostable is inherently biodegradable.

Material claims of biodegradability are meaningless in the absence of compostable or marine/soil degradable certifications. The term biodegradable does not prescribe a set time frame, and if the necessary conditions like temperature, moisture and presence of microbes are not met, biodegradable material can persist in the environment for long periods of time, or worse, fragment into smaller microplastics without truly biodegrading.[68] California, Maryland and Washington have all banned the word 'biodegradable' marketed on products.

Figure 3:
Biodegradable vs. Compostable



Biodegradable

+ Will break down into gases (CO_2), water, residue and biomass

- Can leave microplastics

Compostable

+ Will break down within a specified time frame and into non-toxic materials

+ Will add value to the planet's ecosystem through nutrient-rich materials

Figure 4: Certified Industrially Compostable Materials Must Meet Four Requirements

1. Disintegration

“This is the physical fragmentation of the product... The ultimate goal is that the final compost contains no visible fragments of the biopolymer product."

For industrial composting, also called aerobic (meaning in the presence of oxygen) composting, ASTM International[69,70] standards require that less than 10% of the product’s mass may remain on a 2mm sieve after 12 weeks.

Pretreatment processes at an organics facility may accelerate this "by shredding or grinding the waste, which also increases surface area and allows for an even distribution of the biopolymer products in the compost pile. The combination of moisture, temperature, mechanical action and microbial activity...continues the disintegration process.”

2. Biodegradability

“Not only must the biopolymer product fully disintegrate, the biopolymer molecules must also truly biodegrade."

A material must convert into carbon dioxide, water vapor and microbial biomass via microbial activity (bacteria and/or fungi), often resulting in humus in the soil. The biopolymers must not accumulate in the environment.

For industrial composting, greater than 90% of the organic carbon must convert to carbon dioxide within 180 days. Some biopolymers can completely biodegrade in industrial composting conditions in as little as 28 days.

3. No heavy metals or fluorinated chemicals

The product may not introduce levels of heavy metals or fluorinated chemicals that exceed regulatory limits.

4. No plant toxicity

The final compost may not contain byproducts that have harmful effects on plants.

ASTM International standards “require the full 12 weeks of AC in order to ensure stable, mature compost is obtained prior to beginning the plant trials. Shorter timeframes have shown negative impacts on both emergence and growth due to immaturity of the compost, so even if the test sample has fully disintegrated much sooner, the [industrial composting] period is not allowed to be truncated.”[71]

b. This summary is adapted from a BioCycle article written by Norma McDonald: www.biocycle.net/biological-recycling-biodegradable-plastics/. For further reading and resources, visit BioCycle at www.biocycle.net.

CASE STUDY

The Better Packaging Company

PACKAGING

Compostable materials, such as PLA and PBAT blends, offer new opportunities for alternatives to plastic packaging.

The Better Packaging Company, a rapidly growing New-Zealand-based startup, has been gaining international traction for its assortment of products made of compostable alternatives for traditionally hard-to-replace plastics. The company's comPOST range offers a variety of compostable products and packaging, including courier satchels; sealable, transparent garment bags; courier labels suitable for thermal printing; bubble bags and bubble mailers; zip lock bags; hygiene stickers and gusset liners for swimwear and underwear; and tape. All comPOST products are made of PLA and PBAT, are home compostable and certified to Australasian home composting standard, AS5810.

There are nuances to how the composting process takes place. Most compostability certifications adhere to industrial, aerobic composting conditions; though internationally, there are a few home-compostable certifications.[72,73] ASTM 6400 (USA), EN 13432 (European) or ISO 17088 (International) are recognized industrial composting standards.[74,75]

Anaerobic digestion hosts microbes that can operate in the absence of oxygen, and these differ from the microbes used in industrial (aerobic) composting. Even within anaerobic digestion, different bacteria capable of digesting particular biopolymers can be dormant or active within different temperatures and environments. Due to disparate microbe types and their capacity to digest various biopolymers, not everything certified industrially compostable is anaerobically digestible.

Home Compostable
break down of product can happen in a backyard composting bin—at ambient temperatures and shorter timeframes

Industrially Compostable
(synonymous to commercially compostable) break down of product requires higher temperatures and specific conditions at a large-scale facility

Anaerobically Digestible
break down of product happens through microbial digestion in the absence of oxygen[76]

The many permutations resulting from a biopolymer's suitability in disparate end-of-life environments can be complicated to navigate for a packaging company producing materials or an organics processor seeking feedstocks, let alone for the consumers asked to separate these materials. Selecting biopolymer materials and products that are ***certified compostable*** addresses key challenges in two ways:

1

Certification of compostable products ensures that the appropriate tests were done, adherent to the right standards by credible labs. This testing against industry-accepted standards also helps avoid the unintended consequences of: microplastics and the presence of PFAS.

2

If a certified compostable biopolymer material or package goes into an anaerobic digestion facility and is not processed fully by those anaerobic microbes (for example, high lignin-containing materials), these materials will come out of the anaerobic digestion process as part of the digestate.[77]

Certification is an opportunity, not only to avoid externalities, but also to communicate to consumers where the product should go at end-of-life, and to the recovery system that these compostable products can be a valuable resource to their operations. In this way, ensuring materials are compostable—via industry-accepted third-party certifications—hedges against the risks of incomplete biodegradation into microplastics or other externalities, and maximizes the likelihood that the material will be effectively recaptured by organics processing systems at end-of-life.

CASE STUDY

Celanese

PACKAGING

Cellulose, a naturally-occurring biopolymer, has wide applicability in various product formats and as an alternative to historically petroleum-based products.

Celanese, a Fortune 500 global technology and specialty materials company headquartered in Texas, manufactures a modified cellulose called cellulose acetate from acetic acid, also known as vinegar, and high-purity wood pulp, sourced from sustainably managed forests. In October 2020, the company launched a bio-based and home compostable cellulose-acetate-based resin called BlueRidge™ Cellulosic Pellets that is processable on conventional plastics machinery and leverages Celanese's established global manufacturing footprint. Products made with BlueRidge™ material can be fully transparent, while also offering improved mechanical and temperature performance. End-products may be composted both at home and in industrial facilities, depending on the thickness.

FINDING

5

Reserve marine and soil degradable certifications for specific use cases

What happens when we think beyond packaging, specifically about biopolymers used within our non-solid, consumable product formulations—in everything from the liquids in our shampoos to our laundry detergents?

When biopolymers are applied within product formulations, we want these materials to **do more good, not less bad.**

Biopolymers—many of the same utilized in packaging and textiles—can be one viable way to create healthier-for-you product formulation replacements to toxic chemistries or carbon-intensive petroleum-based ingredients.

For those uses, biopolymer materials can consider certification for marine (ASTM D6691) or soil (ASTM D5988) degradable. Generally, however, these certifications are only suitable when a product's use case is intended for a marine or soil environment, such as an agricultural mulch film. It can be confusing when certifications for soil and marine degradability are applied to packaging and consumer products. It is important to recognize that anything certified marine or soil degradable is likely also compostable. It is also worth noting that these certified materials degrade under specific conditions. Materials certified as marine or soil degradable achieve complete biodegradation and disintegration within marine and soil environments that are colder and have a less dense microbial populations. Lastly, these certifications require that the material is non-toxic to earthworms (in soil degradability) or marine animals (in marine degradability).

That said, laboratory testing for marine and soil degradable products differs from real-world environments.[78] We reserve the value of these certifications for product components with a specific use case, or within a product formulation where the product is net positive for human health. The highest-value, optimal end-of-life scenario for packaging and solid products is *not* to leak into our natural environment, but to be recaptured in a managed end-of-life scenario. Marine and soil degradable certifications do not absolve responsibility for a product or package to be recaptured for recovery of the material's value.

COMPANY SPOTLIGHT

Algalife

TEXTILES

PORTFOLIO COMPANY

While many garments today are made of petroleum-based acrylic, nylon or polyester threads, the most common natural fiber alternative is typically cotton, a land- and water-intensive crop. After fibers are spun into yarn to produce textiles, 20% of global freshwater pollution is caused by the dyeing process. As consumer demand for sustainable apparel surges, bio-based materials without the outsized environmental impacts will garner continued interest as the textile industry transitions toward circularity.

Algalife is an Israeli-based startup replacing synthetic fibers and dyes in textiles with algae-based products—widening the range of bio-based alternative materials on the market. Algalife is working with algae producers to offer unique combinations of micro-algae. The resulting textiles and dyes have natural components such as proteins, vitamins, anti-inflammatory agents and antioxidants and offer a healthier alternative to synthetic chemical fibers and dyes. Now partnering with apparel brands to integrate Algalife materials into new product designs, the company exemplifies that the first step of designing sustainable, circular products begins with material selection.

COMPANY SPOTLIGHT

Naturbeads

PRODUCT FORMULATIONS

Plastic microbeads are intentionally added to many products because they fulfill multiple functions: exfoliants in cosmetics and other personal care products, abrasives in detergents, extenders in paints and coating, binders in leather products and more. They are petroleum-based materials that do not break down, releasing microplastics into waste and water streams.

Naturbeads, a startup based in the United Kingdom, is helping to solve this problem by developing a fully biodegradable and compostable cellulose-based replacement for these microbeads. An example of innovation intended to integrate in product formulation, the startup's technology is currently in early stages of development but offers a solution to a petroleum-based material with few natural alternatives. Naturbeads' alternative material, which has extensive commercial applications, offers clear advantages for consumer health in addition to its positive environmental impact.

FINDING

6

Avoid landfills and leakage to waterways by designing for recapture in the organics processing infrastructure

Too many materials today end up in an unmanaged environment like our oceans. Isn't it better that a material might be biodegradable in landfill, even if that product cannot be certified compostable and recaptured in organics processing facilities? In short, no.

A product that biodegrades incompletely and does not meet the stringent standards of compostability may leave microplastics[79] in the environment—possibly to enter our waterways, our food systems and ultimately our bodies. Purportedly biodegradable products can even retain their full shape and strength after years of high exposure to marine and soil environments.[80] More academic research is needed to fully understand these disintegration mechanisms and determine the scope of these impacts on our health and the environment.

In order to truly capture the value of materials and drive that value through the end-of-life value chain, compostable materials should be designed down to the biopolymer with their end-of-life scenario in mind. Figure 5 grids the aforementioned axes of feedstocks and organics processing end-of-life scenarios. On the left, y-axis, are the feedstocks: either bio-based or petroleum-based. On the top, x-axis, are the end-of-life capabilities of the biopolymer.

Landfill conditions and oceanic environments are highly variable. Biodegradability in landfill or biodegradability in oceans are suboptimal scenarios—and again, these claims are considered illegal in multiple states. A circular economy keeps materials in play and out of landfill, circulating materials as resources for as long as possible.

If a biopolymer—even a bio-based and compostable one—ends up in a landfill or our ocean, we have lost value that could have been recaptured by the organics processing system.

Figure 5: On the left, y-axis, the feedstocks: either bio-based or petroleum-based. On the top, x-axis, the end-of-life capabilities of the material.

End-of-Life

Source		Non-Biodegradable	Biodegradable	Organics Processing: Anaerobic Digestible	Organics Processing: Home Compostable	Organics Processing: Industrially Compostable	Organics Processing: Marine or Soil Degradable
Bio-Based	From virgin bio-sources	Recyclable: Bio-PET Bio-PE Bio-PP PLA* PEF*		NATURAL BIOPOLYMERS PHA TPS PLA* PBAT*	NATURAL BIOPOLYMERS PHA TPS PLA* BIOPBS*	NATURAL BIOPOLYMERS PHA TPS PLA BIOPBS	NATURAL BIOPOLYMERS PHA TPS BIOPBS*
Bio-Based	From agricultural waste bio-sources	(Recyclable, as above)		Ideally Sourced & Responsibly Composted: NATURAL BIOPOLYMERS PHA TPS PLA*	Ideally Sourced & Responsibly Composted: NATURAL BIOPOLYMERS PHA TPS PLA* BIOPBS*	Ideally Sourced & Responsibly Composted: NATURAL BIOPOLYMERS PHA TPS PLA BIOPBS	NATURAL BIOPOLYMERS PHA TPS BIOPBS*
Petroleum-Based		TRADITIONAL PLASTICS PET, PE, H/LDPE, PP, PS, PVC PEF*		PCL	PBAT* PCL	PBAT PBS PCL	PBAT* PBS* PCL*

*Certain Grades, Copolymers or Conditions

Aligning Material Innovation with Recovery Infrastructure to Recapture Value

Invest to Scale Organics Processing Infrastructure

When products or packaging materials outpace the recovery infrastructure needed to recapture them after use, we create new challenges and unintended consequences. We continue to face a vast gap between these material innovations and the necessary recovery infrastructure—apparent in the fewer than 185 full-scale commercial composting facilities across the United States accepting food waste, with even fewer accepting compostable products.

More investment is needed in organics processing infrastructure if biopolymers and compostable alternatives are to meet their full potential. Moving forward, knowledge of the nuances and diversity of materials helps lay the foundation for key investments and collaborations needed to bring new systems to scale and align material innovations with the appropriate infrastructure improvements, whether that's through recycling or composting facilities. Without action, products and packaging will continue to end up in landfills and oceans at a cost to people, the planet and business.

COMPANY SPOTLIGHT

HomeBiogas

INFRASTRUCTURE

PORTFOLIO COMPANY

Anaerobic digestion, another viable end-of-life scenario for organic materials, breaks down materials in the absence of oxygen, producing biogas for energy and fertilizer.

HomeBiogas has innovated on this process by developing affordable household- and community-sized anaerobic digesters that convert food, animal and human waste into biogas for energy and a liquid bio-fertilizer. The portability and price of the product has made it an efficient solution for both small and large use cases, deploying as a distributed solution to meet waste where it is generated. In 2019, the company improved the circularity of their product, further extending the lifespan of the technology to 15+ years and converting the materials of the digester itself be 100% recyclable. They also recently launched HomeBiogas 7.0 for small farmers and small businesses. HomeBiogas BioToilet is an affordable and efficient off-grid option for managing human waste in communities that lack sanitation infrastructure.

COMPANY SPOTLIGHT

Atlas Organics

INFRASTRUCTURE

PORTFOLIO COMPANY

Ensuring effective recovery of biopolymers relies on the expansion of large-scale organics processing infrastructure.

One example of an industrial composting facility operator that breaks down compostable materials at scale is **Atlas Organics**. The company owns and operates multiple industrial composting facilities across the South and Southeast US, accepting diverse feedstocks from municipalities and private sources, including yard waste, biosolids, food scraps and compostable packaging. Atlas deploys state-of-the-art compost aeration systems, among other technologies at their sites, and is growing rapidly to serve an increasing supply of organic waste, as consumers divert organics from municipal solid waste (MSW) streams.

Collaborate Across Diverse Stakeholders to Address Systemic Challenges

To achieve alignment of product design, packaging materiality, infrastructure capacity, incentives and labelling standards, collaboration among brands, manufacturers, organic recyclers, policymakers and investors is an imperative. Well-orchestrated partnerships that consider diverse needs and incentives across the value chain are a prerequisite to scaling a system that brings value to all stakeholders.

Effectively addressing the global plastics problem is a complex issue and necessitates multifaceted solutions. This report unpacks the nuances of biopolymers and compostable packaging as merely one strategy, but there are many priorities ahead of this. As we move forward, implementing holistic strategies can address the challenge from multiple angles with reduction and reuse as top priorities, laying the groundwork for system-wide change toward a circular economy. As the space grows, with the right kind of investment and collaboration alongside continued innovation and iteration, the landscape of tomorrow might look even brighter.

Our Starting Point

Understand

Know the trade-offs of plastic alternatives, contextualizing them in the broader suite of solutions required to address plastic waste

Invest

Catalyze capital to scale the organics processing infrastructure necessary to recover food waste alongside the increasing volume of compostable products and packaging

Collaborate

Galvanize diverse stakeholders to align product design, materiality, infrastructure capacity, incentives and labelling standards to ensure that plastic alternatives bring value across the system

Our Multi-Faceted Approach to Building a Circular Economy for Plastics

Reduce the Extraction of Fossil Fuels
Utilize recycled materials over virgin inputs and develop climate-friendly alternative materials.

Scale Innovative Alternative Materials & Reuse Systems to Prevent Waste
Explore innovative alternative materials. Grow reuse, refill and resale business models to keep valuable materials in play.

Invest in Recovery Infrastructure to Capture Materials
Optimize materials recovery facilities and advanced recycling technologies, among others, to capture existing plastic waste.

Collaborate with Diverse Stakeholders
Work collaboratively with policymakers, consumers, businesses and others to encourage sustainable systems.

Sustain Markets for Recycled & Climate-Friendly Materials
Invest in company and product innovation that uses recycled or climate-friendly alternative materials.

What's Next?

Material innovation is evolving quickly. As new materials arise, we will need to test, evaluate and optimize their performance properties, while also considering their value after use. But, as biopolymers and compostable alternatives grow in the market, assessment of whether or not each use case is the appropriate solution that brings the most value to stakeholders—from producers to composters—is critical. If we expect to continue putting compostable products and packaging into the market, these materials must help to divert food waste while we simultaneously scale the recovery infrastructure for organics processing.

In this report, we've thought through the vocabulary, the risks of contamination and how economic value can be derived from compostable products at end-of-life. We've highlighted how Closed Loop Ventures Group invests in organics recovery and call for more of it: from anaerobic digestion, to industrial composting, to hauling and logistics. This report is a starting point. Considerable work lies ahead.

The questions to be asked by us, fellow investors, and the industry at large include: how should we evaluate trade-offs between material feedstocks? What are best-practices for designing products to be either recyclable or compostable? How do we garner industry consensus to act on which product formats are suitable applications for compostable materials and how to label them?

Ultimately, there is no silver bullet solution to address the global plastics waste crisis. A circular economy is designed to use fewer materials and circulate materials for as long as possible, which means prioritizing and harnessing reuse and refill models, among other strategies. Compostable packaging can play a complementary role in addressing certain non-recyclable packaging formats and capturing food waste, but we believe greater research, investment and collaboration will drive value and avoid unintended consequences. This is the work we're doing—and we invite you to join us.

APPENDIX

Acknowledgements

Many thanks to the investors, innovators, retailers, brands and others who are invaluable partners in our work. In particular, thank you to Nora Goldstein, Sandeep Kulkarni, Norma McDonald, Rhodes Yepsen and the BPI Board of Directors for your feedback and thought partnership on this work.

Disclaimer

Glossary

Aerobic Composting (AC) (used synonymously with Commercial / Industrial / Municipal Composting) is the large-scale composting of products of a particular thickness or particle size, in the presence of oxygen, at elevated temperatures and with specific moisture conditions, oxygen levels and nutrient ratios[81]

Anaerobic Digestion (AD) is the break down of biodegradable material by microbes in the absence of oxygen[82]

ASTM International, formerly known as American Society for Testing and Materials[83]

Bio-based is biologically-derived from plants, from naturally-occurring structures or biologically produced from pathways such as microbial activity

Biodegradable describes a material that breaks down by microbial activity into carbon dioxide, water vapor and microbial biomass

Biopolymer are polymers that are found naturally or produced by living organisms

Compostable describes a material which: disintegrates into smaller pieces with less than 10% of the product's mass remaining larger than 2mm after 12 weeks; biodegrades greater than 90% of the organic carbon into carbon dioxide within 180 days; leaves no residual heavy metals and fluorinated chemicals exceed regulatory limits; and, does not contain any byproducts that have harmful effects in the resulting compost[84, 85]

Contamination results from the wrong material in the wrong recovery stream, or high amounts of residual material on a product or packaging that can impact the quality of the recovered product[86]

End-of-Life is the ultimate disposal destination or recovery method after a products' use

Home Composting is the small-scale composting of a product that can happen in a backyard bin at ambient temperatures and shorter timeframes than industrial composting

APPENDIX

Life Cycle Assessments (LCAs) are cradle-to-grave or cradle-to-cradle analysis techniques to assess environmental impacts associated with all the stages of a product's life[87]

Look-Alikes are bio-based or petroleum-based plastic resins (#1-6) that end up in the organics processing stream and misleadingly look like a compostable product[88]

Microbe is a microorganism, including bacteria, archaea, viruses, fungi, prions, protozoa and algae[89]

Organics Processing Infrastructure is home composting, industrial composting, anaerobic digestion and hauling

Petroleum-based is from fossil fuel-derived sources

Polymer is a chemical made of many repeating units[90]

Sustainable means development that meets the needs of the present without compromising the ability of future generations to meet their own needs[91]

RESIN ACRONYMS

PET (Resin Code #1) Polyethylene terephthalate; commonly referred to as polyester[92]

HDPE (#2) High-density polyethylene

PVC (#3) Polyvinyl Chloride

LDPE (#4) Low-density polyethylene

LLDPE (also #4) Linear low-density polyethylene

PP (#5) Polypropylene

PS (#6) Polystyrene

Resin Code #7 indicates that a package is made with a resin other than the six listed previously, or is made of more than one resin and used in a multi-layer combination

PHA Polyhydroxyalkanoate

PHB Poly(3- & 4-hydroxybutyrate)

PHBH Polyhydroxy-butylhexanoate

PHBV Polyhydroxy-butyratevalerate

PHBO Poly(3-hydroxybutyrate- co-3-hydroxyoctanoate)

PLA Polylactic acid

PBS Polybutylene succinate

PBSA Polybutylene succinate adipate

BDO Butanediol

TPS Thermoplastic starch

PVOH / PVA Polyvinyl alcohol

PBAT Polybutylene adipate terephthalate

AA Adipic acid

PTA Terephthalic acid

PCL Polycaprolactone

PEF Polyethylene Furanoate

APPENDIX

References

1. Beat Plastic Pollution. *UN Environment*. Retrieved December 14, 2020 from https://www.unenvironment.org/interactive/beat-plastic-pollution/
2. Reddy, S., & Lau, W. (2020, July 23). Breaking the Plastic Wave: Top Findings for Preventing Plastic Pollution. *Pew Research*. Retrieved December 14, 2020, from https://www.pewtrusts.org/en/research-and-analysis/articles/2020/07/23/breaking-the-plastic-wave-top-findings#:~:text=An%20estimated%2011%20million%20metric,of%20coastline%20around%20the%20world
3. Gupta, S. (2020, April 6). Bioplastics & Biopolymers Market. Retrieved December 13, 2020, from https://www.marketsandmarkets.com/PressReleases/biopolymers-bioplastics.asp
4. Market update 2020: Bioplastics continue to become mainstream as the global bioplastics market is set to grow by 36 percent over the next 5 years. (2020, December 2). *European Bioplastics*. Retrieved December 13, 2020, from https://www.european-bioplastics.org/market-update-2020-bioplastics-continue-to-become-mainstream-as-the-global-bioplastics-market-is-set-to-grow-by-36-percent-over-the-next-5-years/
5. Goldstein, N. (2019, January 4). Food Waste Composting Infrastructure In The U.S. *BioCycle*. Retrieved December 13, 2020, from https://www.biocycle.net/food-waste-composting-infrastructure-u-s/
6. Facts and Figures about Materials, Waste and Recycling. (2020, November 03). *US EPA*. Retrieved December 13, 2020, from https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling
7. EPA, Facts and Figures, 2020.
8. EU takes action against oxo-degradable plastics. (2018, January 30). *European Bioplastics*. Retrieved December 13, 2020, from https://www.european-bioplastics.org/eu-takes-action-against-oxo-degradable-plastics/
9. Rudin, A., & Choi, P. (2013). Chapter 13 - Biopolymers. In *The Elements of Polymer Science & Engineering (Third Edition)* (pp. 521-535). Cambridge, MA: Academic Press. doi:10.1016/B978-0-12-382178-2.00013-4
10. Narancic, T., Verstichel, S., Reddy Chaganti, S., Morales-Gamez, L., Kenny, S. T., De Wilde, B., Babu Padamati, R., O'Connor, K. E. (2018). Biodegradable Plastic Blends Create New Possibilities for End-of-Life Management of Plastics but They Are Not a Panacea for Plastic Pollution. *Environmental Science & Technology, 58*(18), 10441-10452. doi:10.1021/acs.est.8b02963
11. Dietrich, K., Dumont, M., Del Rio, L. F., & Orsat, V. (2017). Producing PHAs in the bioeconomy — Towards a sustainable bioplastic [Abstract]. *Sustainable Production and Consumption, 9*, 58-70. doi:10.1016/j.spc.2016.09.001
12. Joce, C. (2018, May 8). Polyhydroxyalkanoates: Plastic The Way Nature Intended? [PDF]. *Cambridge Consultants*. Retrieved December 13, 2020, from https://www.cambridgeconsultants.com/insights/bioplastics-pha-whitepaper
13. Lingle, R. (2018, April 10). PHA bioplastics a 'tunable' solution for convenience food packaging. *Plastics Today*. Retrieved December 13, 2020, from https://www.plasticstoday.com/packaging/pha-bioplastics-tunable-solution-convenience-food-packaging
14. Meereboer, K. W., Misra, M., & Mohanty, A. K. (2020, August 17). Review of recent advances in the biodegradability of polyhydroxyalkanoate (PHA) bioplastics and their composites. *Green Chemistry, 22*, 5519-5558. doi:10.1039/d0gc01647k
15. Biodegradable Polymers in Various Environments [Digital image]. (2020, January 23). *The Nova Institute* (presenting research along with partners and sponsors—Kunststoff Technik Stuttgart, OWS, Inc, Marine Sciences, TÜV Rheinland and TÜV Austria). Retrieved December 13, 2020, from http://bio-based.eu/graphics/ and https://www.biocycle.net/excellent-poster-on-biodegradable-polymers/
16. OECD (2013), "Policies for Bioplastics in the Context of a Bioeconomy", OECD Science, Technology and Industry Policy Papers, No. 10, OECD Publishing, Paris, https://doi.org/10.1787/5k3xpf9rrw6d-en
17. Castro-Aguirre, E., Iñiguez-Franco, F., Samsudin, H., Fang, X., Auras, R. (2016, April 1). Poly(lactic acid)—Mass production, processing, industrial applications, and end of life. *Advanced Drug Delivery Reviews, 107*, 333-366. doi:10.1016/j.addr.2016.03.010
18. Royte, E. (2006, August 1). Corn Plastic to the Rescue. Smithsonian Magazine. Retrieved December 13, 2020, from https://www.smithsonianmag.com/science-nature/corn-plastic-to-the-rescue-126404720/
19. How Ingeo is Made. *NatureWorks*. Retrieved December 13, 2020, from https://www.natureworksllc.com/What-is-Ingeo/How-Ingeo-is-Made
20. Byun, Y., Teck Kim, Y. (2014). Chapter 14 - Bioplastics for Food Packaging: Chemistry and Physics. In *Food Science and Technology, Innovations in Food Packaging (Second Edition)* (pp. 353-368). Cambridge, MA: Academic Press. doi:10.1016/B978-0-12-394601-0.00014-X
21. Narancic, 2018.
22. Nova Institute, 2020.
23. Where It Goes - Composting. *NatureWorks*. Retrieved December 13, 2020, from https://www.natureworksllc.com/What-is-Ingeo/Where-it-Goes/Composting
24. Carbiolice - Home Page. Retrieved December 13, 2020, from https://www.carbiolice.com/en/
25. Peters, A. (2019, August 30). Will compostable packaging ever be able to solve our waste problem? *Fast Company*. Retrieved December 13, 2020, from https://www.fastcompany.com/90393297/will-compostable-packaging-ever-be-able-to-solve-our-waste-problem
26. Where It Goes - Landfill. *NatureWorks*. Retrieved December 13, 2020, from https://www.natureworksllc.com/What-is-Ingeo/Where-it-Goes/Landfill
27. Nova Institute, 2020.
28. Biodegradable Polymer "BioPBS™": Products. *Mitsubishi Chemical*. Retrieved December 13, 2020, from https://www.m-chemical.co.jp/en/products/departments/mcc/sustainable/product/1201025_7964.html
29. Burgard, A., Burk, M. J., Osterhout, R., Van Dien, S., Yim, H. (2016). Development of a commercial scale process for production of 1,4-butanediol from sugar. *Current Opinion in Biotechnology*, 42, 118-125. doi:10.1016/j.copbio.2016.04.016
30. Narancic, 2018.
31. Nova Institute, 2020.
32. OECD (2018), Improving Markets for Recycled Plastics: Trends, Prospects and Policy Responses, OECD Publishing, Paris, https://doi-org.ezproxy.cul.columbia.edu/10.1787/9789264301016-en
33. Mashek, W., Krieger, M., Martin, K. (2016, August 29). Bioplastics 2016 SPI Report: Plastics Market Watch. *SPI: The Plastics Industry Trade Association*. Retrieved December 13, 2020, from https://www.slideshare.net/Greenchemblog/bioplastics-2016-spi-report
34. Khan, B., Bilal Khan Niazi, M., Samin, G., & Jahan, Z. (2016, July 10). Thermoplastic Starch: A Possible Biodegradable Food Packaging Material-A Review [Abstract]. *Journal of Food Process Engineering, 40*(3). doi:10.1111/jfpe.12447
35. Narancic, 2018.
36. Nova Institute, 2020.
37. Jian, J., Xiangbin, Z., Xianbo, H. (2020, January 17). An overview on synthesis, properties and applications of poly(butylene-adipate-co-terephthalate)–PBAT. *Advanced Industrial and Engineering Polymer Research, 3*(1), 19-26. doi:10.1016/j.aiepr.2020.01.001
38. Ferreira, F.V., Cividanes, L.S., Gouveia, R.F. and Lona, L.M. (2019, March 9). An overview on properties and applications of poly(butylene adipate-co-terephthalate)–PBAT based composites. *Polymer Engineering & Science, 59*, E7-E15. doi:10.1002/pen.24770
39. Novamont opens world's first commercial bio-based BDO plant. (2016, October 6). *Bioenergy International*. Retrieved December 13, 2020, from https://bioenergyinternational.com/biochemicals-materials/novamont-opens-worlds-first-commercial-bio-based-bdo-plant
40. Zumstein, M. T., Schintlmeister, A., Nelson, T. F., Baumgartner, R., Woebken, D., Wagner, M., Kohler, H. E., McNeill, K., Sander, M. (2018, July 25). Biodegradation of synthetic polymers in soils: Tracking carbon into CO2 and microbial biomass. *Science Advances, 4*(7). doi:10.1126/sciadv.aas9024
41. Nova Institute, 2020.
42. Nair, N.R., Sekhar, V.C., Nampoothiri, K.M., Pandey, A. (2017). Chapter 32 - Biodegradation of Biopolymers. In Current Developments in Biotechnology and Bioengineering, (pp. 739-755). Amsterdam, Netherlands: Elsevier. doi:10.1016/B978-0-444-63662-1.00032-4
43. McKeen, L. W. (2012). Chapter 13 - Environmentally Friendly Polymers. In Plastics Design Library, Permeability Properties of Plastics and Elastomers (Third Edition) (pp. 287-304). Amsterdam, Netherlands: William Andrew Publishing (Elsevier). doi:10.1016/B978-1-4377-3469-0.10013-X

APPENDIX

44. Deconinck, S., & De Wilde, B. (2013, August 9). *Benefits and Challenges of Bio- and Oxo-Degradable Plastics: A Comparative Literature Study* (Report). Retrieved December 13, 2020, from O.W.S. website: https://www.ows.be/wp-content/uploads/2013/10/Final-Report-DSL-1_Rev02.pdf
45. Narancic, 2018.
46. O.W.S., 2013.
47. Nova Institute, 2020.
48. Robertson, L. (2020, March 9). Material Guide: Is Viscose Really Better For The Environment? *Good On You*. Retrieved December 13, 2020, from https://goodonyou.eco/material-guide-viscose-really-better-environment/
49. Elieh-Ali-Komi, D., & Hamblin, M. R. (2016, March 1). Chitin and Chitosan: Production and Application of Versatile Biomedical Nanomaterials. *International Journal of Advanced Research, 4*(3), 411–427. Retrieved December 13, 2020, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5094803/
50. Translating our Science: About Water-Soluble Film. *MonoSol*. Retrieved December 13, 2020, from https://www.monosol.com/translating-our-science/
51. Polyethylene Furanoate (PEF) - The Rising Star Amongst Today's Bioplastics. *Omnexus: The Material Selection Platform*. Retrieved December 13, 2020, from https://omnexus.specialchem.com/selection-guide/polyethylene-furanoate-pef-bioplastic
52. Prieto, A. (2016 September). To be, or not to be biodegradable… that is the question for the bio-based plastics. *Microbial biotechnology, 9*(5), 652–657. doi:10.1111/1751-7915.12393
53. Renewable Polymers. *Avantium*. Retrieved December 13, 2020, from https://www.avantium.com/business-units/renewable-polymers/
54. APR Statement on the Potential Impact of PEF on PET Recycling. *The Association of Plastic Recyclers (APR)*. Retrieved December 13, 2020, from https://resource-recycling.com/plastics/wp-content/uploads/sites/4/2017/10/APR_Statement_on_PEF_Final_Sept2017.pdf
55. Omnexus, Polyethylene Furanoate (PEF).
56. Bentsen, N. S., Felby, C., Thorsen, B. J. (2014, February). Agricultural residue production and potentials for energy and materials services. *Progress in Energy and Combustion Science, 40*, 59-73. doi:10.1016/j.pecs.2013.09.003
57. Preferred Fiber & Materials Market Report 2019. *Textile Exchange*. Retrieved December 13, 2020, from https://textileexchange.org/wp-content/uploads/2019/11/Textile-Exchange_Preferred-Fiber-Material-Market-Report_2019.pdf
58. About BPI's Eligibility Requirements. (2019, December 2). Biodegradable Products Institute - Blog. Retrieved December 13, 2020, from https://www.bpiworld.org/BPI-Blog.html/8160161
59. Fassler, J. (2019, August 5). The bowls at Chipotle and Sweetgreen are supposed to be compostable. They contain cancer-linked "forever chemicals." *The Counter*. Retrieved December 13, 2020, from https://thecounter.org/pfas-forever-chemicals-sweetgreen-chipotle-compostable-biodegradable-bowls/
60. BPI, Eligibility Requirements, 2019.
61. Melgar, D. (2020, December 07). New law protects New Yorkers from toxic PFAS 'forever chemicals' exposure. *US PIRG*. Retrieved December 13, 2020, from https://uspirg.org/news/usp/new-law-protects-new-yorkers-toxic-pfas-%E2%80%98forever-chemicals%E2%80%99-exposure
62. Chemicals & Restricted Substances. *Amazon*. Retrieved December 13, 2020, from https://sustainability.aboutamazon.com/environment/packaging-and-products/chemicals
63. Center for Food Safety and Applied Nutrition. (2020, October 20). Per- and Polyfluoroalkyl Substances (PFAS). *US Food and Drug Administration*. Retrieved December 13, 2020, from https://www.fda.gov/food/chemicals/and-polyfluoroalkyl-substances-pfas
64. Schreder, E., Dickman, J. Take Out Toxics: PFAS Chemicals in Food Packaging. (2018). *Toxic-Free Future and Safer Chemicals, Healthy Families*. Retrieved December 13, 2020, from https://48h57c2l31ua3c3fmq1ne58b-wpengine.netdna-ssl.com/wp-content/uploads/2019/05/Take-Out-Toxics-Full-Report.pdf
65. The Essential Connection Between Food Waste and Compostable Products. (2020, April 15). Biodegradable Products Institute - Blog. Retrieved December 13, 2020, from https://www.bpiworld.org/BPI-Blog.html/8901644
66. Yepsen, R. (2018, November 14). Value Of Compostable Packaging As "Feedstock". *BioCycle*. Retrieved December 13, 2020, from https://www.biocycle.net/value-compostable-packaging-feedstock/
67. McDonald, N. (2019, September). Biological Recycling Of Biodegradable Plastics. *BioCycle*. Retrieved December 13, 2020, from https://www.biocycle.net/biological-recycling-biodegradable-plastics/
68. OECD, 2013.
69. ASTM D6400 - 19. *ASTM International*. Retrieved December 13, 2020, from https://www.astm.org/Standards/D6400.htm
70. ASTM D6868 - 19. *ASTM International*. Retrieved December 13, 2020, from https://www.astm.org/Standards/D6868.htm
71. McDonald, Biological Recycling Of Biodegradable Plastics, 2019.
72. PHA Certifications. *Danimer Scientific*. Retrieved December 13, 2020, from https://danimerscientific.com/pha-certifications/
73. Home Compostability. *O.W.S.* Retrieved December 13, 2020, from https://www.ows.be/tests/home-compostability/
74. Definitions & Standards of Biodegradability. *Biodegradable Products Institute*. Retrieved December 13, 2020, from https://www.bpiworld.org/science-of-composting
75. Industrial Composting Fact Sheet. (2009 November). *European Bioplastics*. Retrieved December 13, 2020, from https://docs.european-bioplastics.org/2016/publications/fs/EUBP_fs_industrial_composting.pdf
76. McDonald, Biological Recycling Of Biodegradable Plastics, 2019.
77. Where It Goes - Anaerobic Digestion. NatureWorks. Retrieved December 13, 2020, from https://www.natureworksllc.com/What-is-Ingeo/Where-it-Goes/Anaerobic-Digestion
78. Hunt, K. (2019 March). Standards for Biodegradable Plastics: A Subcommittee Looks at Next Steps for Plastics Standards. *ASTM International*. Retrieved December 13, 2020, from https://sn.astm.org/?q=features/standards-biodegradable-plastics-ma19.html
79. Kershaw, P. J. (2015). Biodegradable Plastics and Marine Litter: Misconceptions, concerns and impacts on marine environments. *United Nations Environment Programme (UNEP), Nairobi*. Retrieved December 13, 2020, from https://wedocs.unep.org/bitstream/handle/20.500.11822/7468/-Biodegradable_Plastics_and_Marine_Litter_Misconceptions,_concerns_and_impacts_on_marine_environments-2015BiodegradablePlasticsAndMarineLitter.pdf.pdf?sequence=3&isAllowed=y
80. BioCycle World. (2019, August 13). *BioCycle*. Retrieved December 13, 2020, from https://www.biocycle.net/biocycle-world-183/
81. Types of Composting and Understanding the Process. *US EPA*. Retrieved December 13, 2020, from https://www.epa.gov/sustainable-management-food/types-composting-and-understanding-process
82. Basic Information about Anaerobic Digestion (AD). *US EPA*. Retrieved December 13, 2020, from https://www.epa.gov/anaerobic-digestion/basic-information-about-anaerobic-digestion-ad
83. ASTM International. Retrieved December 13, 2020, from https://www.astm.org/
84. ASTM 6400, ASTM International.
85. McDonald, Biological Recycling Of Biodegradable Plastics, 2019.
86. Rachelson, D. (2017, December 4). What is Recycling Contamination, and Why Does it Matter? *Rubicon*. Retrieved December 13, 2020, from https://www.rubicon.com/blog/recycling-contamination/
87. Muralikrishna, I. V., Manickam, V. (2017). Chapter Five - Life Cycle Assessment. In *Environmental Management* (pp. 57-75). Amsterdam, Netherlands: Butterworth-Heinemann (Elsevier). doi:10.1016/B978-0-12-811989-1.00005-1
88. Goldstein, N. (2020, February 4). Editorial: The 2020 Compostable Packaging Narrative. *BioCycle*. Retrieved December 13, 2020, from https://www.biocycle.net/editorial-2020-compostable-packaging-narrative/
89. What is Microbiology? *Microbiology Society*. Retrieved December 13, 2020, from https://microbiologysociety.org/why-microbiology-matters/what-is-microbiology.html
90. The Basics: Polymer Definition and Properties. *The American Chemistry Council*. Retrieved December 13, 2020, from https://plastics.americanchemistry.com/plastics/The-Basics/
91. World Commission on Environment and Development. (1987). Our common future. Oxford: Oxford University Press.
92. Plastic Packaging Resins. *The American Chemistry Council*. Retrieved December 13, 2020, from https://plastics.americanchemistry.com/Plastic-Resin-Codes-PDF/

APPENDIX

News & Media Resources

Engel Bromwich, J. (2018, September 29). Is Your Salad Habit Good for the Planet? New York Times. Retrieved December 13, 2020, from https://www.nytimes.com/2018/09/29/style/healthy-bowls-salad-waste.html

Krieger, A. (2019, August 28). Are bioplastics really better for the environment? Read the fine print. GreenBiz. Retrieved December 13, 2020, from https://www.greenbiz.com/article/are-bioplastics-really-better-environment-read-fine-print

Minter, A. (2020, December 2). Has Bacardi Solved the World's Plastic Problem? Bloomberg. Retrieved December 13, 2020, from https://www.bloomberg.com/opinion/articles/2020-12-02/has-bacardi-solved-the-world-s-plastic-problem?sref=KEEMUxGR

Peters, A. (2020, October 29). Pepsi, Nestlé, and Bacardi are all using this new plastic-like packaging that's compostable anywhere. Fast Company. Retrieved December 13, 2020, from https://www.fastcompany.com/90569273/pepsi-nestle-and-bacardi-are-all-using-this-new-plastic-like-packaging-thats-compostable-anywhere

Schwartz, J. (2020, October 01). Why 'Biodegradable' Isn't What You Think. New York Times. Retrieved December 13, 2020, from https://www.nytimes.com/interactive/2020/10/01/climate/biodegradable-containers.html

CLOSED LOOP partners

CONTACT

All inquiries can be directed to
admin@closedlooppartners.com

closedlooppartners.com
twitter.com/loopfund

Certified B Corporation
bcorporation.net