US Composting Council©

Compostable Products

A PRIMER FOR COMPOST MANUFACTURERS

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Authored by
Nora Goldstein and Craig Coker
BioCycle Associates®
For the US Composting Council®

Design by
Doug Pinkerton
BioCycle Associates®

BioCycle Associates

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Introduction

The role that compostable products play in the marketplace has evolved since they were introduced over 30 years ago. In the early years, high oil prices driving up conventional resin prices and the promise of biobased materials being cheaper, combined with a need to mitigate negative consumer sentiment to rising replacement of "durable" items with disposable ones (e.g., cloth diapers with disposable diapers), were factors. A primary focus was on development of compostable plastic bags. Foodservice and food packaging applications soon became drivers, viewed as tools to facilitate food waste diversion from disposal.

In addition to these drivers, there has been an increasing focus over the last ten years on finding alternatives to single-use plastic packaging due in large part to global concerns about marine plastic pollution, and the unknown impact of microplastics in terrestrial ecosystems, especially agricultural soils and food systems. Global consumer products companies have made commitments, as part of initiatives to transition packaging from the make-take-waste linear model to a circular economy model where the plastic does not become pollution but is instead recirculated as a valuable commodity. For example, signatories of the U.S. Plastics Pact are some of the world's largest beverage and consumer packaged goods (CPG) companies, and they commit to only using packaging that is 100 percent reusable, recyclable or compostable by 2025. Lawmakers are also tuning into consumers' concerns. A growing number of municipal and state governments are considering or passing single-use plastic packaging laws, many of which designate compostable packaging as an acceptable alternative.

The demand for composting facilities to accept food scraps, let alone compostable products, far exceeds the number in the U.S. that accept them. In 2018, *BioCycle* conducted a survey of full-scale composting facilities that process food waste (Goldstein, 2018). *BioCycle* defined a full-scale facility as a municipal or commercial facility equipped to receive and process organic waste streams arriving by truckload volumes from generators and haulers on a year-round basis. The survey identified 185 full-scale food waste composting facilities (<4 percent of the more than 4,700 composting facilities operating in the U.S., most of which accept yard trimmings only (Goldstein, 2017)). Out of the 103 who answered the question about feedstocks accepted, 61 responded that they accept compostable paper products and 49 responded that they accept certified compostable plastic products.

This paper provides an update to "Compostable Plastics 101," a document prepared for the California Organics Recycling Council by Scott Smithline and introduced at the US Composting Council Annual Conference in Santa Clara in 2011. Many of the fundamentals covered in the 2011 paper are still relevant today. This document updates definitions, types, certifications, and issues that compostable products face.

SECTION I

Compostable Products — What Does That Mean?

Compostable products in the context of this document are limited to a discussion of products that are utilized to:

- Physically capture and transport source separated organics, i.e., bags
- Package or label (e.g., produce stickers) foods
- Serve food or contain food for carryout, e.g., cups, straws, utensils, bowls, clamshells

Compostable product formats fall into two basic categories — paper/fiber and plastics. A third format is a "hybrid" of the two, e.g., fiber packaging coated with bioplastic. Compostability of each of these formats is defined by performance according to an established standard (e.g. ASTM International), rather than by material (format) type. This is the common denominator among the formats. An overview of the paper/fiber and plastics categories are provided as an introduction.

Paper/Fiber

Fiber packaging and products can be made from virgin paper, paper with recycled content (e.g., newsprint and cardboard), and plant fibers such as wood pulp, bamboo, bagasse, and wheat straw. It should be noted that plant fibers also are used to make compostable bioplastics. A significant percentage of molded fiber packaging is coated or contains binders.

As one example, bagasse is an agricultural byproduct: it is the fiber left on sugarcane stalks after the juice is extracted. These fibers are blended with water until they create a pulp, which then is converted (via pressure and heat) to a variety of molded fiber products. The process for making molded fiber packaging from wheat straw — the leftover stalk after the wheat has been harvested — is very similar. The wheat straw is turned into pulp, and that pulp can be used to create molded fiber products.

One item of concern is that paper fiber may contain per- and poly-fluorinated chemicals — known as PFAS — that are used to provide a grease or moisture barrier in food-contact packaging. These "forever chemicals" have been used for many years, but their negative health and environmental impacts have been identified more recently. This has led some certifiers of compostable packaging to prohibit intentional use of fluorinated chemicals, including limits on fluorine content.

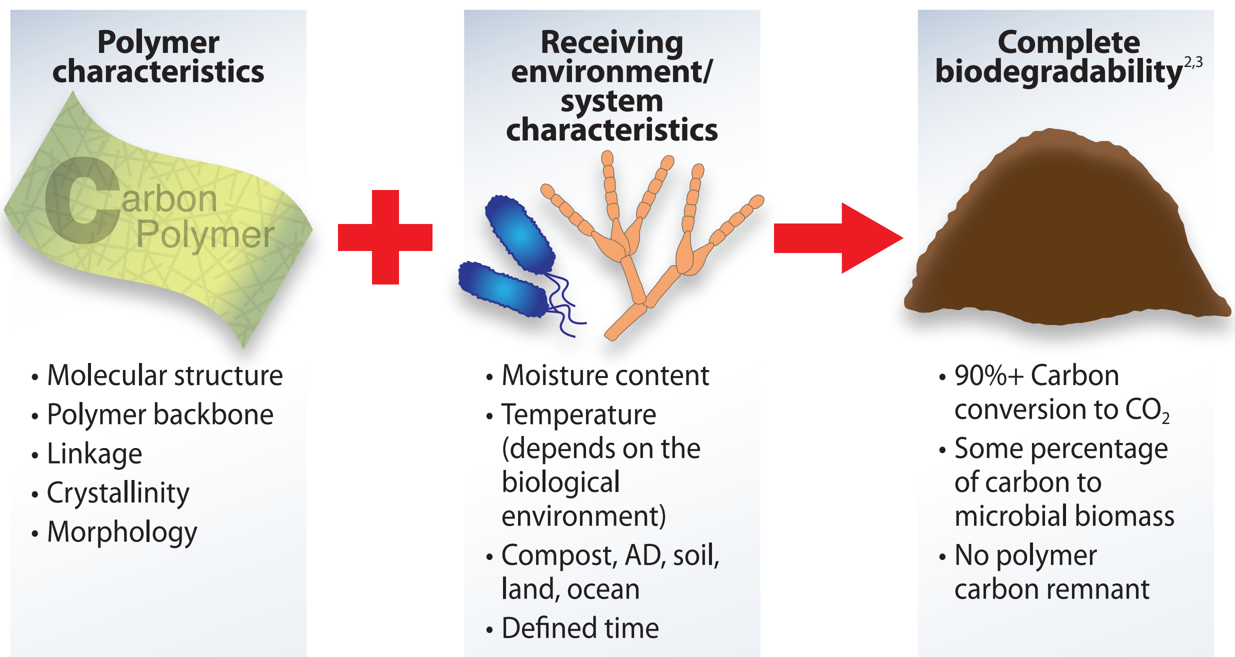
Several compost manufacturers that receive molded fiber trays from foodservice operations, especially schools, have noted that the trays are stacked after use to save space in the organics carts and dumpsters. The stacks get compacted and can pose processing challenges at the composting facility.

Compostable Plastics

Terminology for compostable plastics is confusing for a host of reasons, starting with the terms "biodegradable" and "compostable." The following rule of thumb is a useful guideline: Not all biodegradable products are compostable, but all compostable products (assuming they meet existing standards) are completely biodegradable., i.e., achieve 90+ percent conversion of carbon to carbon dioxide by microbial utilization (personal communication, Dr. R. Narayan, May 2021).

The word "biodegradable" in the context of whether it is or is not compostable takes a bit of unpacking (Figure 1). A paper, "Dos and Do Nots When Assessing the Biodegradation of Plastics," published in *Environmental Science & Technology*, provides a straight-forward explanation (Zumstein, et. al, 2019). "It is crucial to recognize that the biodegradability of a plastic is entirely disconnected from the origin of the carbon in the plastic: while a biobased plastic might be nonbiodegradable, plastics based on fossil carbon may readily biodegrade or vice versa," explain

Figure 1. Complete plastics biodegradation relies on specific polymer material properties and the receiving environment's biological properties[1]



1. Based on "Dos and Do Nots When Assessing the Biodegradation of Plastics," Environ. Sci. Technol. 2019, 53, 17 9967-9969, Narayan, Michigan State University

2. ASTM/ISO/EN test methods and specifications

3. 90% + does not mean that 10% of non-biodegradable carbon polymer/additive can be added. It is a recognition that experimental errors in biodegradation experiments are around +/- 10%. Therefore, from a statistical perspective, the absolute value is set at 90% + for complete biodegradation. Additionally, the 90% value for complete biodegradation recognizes that a few percent of the test carbon would remain incorporated in the cell biomass. Most importantly, the specification standards for compostable plastics (D6400, & D6868) require separate biodegradability testing for organic polymers & modifiers added at the 1-10% levels (to be increased to 1-15%). This additional requirement should address any concern about addition of non-biodegradable polymer.

the authors. "Studies that … question biodegradability of certified biodegradable plastics based on experiments in receiving environments other than the one for which the plastic is certified biodegradable ignore the fact that plastic biodegradability is not only a material property but also largely depends on the properties of the receiving environment."

Dr. Ramani Narayan of Michigan State University, a coauthor of the ES&T paper, provides further context: "Bioplastics is a generic term that includes both 'biobased' and 'biodegradable-compostable' plastics. Biobased refers to a polymer/plastic in which the carbon, in part or whole, comes from renewable plant-biomass resources. Biodegradable refers to end-of-life in which the plastic/polymer carbon is completely converted to carbon dioxide by microbial metabolism. Biodegradability is a system property and the receiving biological environment (soil, compost, land, ocean, temperature, humidity) needs to be identified" (personal communication, Dr. R. Narayan, May 2021).

Navigating the world of biodegradability and compostability is rife with confusion, especially when products labeled biodegradable look very similar to their counterparts that are certified compostable. Section IV, Regulations and Labeling, discusses initiatives designed to mitigate the confusion.

Supply Chain

Finally, it is helpful to understand the compostable packaging supply chain in order to distinguish the various types of companies in the marketplace. The compostable products supply chain originates with the material and input producers (e.g., resin suppliers), followed by the converters and manufacturers of the actual products. Brands and resellers (e.g., distributors) are the next link. Some distributors only sell the compostable packaging that is manufactured for them; others carry multiple types of foodservice packaging (which can cause some confusion when purchasing compostable products from these suppliers).

Buyers of compostable products include food establishments (e.g., cafeterias, restaurants, etc.), consumers (e.g., compostable liner bags from retailers), municipalities (for distribution to residents) and haulers (for distribution to food waste generators on their routes). Ultimately, the compostable products should end up in a composting pile, where they disintegrate, biodegrade and become part of compost, used to improve soil health, grow more plants and start the cycle over again.

SECTION II

Standards

Plastics claiming to be biodegradable and/or compostable entered the market in the 1980s. At that time, no standardized protocol existed to evaluate whether products marketed as biodegradable and/or compostable were technically capable of biodegrading and/or composting.

ASTM Standards

To address this gap, 15 organizations formed the Degradable Polymeric Materials Program as part of the American Society for Testing and Materials' (ASTM) Institute for Standards Research (ISR) in 1991. (ASTM is now known as ASTM International.) The objective of the program was to determine the behavior of degradable polymeric materials in real disposal systems and then correlate those results to laboratory results in order to "assure that such materials are safe for disposal and effectively degraded" (Yepsen, 2017). After five years of testing, the "Standard Guide to Assess the Compostability of Environmentally Degradable Plastics" was issued (October 1996), which became the reference document that the D20.96 ASTM Committee used to create the ASTM standards and specifications for compostable plastics. This guide is now withdrawn as the standards activity has moved forward; it serves as a historical marker.

A compostable plastic is defined by ASTM as "a plastic that undergoes degradation by biological processes during composting to yield carbon dioxide, water, inorganic compounds, and biomass at a rate consistent with other known compostable materials and that leaves no visible, distinguishable, or toxic residue." ASTM D5338 is the test method created for determining "Aerobic Biodegradation Of Plastic Materials Under Controlled Composting Conditions." It analyzed three tiers of testing (1. Rapid screening test; 2. Laboratory and pilot-scale composting assessment; and 3. Field/full scale assessment) and concluded that laboratory and pilot-scale were the most reliable for determining compostability due to an ability to control variables (ISR, 1996).

The ASTM standards used to certify compostable plastics are:

- **ASTM D6400-19**, Standard Specification for Labeling of Plastics Designed to be Aerobically Composted in Municipal or Industrial Facilities (ASTM, 2019)
- **ASTM D6868–21**. Standard Specification for Labeling of End Items that Incorporate Plastics and Polymers as Coatings or Additives with Paper and Other Substrates Designed to be Aerobically Composted in Municipal or Industrial Facilities (ASTM, 2021)

ASTM D6400 covers plastic materials and finished products made from plastics that are designed to be composted under aerobic conditions in municipal and industrial aerobic composting facilities, where thermophilic conditions are achieved. ASTM D6868 covers paper and fiber items that include plastics or polymers where plastic film/sheet or polymers are incorporated (e.g., through lamination, extrusion or mixing) to substrates (such as a paper cup or plate); the entire item is designed to be composted under aerobic conditions in municipal and industrial composting facilities, where thermophilic temperatures are achieved.

The four requirements in the ASTM standards are (McDonald, 2019; BPI, 2021):

1. Disintegration: This is the physical fragmentation of the product. Pretreatment processes (i.e, such as heating samples) is prohibited, but larger samples may be reduced in size, which increases surface area and allows for an even distribution of the compostable plastic products in the compost pile. Because the combination of moisture, temperature, mechanical action and microbial activity — during both the active phase and stabilization/maturation phase — contribute to the disintegration process, these parameters are closely monitored and reported. The ultimate goal is that the final compost contains no visible fragments of the compostable plastic product. The standard also establishes that <10 percent of the product's mass may remain on a 2mm sieve after 12 weeks of aerobic composting. Since thickness plays a key role, some products disintegrate far more rapidly than others (analogous to a toothpick and a 2 x 4). Therefore, the disintegration test sets the maximum thickness or density of an item claimed as compostable.

2. Biodegradability: Not only must the product fully disintegrate, the compostable plastic molecules must also truly biodegrade and not accumulate in the environment. For industrial aerobic composting, >90 percent of the organic carbon must convert to carbon dioxide within 180 days. This is considered complete biodegradation since the remainder of the carbon has been converted into biomass by the microbes. Where multiple materials are present between 1 to 10 percent, additional testing is required.

3. Heavy Metals: The product may not introduce significant levels of 11 heavy metals (the limit is 50% or less than the U.S. EPA 40 CFR Part 503 pollutant limits). It should be noted that ASTM does not have a fluorine requirement today (which is one aspect of restricting fluorinated chemicals like PFAS), but that is under consideration. One challenge is lack of a uniform test method for fluorine that is appropriate for packaging.

4. Plant Toxicity: The final compost may not contain residuals/byproducts that have harmful effects demonstrated through plant toxicity testing on at least two plant types. The testing standards require the full 12 weeks of aerobic composting 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 (two criteria measured) due to immaturity of the compost, so even if the test sample has fully disintegrated much sooner, the aerobic composting period is not allowed to be truncated.

All four requirements must all be met in order for the product to pass, and each test requires following a standardized test method. For example, D5338 is a standard test method required to determine aerobic biodegradation in composting, whereas ISO 16929 is a standard test method to determine disintegration in aerobic composting.

International Standards

Several other standard specifications for compostability are used around the world. All have the same basic four requirements described above, and use the same general pass/fail requirements.

The International Organization for Standardization (ISO) has an international standard for compostability — ISO 17088:2012 — that similarly addresses disintegration and biodegradation during composting, negative effects on the composting process and facility, and negative effects on the quality of the resulting compost, including the presence of high levels of regulated metals and other harmful components (ISO, 2021). "This specification is intended to establish the requirements for the labeling of plastic products and materials, including packaging made from plastics, as 'compostable' or 'compostable in municipal and industrial composting facilities' or 'biodegradable during composting'" (ISO, 2021). The criteria are the same as ASTM, except that there is no requirement for coatings on paper to be tested separately for biodegradation (like ASTM D6868).

In Europe, EN 13432 is the European Union's standard for compostable and biodegradable packaging. They mirror the ASTM and ISO standards. Several differences are that EN 13432 does not require ingredients present between 1 to 10 percent to be tested separately for biodegradation, whereas ASTM and ISO do. Instead EN 13432 allows retesting the final structure for biodegradation. In addition, the regulated levels of heavy metals are more restrictive than ASTM.

Other countries have similar standards, including Australia (EPA, AS4736-2006, "Biodegradable plastics suitable for composting and other microbial treatment"), and Canada (CAN/BNQ, 0017-088). Australia's standard includes an earthworm toxicity test. The Canadian standard follows ISO 17088.

SECTION III

Certifications

Certification organizations have been established to verify that materials and products intending to be sold as compostable actually are compostable based on the standards reviewed in Section II. This is important for several reasons, namely because a compostability claim is not based on a single pass/fail test, but rather multiple tests that depend in part on the product formulation and final structure. There are a few established certifiers: the Biodegradable Products Institute in the U.S., BNQ in Canada, and DIN Certco and TÜV AUSTRIA in Europe. A relatively new company in the U.S., Compost Manufacturing Alliance, is establishing a certification based on "field disintegration testing," i.e., at compost manufacturing facilities following a privately developed protocol.

BPI Certification

The Biodegradable Products Institute (BPI), formed as a nonprofit in 1999, initiated a compostable packaging certification program in partnership with the US Composting Council (USCC) based on the ASTM standard specifications, whereby products were designed to break down in facilities operated according to the USCC's "Compost Facility Operating Guide" (1994 and 1997). BPI's eligibility requirements for certification extend beyond passing the tests required by the ASTM standards. They include:

- Only products that are associated with the diversion of feedstocks desired by compost manufacturers, such as food scraps and yard trimmings, are eligible. This requirement is in place to limit the types of products that are not typically accepted at composting facilities. Products also cannot be a redesign of something that's a better fit for recycling, and cannot require disassembly to be composted.
- BPI requires that its Certification Mark (Figure 2) is used on all products and packaging unless there is a category exemption in place. This is to help make compostable items readily and easily identifiable.
- Fluorinated chemicals are prohibited, with all certifications needing a test with <100 parts per million (ppm) total fluorine (a screening method to pick up PFAS or Per- and polyfluoroalkyl substances); a statement indicating that there are no intentionally added fluorinated chemicals (including as process aids like mold release agents); and a review of safety data sheets (SDS) of all ingredients to determine if they include PFAS. This requirement went into place on January 1, 2020 and resulted in the removal of over 2,000 products from BPI's program (primarily fiber-based products).

Figure 2. BPI Mark (no FTC language)

DIN Certco and TÜV AUSTRIA

Figure 3. DIN Certco mark

DIN Certco issues certificates (Figure 3) for compostable plastics based on ISO 17088, EN 13432, or ASTM D6400 and D6868 standards. TÜV AUSTRIA (formerly Vincotte) issues certificates (Figure 4) for compostable plastics based on those same standards, as well as certificates for plastics that can be composted in home composting (OK compost HOME), and plastics that biodegrade in soil (OK biodegradable SOIL), water (OK biodegradable WATER), and OK biodegradable MARINE.

Compost Manufacturing Alliance

Figure 4. TÜV Austria OK mark

Formed in 2017, the Compost Manufacturing Alliance (CMA) is a for profit company that works with the manufacturers and users of compostable packaging (e.g., consumer brands) to field verify disintegration at composting facilities that are part of the CMA network. These facilities use different composting methods, which enables field testing under various conditions, e.g., windrows, aerated static piles (ASP), covered ASP, etc. CMA uses ASTM D6400 and D6868 pass/fail results and field disintegration tests. The company offers certification to compostable product manufacturers.

Home Composting Certification

ASTM International Committee D20 continues to discuss the need for standards for backyard or "home" composting. This proposed method has evolved over the years and is currently focusing on a determination of disintegration in backyard composting. The proposed standard is under the jurisdiction of Subcommittee D20.96 on Environmentally Degradable Plastics and Biobased Products, which also developed the D6400 and D6868 standards. The proposed standard will contain performance requirements for "home compostability," requiring that products biodegrade within a certain time frame. After a material is tested by an independent laboratory and approved as "home compostable," a logo could be printed on the package for consumers. BPI is also conducting a scientific review of home composting conditions in the U.S. in an effort to determine appropriate time frames and temperatures for a standardized test and specification.

Products currently sold as "home compostable" in the U.S. often use the "OK compost HOME" certification offered by Austria's certifier of compostable packaging, TÜV AUSTRIA's OK (Figure 5). TÜV AUSTRIA bases its home compostable test mainly on adaptations to the commercial compostability tests, doubling the time frame and lowering the temperatures. An Australian standard called AS 5810, entitled "Biodegradable plastics suitable for home composting" is similar (UrthPact, 2020). Both require disintegration in six months, and biodegradation and compost formation in 12 months.

Figure 5. TÜV Austria OK Home Composting Mark

SECTION IV

Regulations And Labeling

Compostable products are subject to specific labeling requirements — primarily as they relate to claims about compostability and access to composting facilities. These have been established by the Federal Trade Commission (FTC) and various state and local governments.

FTC Green Guides

The FTC first issued its Green Guides in 1992 to help marketers avoid making misleading environmental claims. Revisions in 1998 included guidance on compostable claims, noting that "marketers should possess competent and reliable scientific evidence showing that 'all the materials in the product or package will break down into, or otherwise become a part of, usable compost (e.g., soil conditioning material, mulch) in a safe and timely manner in an appropriate composting program or facility, or in a home compost pile or device.'"

A revision in 2012 (FTC, 2012) clarified that "timely manner" means "in approximately the same time as the materials with which it is composted." The FTC also reiterated the 1998 guidance that marketers clearly qualify compostable claims, if, for example, their product cannot be composted safely or in a timely manner at home, or if necessary large-scale facilities are not available to a substantial majority of the marketer's consumers. The guidance includes examples of usage of the term compostable that falls within its guidelines.

With regard to product labeling, the FTC requires that all claims of "Compostable" be qualified to indicate whether the item is Commercially Compostable, Home Compostable, or both. Items that are "Commercially Compostable Only" must explicitly state this limitation and also make clear that consumers may not have access to commercial composting facilities.

The Green Guides are not agency rules or regulations. Instead, they describe the types of environmental claims the FTC may or may not find deceptive under Section 5 of the FTC Act. Under Section 5, the agency can take enforcement action against deceptive claims, which ultimately can lead to Commission orders prohibiting deceptive advertising and marketing and fines if those orders are later violated. The first time the FTC filed a complaint against a company for making claims of compostability was in 2013 (FTC, 2013). The company, AJM Packaging Corporation, manufactures paper products, including paper plates, cups, bowls, napkins, and bags, for sale throughout the U.S. The company violated a 1994 FTC consent order that barred it "from representing that any product or package is degradable, biodegradable, or photodegradable unless it had competent and reliable scientific evidence to substantiate the claims," according to a 2013 FTC press release. "Despite the terms of the order, AJM began making new environmental claims for a number of its papers products, including claims that they were "biodegradable," "compostable" or both."

State Labeling Requirements

A handful of states have labeling requirements that apply to compostable packaging:

California: California was an early adopter of restrictions on use of "degradability" terms. In 2011, legislation was passed that extended restrictions on use of degradability terms to nearly all plastic products (California PRC 42355-42358.5). (See Public Resources Code (PRC) Sections 42355-42358.5.) The law requires clear scientific evidence for environmental claims, noting biodegradation is a complex process dependent on physical and chemical structure, environmental conditions, and time. It required plastic bags and food packaging items (including utensils) labeled as compostable to demonstrate compliance with ASTM D6400. It also required that compostable plastic bags meet explicit labeling requirements. In 2018, a complaint was filed against Costco Wholesale and JBR, Inc. by 25 California district attorneys for violating this law when selling coffee pods as "compostable" and "biodegradable" (North Bay Business Journal, 2018).

Also in 2018, a consumer protection lawsuit filed by the Monterey County (CA) District Attorney against Amazon for selling and advertising plastic products that are misleadingly labeled as "biodegradable" was settled for $1.5 million. The complaint was filed in conjunction with 22 other California district attorney's offices. The judgment prohibits Amazon from unlawfully selling or offering for sale any plastic products labeled "biodegradable," or selling or offering for sale plastic products labeled "compostable" without the appropriate certification (Californians Against Waste, 2018).

Washington: In 2019, Washington state enacted a law (RCW 70A.455) that prohibits use of "compostability" and "biodegradability" claims for plastic products that do not meet uniform standards identified by the state. The law, which became effective on July 1, 2020, is the most comprehensive statute directly addressing labeling for compostable products and packaging in the United States. It forbids use of terms like "biodegradable," stating, "Except as provided in this chapter, no manufacturer or supplier may sell, offer for sale, or distribute for use in this state a plastic product that is labeled with the term "biodegradable," "degradable," "decomposable," "oxo-degradable," or any similar form of those terms, or in any way imply that the plastic product will break down, fragment, biodegrade, or decompose in a landfill or other environment" (Washington, 2019).

The following text is excerpted from the law:

(1)
(a) A product labeled as "compostable" that is sold, offered for sale, or distributed for use in Washington by a supplier or manufacturer must: (i) Meet ASTM standard specification D6400; (ii) Meet ASTM standard specification D6868; or (iii) Be comprised of wood, which includes renewable wood, or fiber-based substrate only;
(b) A product described in (a)(i) or (ii) of this subsection must: (i) Meet labeling requirements established under the United States FTC's guides; and (ii) Feature labeling that:

(A) Meets industry standards for being distinguishable upon quick inspection in both public sorting areas and in processing facilities;
(B) Uses a logo indicating the product has been certified by a recognized third-party independent verification body as meeting the ASTM standard specification; and
(C) Displays the word "compostable," where possible, indicating the product has been tested by a recognized third-party independent body and meets the ASTM standard specification.
(2) A compostable product described in subsection (1)(a)(i) or (ii) of this section must be considered compliant with the requirements of this section if it:
(a) Has green or brown labeling;
(b) Is labeled as compostable; and
(c) Uses distinctive color schemes, green or brown color striping, or other adopted symbols, colors, marks, or design patterns that help differentiate compostable items from noncompostable materials.

Maryland: The State of Maryland's compostable product labeling statute (Maryland PRC, 2015), effective "on or after October 1, 2018" has the following requirements (text excerpted from the law):

(A) Prohibits for sale in the State a plastic product that is labeled as biodegradable, degradable, decomposable, or with any other term to imply that the product will break down, fragment, biodegrade, or decompose in a landfill or any other environment.
(B) Prohibits for sale in the State a plastic product that is labeled as compostable or home compostable unless the plastic product meets the following standards:
(1) A plastic product labeled as compostable, the plastic product shall meet the ASTM D6400 standard specification or the ASTM D6868 standard specification; and must meet any applicable labeling guidelines in the FTC 's Guides for the Use of Environmental Marketing Claims.
(2) For a plastic product labeled as home compostable, the plastic product shall meet the OK Compost Home certification standard adopted by Vincotte; and any applicable labeling guidelines in the FTC's Guides for the Use of Environmental Marketing Claims.
(C) A person that distributes or sells a compostable food or beverage product intended for sale or distribution by a retailer in the State shall ensure that the compostable food or beverage product is labeled in a manner that is readily and easily identifiable from other food or beverage products; is consistent with the FTC's Guides for the Use of Environmental Marketing Claims; and has a certification logo indicating the compostable food or beverage product meets the ASTM D6400 standard specification or ASTM D6868 standard specification; or as compostable.

Minnesota: A law passed in Minnesota in 2009 (Minnesota, 2020), 325E.046 Standards For Labeling Plastic Bags, requires that "a manufacturer, distributor, or wholesaler may not offer for sale in this state a plastic bag labeled 'compostable' unless, at the time of sale, the bag meets the ASTM Standard Specification for Compostable Plastics (D6400). Each bag must be labeled to reflect that it meets the standard." Legislation currently in the Minnesota House and Senate proposes to add ASTM D6868 to that statute.

BPI Labeling Requirement

Figure 6. BPI Mark with FTC language

All consumer- and market-facing packaging certified as compostable by BPI must include the BPI Certification Mark, which is designed to meet some of the basic requirements (i.e, the word compostable, a third-party mark, the color green). BPI also provides a version of its Certification Mark that includes the FTC required language (Figure 6). BPI strongly recommends that the following disclaimer language be used on all products and packaging featuring the BPI Certification Mark: "Commercially Compostable Only. Facilities May Not Exist in Your Area." In cases where there is not enough space to fit all of the required disclaimer and qualifying language, BPI will work with licensees to come up with solutions that make maximum use of the available area for the required language. BPI also prohibits the use of terms like "biodegradable" and "trash."

In September 2020, BPI released Guidelines for the Labeling and Identification of Compostable Products and Packaging (BPI, 2020) to establish consistent, category-specific identification guidelines for product and packaging manufacturers and brand owners. Intended benefits are to reduce end user (e.g., foodservice) and consumer confusion, reduce contamination and, ultimately, lead to higher quality feedstocks for composters, noted BPI. When the guidelines were released, BPI requested input from compost manufacturers and continues to seek feedback from all stakeholders.

Figure 7. Bioplastic cold beverage cup

Technical options and spatial considerations that manufacturers and brand owners have to evaluate are part of the guidelines. For example, printing is a reliable method of delivering specific information on a product or package, e.g., use of a stripe, words and/or symbols, but can pose a significant challenge on some BPI-certified products (Figure 7). Material coloring and tinting are options for achieving visual differentiation but aren't sufficient on their own to clearly identify compostable products and packaging. Lack of space is often cited by manufacturers and brand owners as a challenge when considering language and logo usage on compostable products and packaging, especially when complying with the FTC guidelines. The BPI document includes suggestions for resolving space constraints.

SECTION V

Bioplastic Resins

Bioplastics intended to biodegrade within organics processing infrastructure have evolved over the decades and, as noted in the beginning of this paper, generally fall into two categories: Biopolymers that are naturally occurring or produced by biological organisms; and Fossil-based biodegradable polymers.

"Navigating Plastic Alternatives In A Circular Economy," authored by Hannah Friedman with Closed Loop Partners' Closed Loop Ventures Group (Friedman, 2020), created an easy-to-understand overview of compostable materials that are captured in the figure, "Mapping the End-of-Life Pathways for Plastic Alternatives," reprinted here (Figure 8). The figure divides materials intended for use in compostable packaging into three sections:

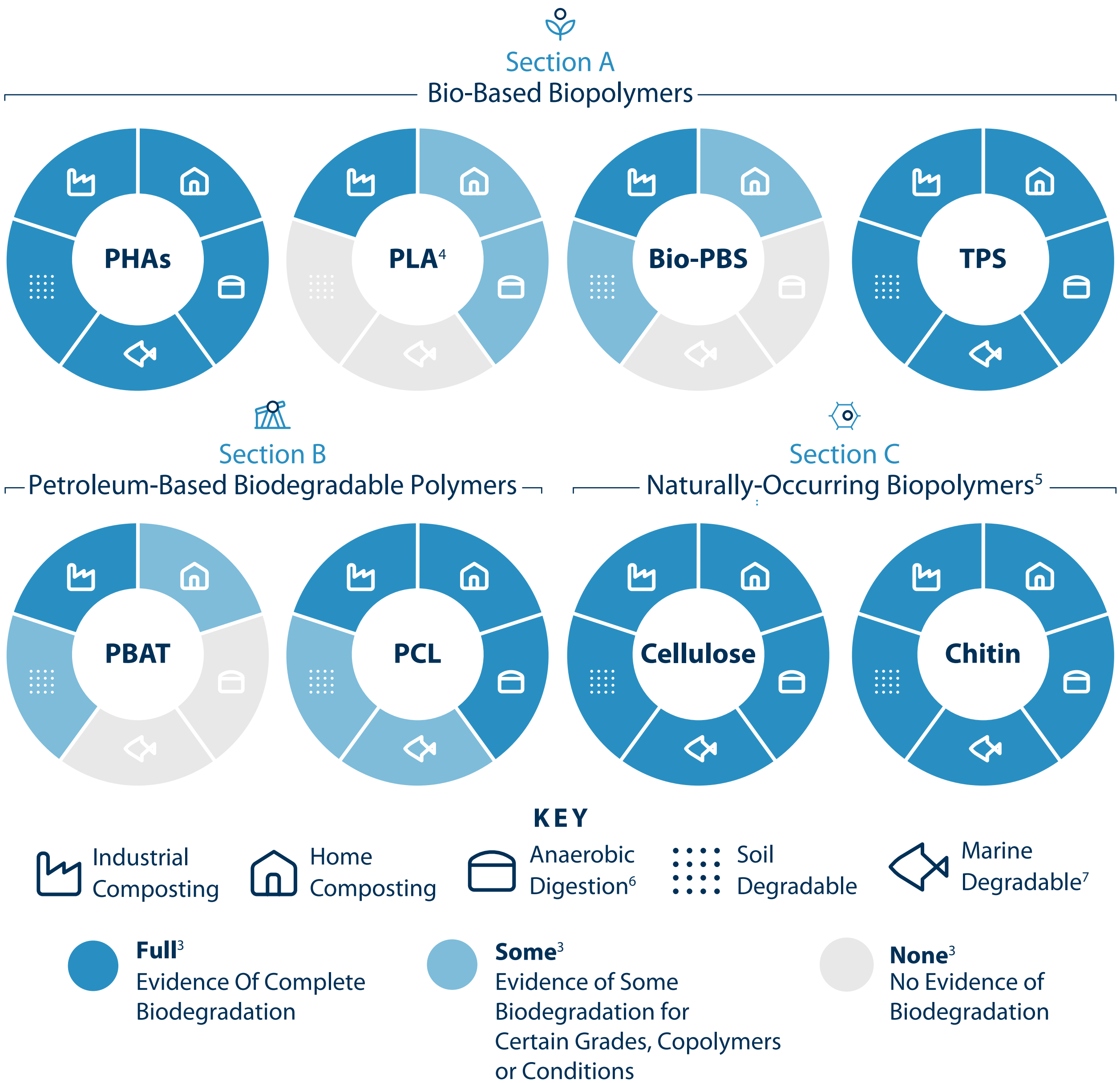
1. **Bio-based biopolymers**: PHAs (Polyhydroxyalkanoates), PLA (polylactic acid), Bio-PBS (polybutylene succinate), TPS (thermoplastic starch)
2. **Petroleum-based biodegradable polymers**: PBAT (Polybutylene adipate terephthalate), and PCL (Polycaprolactone)
3. **Naturally-occurring biopolymers**: Cellulose (a polysaccharide) and Chitin (an amino polysaccharide polymer)

Each biopolymer is listed by its end-of-life degradation options: industrial composting, home composting, anaerobic digestion, soil degradable, and marine degradable. Four biopolymers were identified as having evidence of complete biodegradation in all end-of-life alternatives: PHAs, TPS, cellulose and chitin. The other four biopolymers evaluated — PLA, Bio-PBS, PBAT and PCL — all were identified as having evidence of complete biodegradation in industrial composting. Descriptions of each of these materials are in the Appendix.

Among the biopolymers highlighted, PLA is probably the most widely recognized bioplastic. In the U.S., the major manufacturer of PLA is NatureWorks, LLC, which markets its PLA under the brand name Ingeo. Ingeo is derived in a two-step process that starts with fermenting the dextrose derived from a simple hydrolysis of corn starch. The product of the dextrose fermentation, lactic acid, is the basic building block of the Ingeo polylactide family of plastics (USCC, 2011). Lactic acid is further treated to create an intermediary monomer product called lactide, which is then polymerized through a process called ring opening polymerization to form Ingeo.

PHAs are a class of microbially produced polyesters that use sugar, plant oils, and other bioresources. PHB (polyhydroxy butyrate), PHBV (Polyhydroxy butyrate-co-valerate), PHBH (polyhydroxy butyrate-co-hexanoate) are examples of these microbial polyesters. PHAs are naturally occurring organisms in sewage sludge and digestive tracts, but are commercially produced using a variety of fermentation approaches.

Figure 8. Mapping the end-of-life pathways for plastic alternatives[1, 2, 3]



1. Excerpted, with permission from Closed Loop Partners, from "Navigating Plastic Alternatives In A Circular Economy." December, 2020.
2. Figure 8 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.
3. The biodegradability indicators (full, some, none) are general trends and not a substitute for actual testing in the selected environment using approved ASTM/ISO standards.
4. Historically, PLA has been widely recognized as industrially compostable only. However, some new advances and the tactic of blending PLA with other biopolymers seeks to achieve home compostability.
5. The naturally-occurring biopolymer form of Cellulose & Chitin is most often plasticized via chemical processes to create fully biodegradable and compostable materials.
6. Often, not all carbon from polymers converts to methane from anaerobic digestion. When materials do not fully biodegrade in the anaerobic digestion process — resulting in a residual called digestate — the material can be sent into industrial composting processes where complete biodegradation happens via aerobic microbes.
7. Marine degradable is based on a standard lab test method operating at 30°C. The ocean temperature average is around 4°C, thus the rate of biodegradation is expected to slow down considerably and can result in incomplete biodegradation of materials that end up in oceans.

Mango Materials, a PHA resin developer, uses a fermentation technology that involves the production of PHA from waste biogas (methane). Early PHA homopolymers were brittle, and had to be blended with other biodegradable additives to enhance the processability and performance. Danimer Scientific manufactures a PHA resin made of polyesters "biosynthesized by a bacterium fed by inexpensive oils derived from the seeds of plants such as canola and soy" (Danimer Scientific, 2021).

Thermoplastic Starch (TPS) is processed starch from a number of plant-based sources such as corn, wheat, or rice. The native starch is transformed to provide enhanced polymeric properties (i.e., blended to take advantage of the inherent plastic-like polymer nature). Most frequently, the starch is first heated to destroy, or open up its inherently weak polymer structure, then is blended with complexing agents — other polymers that reform with the starch creating a stronger biobased plastic. One of the largest TPS producers is Novamont; its biopolymer is sold under the name Mater-Bi.

SECTION VI

Current Landscape For Compostable Products

The 2011 Compostable Plastics 101 paper reported five key challenges that stakeholders identified at a one-day symposium: Identification/labeling; Enforcement legislation; Need to refine ASTM Standards; Consumer education; and National Organic Program (NOP) impacts.

Ten years later, progress has been made on resolving some of those challenges, e.g., several state's labeling laws. Enforcement actions are built into those laws, e.g., Maryland imposes penalties up to $2,000 for violations. The BPI labeling guidelines provide a takeoff point for discussion on how to improve identification of products, and aid in consumer education.

The National Organic Program within the U.S. Department of Agriculture still prohibits inclusion of compostable plastics packaging in organic agriculture inputs. Petitions to change the prohibition have been filed, such as for soil biodegradable mulch film, but the process is very lengthy and still ongoing.

Field Verification

One challenge identified in 2011 — refinement of the ASTM standards — has evolved, with a specific focus on the field verification step. Since the standards were adopted in the 1990s, an increasing number of compost manufacturers have shortened their processing times to as little as 45 days for active composting and curing, with a range of 60 to 120 days from start to finish being more typical. Part of the challenge in determining if certified compostable products will break down is due to this variability in processing time frames and conditions at commercial composting facilities (which makes it challenging to verify and update the ASTM standards). It is also worth noting that shortened composting times may not result in a fully matured, though still marketable, compost product.

The ASTM standard for disintegration is 12 weeks or 84 to 90 days, which on face value is out of sync with shorter time frames. However, that timeframe was set in the ASTM ISR study (ISR, 1996) based on a comparison to <60-day field tests because it was more conservative (e.g., harder to pass than the full scale test), and would avoid false positives. In other words, the study found that items failing the lab/pilot scale were still passing in the more aggressive time frames and conditions in the full scale tests, which is preferable to having products pass the lab/pilot scale and fail in the full scale facility, which would be a false positive.

Biodegradation is a process (not visible to the human eye) where microorganisms consume the organic carbon and convert it to carbon dioxide, water vapor and humus. It cannot be measured in a field test, but instead is determined by a laboratory test. (As noted in Section II, ASTM D5338 is the standard test method required to determine biodegradation.) By comparison, disintegration is a visual and physical breakdown that can be measured in a field test. The maximum time frame for biodegradation in the ASTM D6400/D6868 standard for industrial compostability is 180 days. Little data is publicly available to know how much organic carbon from a compostable product may still remain before the compost leaves facilities. In addition, it would be nearly impossible to know whether the carbon detected came from a compostable product versus a conventional plastic contaminant.

The 180-day time frame for biodegradation is commonly confused with the 12 week/84-day time frame for disintegration, and is cited by some as a reason why the ASTM standards are out of synch with the operational requirements of composters. The regulations drafted to implement a law, "Sustainable Packaging for the State of California Act of 2018" (CA Public Resources Code, 2018), enacted in California is a case in point. The law requires food service facilities located in a state-owned facility, operating on or acting as a concessionaire on state-owned property, or under contract to provide food service to a state agency to dispense prepared food using food service packaging that is reusable, recyclable, or compostable. The regulatory language establishes the parameter of 90 percent biodegradation of compostable products with 60 days — a requirement that is not based on standards, and a high bar that manufacturers of compostable products may not be able to meet.

Since 2011, two organizations have introduced field testing to assist compost manufacturers in determining whether products certified as compostable by BPI and/or meeting the ASTM D6400/D6868 standards disintegrate in their specific process and timeframe. Both tests measure disintegration, not biodegradation. Generally speaking, field conditions have high variability, which has to be factored in when making assessments of a given sample.

The first initiative is the International Field Testing Program, developed in 2017 by the Compost Research & Education Foundation (CREF) and BSIbio Packaging Solutions/BÉSICS® (BSIbio), with a steering committee involving members of BPI, ASTM, and other experts in the compost manufacturing and compostables industry (CREF, 2021). Compost manufacturers receive the tools and a standardized protocol to test certified compostable products on site. Their results are then anonymously posted in the testing program's database for others to learn from (i.e., it is an open source database). In short, note CREF and BSIbio, "they have the ability to answer their own questions about how specific materials may work in their operations, and at the same time contribute to a larger, broader understanding throughout the industry" (Strand and McGill, 2017; McGill and Oshins, 2018).

The second is the field testing service offered by the Compost Manufacturing Alliance (CMA), as described in Section III.

Roadmap To Address Barriers

In March 2021, a roadmap and action plan on how to address existing barriers to broader acceptance of compostable packaging by compost manufacturers was released by BPI (BPI, 2021). The Roadmap is the outcome of a BioCycle/BPI workshop-based consensus building process that involved stakeholders from four groups: Compost manufacturers and haulers, municipalities, operators (e.g., users of compostable products) and brands, and compostable product and material manufacturers. The consensus-building process was anchored by the reality that there is tremendous market demand for compostable packaging, but composters are having varying degrees of success accepting and processing the material (Goldstein, 2021).

Table 1 summarizes the six key barriers identified by stakeholders, along with the "future states," i.e., the end goals to be reached by resolving the barriers. The goal of the document is to involve as many stakeholders as possible in the steps needed to resolve the barriers with the aim of a single set of acceptability criteria that both compostable products companies and compost manufacturers agree on.

Table 1. Six barriers and future states

Barrier	Future state
Value proposition uncertainty	Correlation between compostable products, food scraps diversion, and participation rates for organics programs is clear
Regulatory inconsistency	Agreed upon labeling criteria and definition of compostability provide consistency and trust along the value chain
Contamination	Contamination from non-compostable products does not prevent composters from accepting and successfully processing compostable products
Infrastructure funding	Increased cost of collecting and processing compostable products in a food scraps program is supported by product and material manufacturers
Compostability standards	Composters have enough information on "real world" performance to trust that products meeting ASTM standards will break down in facilities designed to accept food scraps and packaging
Organic agriculture rules	Compostable products are an allowable input under the requirements of the National Organic Program (NOP) for finished compost

Compost Manufacturer Acceptance

It is anticipated that in this decade, consumer packaged goods will increasingly utilize compostable alternatives for their packaging. Synching introduction of these products with capacity and willingness of compost manufacturers to accept them is necessary.

The gap between the number and types of compostable products being introduced into the marketplace and the number of compost manufacturers willing and able to accept those products is significant. Compost manufacturers — those accepting food scraps and those that are not — are being approached regularly about receiving compostable products. During interviews for the decision-making guide, one compost manufacturer held up his cell phone and said a recent call was about accepting compostable cell phone cases.

Those already accepting compostable packaging — primarily along with food scraps — are struggling with contamination from lookalike products. Some note that when a consumer or food service worker sees a certified compostable bag or cup in the organics bin, they assume that any bag or cup can go in, whether compostable or not.

This paper, the USCC virtual workshops and Summit, and a decision-making guide for compost manufacturers on acceptance of compostable packaging, are designed to help compost manufacturers navigate this complex landscape.

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APPENDIX

Biopolymers

Excerpted, with permission from Closed Loop Partners, from "Navigating Plastic Alternatives In A Circular Economy: A Closed Loop Partners Report." December, 2020, by Hannah Friedman.

Section Titled: Demystifying Alternative Material Innovations: From Feedstock to End-of-Life Recovery; pp. 20-23.

Biobased Polymers

• **PHAs**: Polyhydroxyalkanoates are another family of increasingly common biopolymers — including poly (3-hydroxybutyrate), or PHB, and all its variants: PHBH, PHBV and PHBO, just to name a few. 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 biodegradable in almost all environments (aerobic, anaerobic, marine and soil). Although this is rapidly changing, today the space does not have significant manufacturing capacity for PHAs, and PHAs have traditionally been expensive to produce.

• **PLA**: Polylactic acid 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. Historically, PLA can be brittle and can have poor gas barrier properties compared to polyolefins; most grades of PLA don't hold up well to heat. PLA is often blended with other materials or biopolymers to address these performance challenges. PLA is typically only compostable in industrial composting conditions where criteria for temperatures, moisture, oxygen levels and nutrient ratios are met. While new variations are evolving to biodegrade in home composting environments, most PLA-based products are not currently home compostable; in a landfill, PLA can take as long as PET to degrade.

• **Bio-PBS**: Bio-PBS has the prefix "bio" because it is chemically identical to its petroleum-based sister PBS, or polybutylene succinate. 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. Both bio-PBS and petroleum-based PBS are highly degradable in an industrial composting setting, but less degradable in ambient environments like soil and seawater.

• **TPS**: Thermoplastic starch (TPS), is a common biopolymer made by the plasticization of starch. 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. Therefore, like PLA, TPS is often blended with other polymers to achieve better attributes in packaging applications. The compostability of TPS blends 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.

Petroleum Based Biodegradable Polymers

- **PBAT**: Polybutylene adipate terephthalate is made through the polycondensation of butanediol (BDO), adipic acid (AA) and terephthalic acid (PTA). Today, PBAT is mostly petroleum-based, though companies have started to use bio-based BDO and other inputs for a partially bio-based polymer. PBAT is notable for its clear biodegradability and compostability. 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. Similar to PBAT, PCL is readily biodegradable and compostable in most scenarios despite its petroleum-based feedstocks. 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.

Naturally-Occurring Biopolymers

Common natural biopolymers come from a variety of bio-based feedstocks found naturally in the environment. Naturally-occuring polymers are known to biodegrade in all environments, given they do exist naturally in the world around us today. Compostable certification of these products and packaging is still best practice.

- **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).

- **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.

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