ECOENCLOSE

BIOPLASTICS ARE NOT A SILVER BULLET SUSTAINABILITY SOLUTION

EXECUTIVE SUMMARY

With 19 million tons of bioplastics produced annually, the interest surrounding bioplastics is growing.

Bioplastic is a broad term used to describe any plastic that is made from 20 percent or more of renewable materials derived from biological sources, such as corn, sugarcane, potato starch or the cellulose from trees and straw. Bioplastic refers to a number of different materials, all with extremely different characteristics.

This broad usage of the term "bioplastics" is yielding tremendous confusion and misguidance on when, why and how to use bioplastic. When asking whether or not your company should embrace bioplastic packaging, you'll want to take the line of questioning a few steps farther: What kind of bioplastic (renewable and recyclable, renewable and compostable, nonrenewable and compostable?) and "to what end."

Current bioplastic materials are not the solution to our ocean / marine pollution crisis. Eliminating litter (and improving waste management) in developing nations and creating stronger markets for recycled plastic are important next steps.

Bioplastic, compostable solutions have an important place in the world of single-use packaging. They are most interesting and relevant in the world of food packaging, because over time, they can encourage more and more food to be composted.

Outside of these scenarios, EcoEnclose believes that bioplastic is not the silver bullet solution to our single use packaging woes. Instead, packaging made with as much recycled content as possible and that are as easily recyclable as possible are preferred.

When the functional and cost benefits of plastic are needed, use 100 percent recycled plastic.
When this is not the case and you are focused on optimal end-of-life - use 100 percent recycled paper.

Most importantly, be a thoughtful buyer. As this white paper illustrates, the world of bioplastic is complex and confusing, and largely unregulated in terms of what companies are allowed to say on their products.

If you see bioplastic packaging that claims to be recycled, recyclable, and biodegradable, ask the supplier lots of questions. There is a high probability that these claims are untrue, or are at least unverifiable. Ask for:

- A breakdown of source materials in the packaging
- Exact percentage of material in the packaging that is recycled
- What makes the material biodegradable
- Any certifications related to biodegradability or compostability they can share
- Any verification related to the recyclability of the material they can share
- Information on where the raw material and final packaging is manufactured

If you don't get answers to the above, proceed with caution. Be thoughtful about how you present this packaging to your customers, so you don't mislead them or cause them to dispose of this packaging irresponsibly.

INTRO

The global packaging industry is worth $424 billion, growing at an annual rate of 3.5 percent.[1] In the US alone, an estimated 78,000 tons of packaging was used and discarded in 2015, which has led consumers adn companies to look for eco-friendly alternatives. Thus, the "sustainable packaging" industry was born.

The goals of sustainable packaging are to reduce the carbon footprint of packaging (end to end across the lifecycle), reduce (and ideally eliminate) the amount of packaging that is not recovered and therefore goes to waste, and to eliminate instances of packaging ending up as litter and/or pollution (ultimately making its way to our oceans and waterways).

In the current climate, conversations on the topic of "sustainable packaging" often redirect to bioplastic.

Bioplastic sounds like the silver bullet solution to all of our single use plastic challenges, but the reality is far more complicated than that. In this paper, we discuss:

1. What is sustainable packaging?
2. What is bioplastic and what different materials does this single word actually describe?
3. The benefits of bioplastic as well as its challenges. Packaging situations where bioplastic is the right solution, and alternative sustainable packaging solutions when bioplastic is not optimal.
4. Guidance to help organizations create the right framework to make strategic sustainable packaging decisions.

Our goal in this paper is to provide expert guidance and equip decision makers with the data to guide their organizations through the complex decision making process of finding the optimal and most eco-friendly packaging solution and product(s) available.

WHAT IS BIOPLASTIC?

Plastics are human-made, synthetic polymers derived from long chains of carbon and other elements. Plastics can be derived from materials found in nature, such as natural gas, oil, coal, minerals and plants. For "petroleum-based plastic", a process called cracking allows crude oil and natural gases to be converted to hydrocarbon monomers like ethylene, propylene, styrene, vinyl chloride, ethylene glycol, and so on. These are mixed with other chemicals to produce a desired finished product. For example, plasticizers like phthalates to make PVC soft or butadiene to make plastic #7 tough.

Bioplastic is a broad term used to describe any plastic that is made from 20 percent or more[1] of renewable materials derived from biological sources, such as corn, sugarcane, potato starch or the cellulose from trees and straw.[2]

19 million tons of bioplastics are produced annually (just four percent of the global plastics market).[3] However, it is important to note that 17 million tons of this production is actually made up of "old economy" bioplastics - materials that have been around since before petroleum based plastics - such as rubber, gelatin, cellulose, and linoleum.

"New economy" bioplastics - materials designed to replicate the qualities and applications of traditional fossil fuel based plastics, but using plant based feedstocks instead - are the field that is getting all of the buzz, and though it is still a tiny percent of the overall plastics market, it is growing rapidly - at a rate of approximately 15 percent annually from 2013 to 2016.

1 https://www.pdachain.com/2016/11/30/packaging-statistics-that-might-surprise-you/

1 https://blogs.ei.columbia.edu/2017/12/13/the-truth-about-bioplastics/
2 https://www.creativemechanisms.com/blog/everything-you-need-to-know-about-bioplastics
3 https://sustainablepackaging.org/2020-bioplastics-market-forecast/

Common Bioplastic Formulations

Many different materials, with highly diverse characteristics, can be described by the term "bioplastic." This section describes several common types of bioplastic formulations.

Note that the resulting packaging that you can touch and feel often includes several different bioplastic formulations, in addition to plasticisers and additives to give the packaging required characteristics (flexibility or rigidity, strength, ability to withstand heat, etc). The following section discusses categories of bio-based packaging in greater detail.

The primary distinctions between different types of bioplastic formulations include:

1. **Feedstock**: Feedstock can be renewable - including corn, wood, sugarcane, algae, potatoes and more. Research is being conducted to commercialize and scale the production of bioplastics from lignocellulosics such as bagasse, wood chips, straw, and switch grass. Alternatively, some materials that are considered bioplastic are actually derived from organic compounds found in fossil fuels.

2. **Drop-in versus new formulation**: This describes whether or not the bioplastic formulation is designed to be identical (on a molecular level) to a fossil-based plastic or represent an entirely new formulation altogether. Typically drop-in formulations have the same end-of-life characteristics as the petroleum based alternatives they are designed to mimic.

3. **End-of-life**: Bioplastic formulations are either durable or biodegradable. Durable bioplastics might be readily recyclable. Biodegradable bioplastics may or may not be readily compostable.

Cellophane

Feedstock: Commonly made from wood, cotton or hemp

Formulation: "New" formulation, i.e. formulation that is unique to itself (and does not try to mimic a traditional petroleum-based plastic).

End-of-Life: Readily biodegradable and compostable

Cellophane is a plastic that is made out of cellulose and produced from fibers derived from materials such as wood, cotton or hemp. The cellulose from these sources is dissolved in alkali and carbon disulfide to create a solution known as viscose, which is then extruded through a slit into a bath of dilute sulfuric acid and sodium sulfate to reconvert the viscose into cellulose. The film is then passed through several more baths, one to remove sulfur, one to bleach the film, and one to add softening materials such as glycerin to prevent the film from becoming brittle. Interestingly, a similar process and source material is used to make rayon.

Cellophane, the world's first transparent packaging film, was invented in 1908 by the Swiss engineer Jacques Brandenberger. He assigned his patents to La Cellophane Societe Anonyme, a French company formed for the sole purpose of marketing the invention and in 1923, the company licensed exclusive rights to make and sell cellophane in the U.S. to DuPont.

Cellophane had its heyday between World War I and the discovery of polypropylene in the 1950's. It has since been largely replaced by petroleum-based plastics (as well as emerging, new technology bioplastics). However, you'll still find cello being used in clear packaging tape and the loud, crinkly, clear plastic bags used by confection and candy companies.

Uncoated cellulose film typically degrades within 10 days to 1 month in a compost environment and nitrocellulose-coated cellulose degrades in 2-3 months. Uncoated cellulose can therefore be backyard composted, while coated cellulose may be better suited for industrial composting environments. Cellophane will biodegrade within one month in a marine environment.

Polylactic Acid, or PLA

Feedstock: Commonly made from corn, sugarcane or beets

Formulation: "New" formulation, i.e. formulation that is unique to itself (and does not try to mimic a traditional petroleum-based plastic).

End-of-Life: Compostable in controlled settings (industrial composting facilities). PLA is typically designated by a recycling symbol with a 7 in the middle of the chasing arrows.

Typically made of corn or sugarcane, PLA is a thermoplastic made through fermentation by bacteria. To transform corn into plastic, corn kernels are immersed in sulfur dioxide and hot water, where its components break down into starch, protein, and fiber. The kernels are then ground and the corn oil is separated from the starch. The starch is composed of long chains of carbon molecules, similar to the carbon chains in plastic from fossil fuels. Some citric acids are mixed in to form a long-chain polymer (a large molecule consisting of repeating smaller units) that is the building block for plastic.

PLA is brittle and its application is more restricted than other traditional plastics and bioplastics. It is inferior in strength, thermal robustness, and barrier properties. Therefore, manufacturers must often include additives or polymers, depending on the specific application of PLA.

PLA (pure and blended with additives or polymers) can be used as grocery bags, food packaging, bottles, cups, and plates. Since it decomposes well in the presence of acids, it can be used in some medical applications such as medical sutures and plates, where it dissolves after 90 days.

Polyhydroxyalkanoate, or PHA

Feedstock: Commonly made from corn, sugarcane or beets

Formulation: "New" formulation, i.e. formulation that is unique to itself (and does not try to mimic a traditional petroleum-based plastic).

End-of-Life: Biodegradable and compostable in controlled settings

PHA is a bioplastic made of polymers that are produced by bacteria.

PHAs are naturally occurring polymers that can be produced in different ways by specific strains of bacteria. There are two ways to produce PHA. In the first approach, bacteria is exposed to a limited supply of essential nutrients such as oxygen and nitrogen, which promotes the growth of PHA - granules of plastic - inside its cells as food and energy reserves. A separate group of bacteria has also been identified that do not require nutrient limitation for PHA production, but accumulate it during periods of rapid growth.

Regardless of how the PHA is produced, it is then harvested and synthesized into different formulations through genetic engineering.

PHA is still an emerging science that has recently seem some breakthroughs with the discovery of bacteria that can more readily create PHA from a range of carbon sources including waste effluents. This is promising as it means PHA could eventually be produced from food waste, rather than requiring the production of new materials solely to support bioplastic production.

Additionally, scientists are now taking the genes from this plastic-growing bacteria and inserting them into corn plants, essentially creating a GMO corn that can "grow" plastic.

PHA is fully biodegradable under the right conditions (high temperature, microbe rich environment) and is non-toxic. PHA takes two months to decompose in backyards (and less time in industrial composting facilities). The rate of decomposition is much slower in marine waters where less than 50 percent is broken down after six months.

Some plastic items are made entirely of PHA; however, more commonly, PHA is blended with starch and cellulose to make it more economical.

PHAs are used as food wraps, cups, plates, coating for paper and cardboard, and many medical uses, including sutures and gauzes. According to Bio Based Press, it can replace most of the major fossil fuel based plastic types currently used, such as PE, PS, PVC, and PET.

Bio-Polyethylene Terephthalate (Bio-PET) and Bio-Polyethylene (Bio-PE)

Feedstock: Commonly made from corn, sugarcane or beets

Formulation: Drop-in formulation, designed to mimic petroleum-based plastic counterparts

End-of-Life: Durable, recyclable with traditional plastic counterparts

Polyethylene Terephthalate and Polyethylene are traditionally petroleum-based polymers.

However, recent innovations have led to the development of HDPE, LDPE and PET derived from bioethanol, typically from sugarcane, corn or beets.

Bio-PET is typically being used in beverage bottles and other containers, and Bio-PE is being used in flexible packaging and bags.

These formulations are chemically and physically identical to traditional polyethylene and as such, they cannot biodegrade (but they can be recycled along with their petroleum-based counterparts).

Polybutyrate (PBAT)

Feedstock: Fossil fuel based

Formulation: New formulation

End-of-Life: Biodegradable and compostable in controlled environments

Polycaprolactone (PCL) is similar to PBAT. PBAT is actually derived from fossil fuels - butylene adipate and terephthalate - but is biodegradable. It mimics the characteristics of low-density polyethylene such as flexibility, elasticity and pressure residentance, making it a viable material for bags and wraps (and compost bags in particular). PBAT is also often used as an additive that can give rigid bioplastics more flexibility while retaining the biodegradable properties of the final product.

WARNING!

Additives for Degradability

There is another category of materials that some might consider bioplastic - Biodegradability Additives in Petroleum-Based Plastics (such as products labeled as Oxo-Biodegradable). EcoEnclose does not consider these bioplastics as they are neither derived from renewable materials nor are they biodegradable or compostable. They encourage misguided consumer actions (either littering plastic or composting plastic in a way that contaminates industrial composting facilities), have unknown and potentially harmful impacts on the recycling stream, and are harmful to ocean life (if they do end up as litter) because they lead to the rapid degradation of plastic into microplastics.

https://sustainablepackaging.org/sustainable-packaging-coalition-takes-formal-stance-biodegradability-additives-petroleum-based-plastics/

BIOPLASTIC PACKAGING

The above section summarizes common bioplastic formulations.

The actual bioplastic packaging you see, feel and use is typically made a combination of materials.

This section showcases several examples of bioplastic materials in action in everyday life. Differences between them typically include:

1. The primary type(s) of bioplastic formulations being used for the packaging (i.e. PLA, PHA, Bio-PET, etc)
2. The percentage of material that is made with bio-based carbon. Packaging can be deemed as "bioplastic" if it ranges from being made up of 20 percent renewable materials to 100 percent renewable materials.
3. Application of the packaging, and the resulting blends and additives that are used.
4. End-of-life, and whether or not the packaging is suitable for recycling (curbside or hard-to-recycle), industrial composting, landfill (or incineration). This is driven both by the blend of materials used in the item or packaging itself, as well as the items shape and size, and how well it will fits into existing recycling or composting schemes.

Here are several examples of bioplastic packaging, all with diverse characteristics and use-cases.

30 Percent Plant Based Bottle

In 2009, Coca-Cola introduced the PlantBottle™ technology. This bottle was 30 percent plant based, made with a combination of 30 percent sugarcane-based PET (bio-PET) and 70 percent petroleum-based PET.

Now, PlantBottle packaging accounts for 30 percent of Coca-Cola's packaging volume in North America and 7 percent globally, some 6 billion bottles annually, making The Coca-Cola Company a large bioplastics end user.

Additionally, this innovation and the licensing of the PlantBottle™ technology has allowed many other consumer products brands to bring similar bottles to market. One example is Wholesome!, a maker of

sweeteners, who introduced its new Green Bottle, a 30 percent sugarcane-based PET bottle, in 11.75-, 23.5-, and 44-oz sizes in 2016.

The bio-PET in these bottles, which are supplied by Berlin Packaging, are a “drop-in” bioplastic and therefore, are exactly like the petroleum-PET they are blended with. This means these bottles are 100 percent recyclable along with other PET bottles.
The use of “drop-in” bioplastic that makes the entire bottle recyclable is extremely important in this use-case.

First, recycling is the preferred end-of-life scenario for an empty beverage bottle (after it is reused as many times as possible). PET is a relatively easy material to recycle, and the majority of curbside recycling services in the U.S. accept and can quickly sort, batch and sell recycled PET.

Second, while the recycling rates of PET bottles are not superb, they are significant and growing. In 2016, approximately 30 percent of PET bottles used in the U.S. were recycled, a number that has - on the whole (despite occasional year over year dips) - grown each decade. As consumers become more and more accustomed to the positive step of recycling their bottles, it is important that new materials and technologies fit in and support these positive trends. A non-recyclable bottle would confuse consumers and either frustrate them or lead them to recycle bottles anyway, causing contamination throughout the recycling supply chain.

Third, because it is still so challenging to create a 100 percent bio-based plastic bottle, a blend of traditional and bioplastic is still our reality, suggesting that biodegradation and compostability is not an option. This further strengthens the importance of ensuring that the entire bottle is recyclable.

100 Percent Plant Based Bottle

It has been almost a decade since the 30 percent plant-based bottle made headlines. To date, a 100 percent plant-based bottle exists, but not at a commercial scale.

Coca-Cola debuted an updated version of its PlantBottle™, its first bottle made from 100 percent plant materials at the World Expo in Milan in 2015, developed through its joint venture partnership with U.S.-based biotechnology company, Virent. PepsiCo has partnered with biotechnology leader Danimer Scientific in an agreement that will push their ability to develop 100 percent bio-based packaging as well.

Additionally, the world’s two largest bottled water companies, Danone and Nestlé Waters, have teamed up with Origin - a California startup - to develop and launch, at commercial scale, a PET plastic bottle made from 100 percent bio-based material. The collaboration, known as the NaturALL Bottle Alliance, aims to use non-edible biomass feedstocks (such as previously used cardboard and sawdust) to create a lightweight, transparent, recyclable and functional bio-based PET. The alliance aims to develop the process for producing at least 75 percent bio-based PET plastic bottles at commercial scale as early as in 2020, scaling up to 95 percent in 2022. The partners say they will continue to conduct research to increase the level of bio-based content, with the objective of reaching 100 percent.

Again, these initiatives are all aiming to create a 100 percent bio-based, drop-in PET that would act exactly like petroleum-based PET. As such, these end products would be fully renewable and 100 percent recyclable, but would not be compostable or biodegradable.

Spudware

Spudware(R) makes a diverse line of bioplastic cutlery. One of their products is a high performance, heat tolerant cutlery, that is a blend of vegetable starch, plant-based cellulose, traditional polypropylene, and modifying agents. The cutlery is heat tolerant up to 266 degrees, and as such, is considered reusable and dishwasher safe.

The company's desire to make a reusable, dishwasher safe product meant that a 100 percent bioplastic, compostable item was not feasible. The item is also not recyclable, both because there is currently no commercial use for the unique formulation and blend of materials and because the small size of disposable cutlery has made it impossible for most recycling facilities to be able to handle and sort these items.

As such, the company's goal was to replace as much petroleum-based plastic as possible in the product, to have these items reused as many times as possible, and then have these items end up in a landfill.

BioBag

European-based BioBag sells a line of certified compostable bags (including waste bags and grocery shopping bags). The bags are made with Mater-bi, a unique material that was developed by Italian company Novamont, that is made of a combination of renewable and nonrenewable plastics, including corn starch, vegetable oil derivatives, and biodegradable synthetic polyesters.

These flimsy, bioplastic bags are certified compostable in industrial facilities (they are not recommended for home composting). They are entirely biodegradable, though their research to date does not specify how long it will take for these bags to biodegrade in the sea. Their website states that their "bags are not water soluble and therefore disintegration will not start immediately, but will require several months to be achieved, primarily through hydrolysis."

These bags are not recyclable, and should not be mixed into the flexible plastic recycling stream (which typically includes LDPE #2 and HDPE #4).

Eco-Products Cold Cups

Launched in 1990, Eco-Products was established to develop a green solution to disposable food packaging. Their Cold Cups line is made with 100 percent Ingeo, the trademarked brand name for a range of (largely corn-based) polylactic acid (PLA) biopolymers owned by NatureWorks (which is owned by Cargill and PTT Global Chemical).

These are not heat tolerant cups, and will distort or melt at temperatures above 105 degrees Fahrenheit. As such, the company recommends storing them in a cool place, away from direct sunlight.

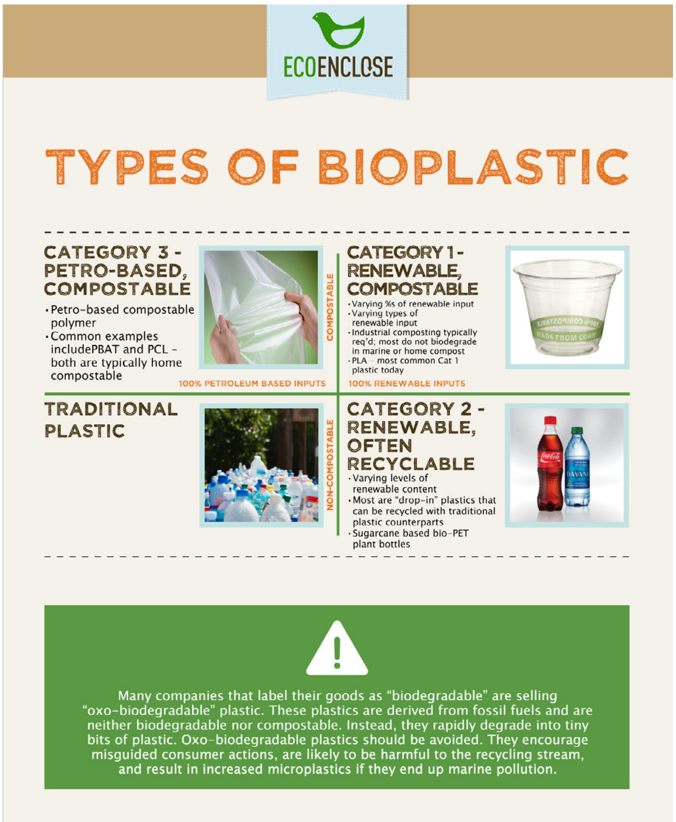
The cups are certified compostable in industrial facilities. They are unlikely to biodegrade in the ocean.

Eco-Products Hot Cups

Because Eco-Products cold cups are unsuitable for hot beverages like coffee, their hot cups line differs greatly from the above 100 percent PLA cold cups line. As such, these cups are also certified compostable in industrial facilities. With the blend of paper and bioplastic, they are not recyclable. In a non-controlled environment, the paper portion of these cups would biodegrade over time (but the PLA coating would re main).

For the remainder of this paper, we will reference bioplastic packaging in a few categories:

Category 1: Packaging that is renewable / partially renewable and certified compostable. Note that within Category 1, packaging can be certified compostable only for industrial settings, or can be readily biodegradable such that it would biodegrade in a backyard compost or in a marine environment. We will describe the distinctions as we discuss this category throughout the remainder of this paper.
Category 2: Renewable / partially renewable and recyclable with petroleum-based plastic counterparts
Category 3: Packaging that is Non-Renewable and certified compostable



BENEFITS AND CHALLENGES OF BIOPLASTIC

Summary of Benefits and Challenges

This section discusses the pros and cons of bioplastic across multiple considerations - functionality, source material, end-of-life, and overall greenhouse gas emissions and carbon footprint. The following table provides a summary of benefits and challenges, which are detailed further in the subsections that follow.

BENEFITS AND CHALLENGES OF BIOPLASTIC

	BENEFITS	CHALLENGES
FUNCTIONALITY	Flexible, moisture proof, thin and lightweight	Category 1 and 3 plastic is not as strong, is sensitive to light and more air permeable than petro-plastic
RAW INPUTS	Category 1 and 2 made from renewable resources R&D could lead to more sustainably produced over time – i.e. straw, bagasse, and food waste	Bioplastic = virgin material; no recycled content. Common inputs require resource intensive, industrial ag. Often only partially made with bioplastic.
END OF LIFE	Category 1 compostable in industrial settings. A SMALL set would biodegrade naturally / backyard compost Category 2 can often be recycled with petro-based plastics	Access to industrial compost = limited Bioplastics=limited Vast majority never biodegrade as litter. Ocean pollution – customers being mislead. Consumer confusion leads to high levels of contamination.
CARBON EMISSIONS	Lower GEG emissions than virgin, traditional plastic counterparts.	Often, higher GHG emissions than recycled traditional plastic

DETAILED REVIEW

Functionality

8.3 billion metric tons of virgin plastic have been produced worldwide since the material was first introduced at a commercial scale in 1950. According to the BBC, that's equivalent to the weight of 25,000 Empire State Buildings or a billion elephants. There is a reason plastic is now so ubiquitous despite the fact that mankind lived without it for thousands of years.

Compared to other packaging options (glass, aluminum, paperboard, etc) plastic is lightweight, durable, liquid proof, can be molded into virtually anything, and is significantly less expensive than other materials that could accomplish the same functions. Bioplastic exhibits many of the basic qualities as its traditional plastic counterparts, making it an incredibly functional and versatile material. Bioplastics can typically be used in the manufacturing equipment that is already ubiquitous in the world of plastics.

Category 2 bioplastics (bio-based plastics that mimic conventional plastic and are recyclable) typically have identical functional benefits to their petro-based counterparts. They form a strong barrier against moisture and gas.

Some other categories of bioplastics are not quite as functional as petro-based counterparts. Like all plastics, bioplastics in categories 1 are lightweight and efficient in terms of material usage. However, some these bioplastics are relatively permeable, and do not necessarily exhibit the moisture resistance of traditional plastics. As such, they may not perform as effectively as packaging for food that is intended to be shelf-stable for an extended period of time, or other products that need to be fully protected from the environment. Additionally, Category 1 bioplastics typically have low melting temperatures, as low as 100 degrees. This could cause bioplastic to melt just by sitting in a hot car for a brief time.

SOURCE MATERIAL

Categories 1 and 2 of bioplastic are made in part by relatively rapidly renewable materials, such as corn and sugarcane.

There are inherent environmental benefits to using renewable raw materials. In general, renewable sources means that carbon is sequestered as the plastic's raw materials are produced. Additionally, because bioplastics are not made directly from fossil fuels, their production consumes a lower amount of fossil fuel and releases fewer greenhouse gases into the environment.

However, the "bio" component of bioplastic typically has no recycled content - it is all virgin material grown specifically for the purposes of bioplastic. As bioplastic becomes more common, and processes, equipment and infrastructure are established to sort, recycle and use recycled bioplastic material, this challenge may change. This is a major downside to bioplastic in our view, given how important it is that the existing plastic in the world have a thriving recycling market through which it be cycled.

Another downside to bioplastic is that it is often grown via industrial agricultural in resource intensive and land degrading ways. Our trend of utilizing agricultural, and corn in particular, to replace plastic and fossil fuel energy could strain land usage long-term, and lead to the destruction of more and more forests and healthy soil.

However, when it comes to the production benefits and downsides of bioplastic, it is important to dig in further as not all renewable sources are equal. Reviewing every potential bioplastic source is beyond the scope of this paper, however, we will dive into four here.

Corn

In the U.S., the vast majority of bioplastic you see is made from the same type of corn that is used for animal feed and ethanol production. NatureWorks LLC, which is jointly owned by two major industrial companies - PTT Global Chemical and Cargill - is the nation's largest supplier of PLA, a material largely made from corn, though also produced from beets, cassava and sugarcane.

There are important benefits to corn-based plastic. Corn grows quickly, and economies worldwide already have the knowhow to and infrastructure to produce massive volumes of high yield corn, as corn products are an ingredient in countless products we use daily, ranging from corn syrup to gasoline (which is typically an oil and ethanol blend). A 2017 study determined that switching from traditional plastic to corn-based PLA cuts greenhouse gas emissions by 25 percent - a significant reduction.

However, even NatureWorks would agree that growing our plastic from corn is not a panacea. The world's agricultural practices are controversial and are not always in the best interest of the planet and its communities. Large scale production of corn for bioplastic requires industrial farming. Grassland, non industrial farms, and forests need to be cleared to make way for industrial farmland and though corn "captures" carbon, it is actually less effective at sequestering carbon than the land uses that were cleared for the farmland in the first place.

Additionally industrial farming practices, particularly those using genetically modified corn (which the majority of U.S. corn is made from) that require heavy doses of fertilizer and chemical pesticides that promote fallow, unproductive soil and desertification. This type of corn production leads to chemical runoff into our water supplies and ultimately, into the ocean.

Sugarcane

As described briefly above, sugarcane is the main for the PlantBottle™, and is most typically used for drop-in bio-PET rather than for compostable PLA.

Brazil-grown sugarcane is used for the plant-based portion of these bottles for a number of different reasons. First and foremost, sugarcane is a cost effective and efficient source for bio-PET. Additionally, Brazilian sugarcane ethanol is considered to be an "Advanced Renewable Fuel" by the Environmental Protection Agency (EPA). For every unit of fossil energy consumed when sugarcane is grown and produced into ethanol, more than eight units of renewable energy are typically produced.

While many of the same arguments exist for sugarcane and corn, because both are intensive, industrial agricultural products, Coca-Cola claims that many of these concerns are less relevant for Brazil-grown sugarcane. Sugarcane production in Brazil does not displace agricultural food production, and instead rejuvenates lost pasture land. In fact, Brazilian sugarcane production is often on degraded pastures that generates a positive carbon credit as the sugarcane captures significant amounts of carbon. They believe this crop does not negatively impact the Amazon, as over 99 percent of Brazilian sugarcane plantations are located over 2,000km from the Amazon.

Lignocellulosics, such as bagasse, wood chips, switch grass or straw

In many ways, these are the most interesting source of biopolymers, though there are no cellulose-based biopolymers in mass production today for packaging. These bioplastics would not displace agricultural land (or require the conversion of forest land into agricultural land) and would allow waste (food waste and wood / straw waste) to be converted into plastic.

However, producing bioplastics from biomass like wood requires that the raw material is converted into components such as cellulose, hemicelluloses and lignin. These processes are now technologically demanding and not profitable today.

Companies and collaborations like NaturALL (described above) aim to allow these types of materials to be manufactured and utilized cost effectively at a mass scale.

Algae

Currently, there are no industrial scale plastic products made from algae. However, algae-based plastic has been experimented with and many believe it can be the future. Like other renewable bioplastics, algae consumes and sequesters carbon dioxide (CO_2) and emits oxygen as they grow, helping to reduce the total amount of CO_2 in the atmosphere.

Algae also has additional benefits beyond feedstock such as corn. Algae can produce between 2,000-5,000 gallons of fuel per acre, far more than any other renewable feedstock. Algae can also grow on marginal, or non-crop, land, so they don't compete with valuable agricultural land. They can grow in brackish, salt- or polluted water, so they don't require freshwater resources.

End-of-Life

Bioplastic packaging can embody one or more of the following end-of-life characteristics.

Curbside recyclable: Curbside recyclable bioplastic should have the chasing arrows recycling sign on it, with either a recycling number or written guidance on "how to recycle."

Recyclable in separate streams: Some materials, including several types of plastic, are categorized as "difficult-to-recycle." These are typically labeled as such because the sorting processes and machinery of most "materials recovery facilities" (MRFs) - the facilities that accept, process and sell your single stream curbside recycling - cannot handle these materials. Plastic bags, for example, are flimsy and light, and get caught in the gears of MRF sorting equipment. Disposable cutlery is so thin that it can't be auto-sorted with MRF equipment, causing it to be filtered out and sent to the landfill (if it does end up in a single stream recycling bin). Many of these items ARE in fact recyclable, and have strong end markets that are seeking this material, and therefore have dedicated places where consumers and businesses can recycle them. Plastic bags are recyclable, but must typically be recycled at dedicated grocery drop off bins, so that sorting isn't required.

Certified compostable, which refers to a plastic that is "capable of undergoing biological decomposition in a compost site as part of an available program, such that the plastic is not visually distinguishable and breaks down to carbon dioxide, water, inorganic compounds, and biomass, at a rate consistent with known compostable materials (e.g. cellulose). and leaves no toxic residue." Bioplastic that is certified compostable typically requires the controlled temperature and moisture settings of an industrial composting facility. Bioplastic must be certified as compostable in order for a facility to accept it. There are several standards and certifications for compostability. U.S. Standard ASTM D6400 and the European Standard EN 13432 is the gold standard, and ASTM D6868 covers the compostability of items that are laminated in bioplastic (such as paper lined with plastic). One of the most common U.S.-based certifications (that certified products according to the above ASTM standards) is the BPI compostable certification. This mark makes it clear to consumers that they can in fact discard their goods in industrial compost. European Bioplastics offers the "seedling" label, which certifies that the product will biodegrade completely in a well-run industrial compost facility, but not necessarily in a backyard compost or in the environment.

BPI ®
COMPOSTABLE
IN INDUSTRIAL FACILITIES
Check locally, as these do not exist in many communities. **Not suitable for backyard composting.** CERT # SAMPLE

Marine biodegradable: A new standard, ASTM D669 (Aerobic Biodegradation of Plastic Materials in the Marine Environment by a Defined Microbial Consortium or Natural Sea Water Inoculum) is designed to test whether or not a bioplastic can completely biodegrade - leaving no trace of plastic - in a marine environment.

Many bioplastics embody none of the above characteristics and as such, will biodegrade at the same rate of traditional petroleum based plastics and should be sent to a landfill.

Again, oxo-biodegradability is not explored above, as it does not indicate true biodegradability and instead suggests that the traditional plastic material will degrade into tiny fragments over an unspecified period of time. At this time, oxo-biodegradable items are not recyclable. As such, they should be landfill bound (whether they will degrade at the same rate as all other plastics in the landfill).

The vast majority of bioplastic packaging today is (1) recyclable but not biodegradable or compostable, (2) compostable but not recyclable, (3) neither compostable nor recyclable.

Additionally, only a small subset of the packaging in (2) and (3) would also biodegrade over time if they ended up as litter and ultimately found their way into a marine environment. While bioplastic is often touted as the answer to our landfill or marine plastic pollution problem, this is not really the case, given that most bioplastic today is either bio-PET or PLA, neither of which meet ASTM D669 standards.

Composting is good right?

It certainly isn't bad, but there are some important downsides.

Recycling is often preferred to composting: Unbeknownst to most consumers, unless an item is covered in food, recycling that item is a preferred end-of-life outcome as opposed to composting it.

Why? All of the source material and resources that went into something to begin with are ideally put back to industrial use (rather than put back into soil). When recycled, these items displace the need for virgin material to be extracted and manufactured, and lead to a recycled products that are far more energy efficient than their virgin counterparts.

For most items (when a material is not coated in food at the time it is discarded), the optimal waste hierarchy order as follows:

1. Recycle
2. Compost
3. Landfill
4. Litter

For food packaging that is likely to be coated in food at the time it is discarded, the optimal waste hierarchy order as follows:

1. Compost (industrial or backyard)
2. Recycle
3. Landfill
4. Litter

Limited Access: Unfortunately, only about 5 million U.S. households have access to government-supported curbside collection, while an additional 6.7 million households have access to drop-off sites for source-separated food waste. This is just about 9 percent of the U.S.

Within that small number, only a smaller subset of these composting facilities accept bioplastics. Almost all accept (and were actually launched to accept) yard trimmings. Many now accept food waste. These are two composting inputs that contain relatively little contamination, are highly beneficial to compost, and help create a valuable end product for composting facilities to sell.

This means that as of 2018, the vast majority of Americans would have to landfill their compostable packaging (though it should be noted that this number is rising, with compost facilities rates having almost doubled since 2014).

Why don't many composting facilities yet accept bioplastic? Compost does not necessarily thrive with bioplastic. If bioplastic helps bring food to compost, great. If not, and compost facilities are flooded with bioplastic such that the ratios of bioplastic are higher than other inputs, this can lead to low quality, difficult to manage, unsellable compost.

Consumer Confusion and Contamination: Additionally, bioplastics are far more likely to bring contamination that is harder to sort than yard trimming and food waste alone.

For example, well meaning consumers compost something that is actually a traditional, non-compostable plastic. Or a container might have a compostable bottom, but a recyclable top. This means composting facilities that accept bioplastics now need to invest in the infrastructure and human capital to address this contamination. These facilities are also likely to have a lower quality output in the end. Or, an unlabeled item that non-recyclable goods end up in the recycling stream where they are sorted out and into the landfill or, worse, baled with recyclable plastic where they contaminate and cheapen the bale (sometimes with so much contamination that the entire bale is rejected).

Additionally, the fact that some bioplastics are compostable (and some are labeled as "biodegradable") leads to consumer confusion and ultimately, to litter. Consumers have a false sense that this material will disintegrate quickly in any conditions and may be more prone to littering or to directing things to the landfill that could be composted.

Most items labeled this way will only break down in the high temperatures and conditions of an industrial composting facility. If it ends up as litter, it likely won't degrade. If it ends up in the ocean, it likely won't degrade. If it ends up in the landfill, it almost definitely won't degrade.

So you have a material that acts like traditional plastic in these environments, but that consumers may be more inclined to toss away carelessly because of how it is labeled.

OTHER SUSTAINABLE PACKAGING OPTIONS

Those looking into bioplastic packaging solutions typically explore a variety of other packaging materials as well. This section describes several other common materials used in packaging.

Recycled Plastic

When the benefits of plastic are needed - flexibility, strength, a moisture and/or air-proof barrier, etc. - plastic made with recycled content can be an excellent, sustainable solution. Recycled content can can refer to either post-consumer or post-industrial waste, and typically, recycled plastic contains some combination of the two.

The benefits of recycled plastic are vast.

In 2015, the U.S. produced 14 million tons of plastic packaging waste.

We, as consumers and businesses, are encouraged to recycle all of the plastic in our lives, but recycling is only feasible if an end market exists for that recycled material. As such, using recycled plastic is essential to ending our waste, litter and landfill challenges related to non-compostable plastic.

Additionally, recycled plastic in itself is better for the environment.

Typically, the carbon footprint of a plastic product can be reduced 25 to 80 percent by using recycled plastics (depending on the type of plastic being discussed). Also, waste can be reduced by 50 to 75 percent by using recycled plastics since the waste plastic is recycled and not sent to landfill. According to the U.S. EPA, the generation of clean recycled plastic resin required 71 trillion Btu less than the amount of energy that would be required to produce the equivalent tonnage of virgin PET and HDPE resin. All of these calculations do include the carbon emissions of recovering and remanufacturing the plastic.

As with all sustainable materials, recycled plastic packaging does pose important challenges. Particularly in the world of flexible, film packaging, utilizing post consumer waste is still very challenging. As such, much of the post-consumer LDPE and HDPE that is used is "downcycled" into materials such as composite wood. Recycled LDPE and HDPE therefore typically uses a relatively high percentage of post-industrial content and a smaller percent of post-industrial waste.

As with all materials, recycled content can only get us so far. Plastic can only be recycled once or twice, before it is then landfilled or downcycled (into something like composite wood). Paper, on the other hand, can be recycled four to seven times and aluminum can be recycled countless times. This is both due to how the material is altered in each recycling process, and how much contamination affects the recycled material that is output. As such, using recycled plastic long-term requires that virgin plastic be produced as well. That said, given that petroleum-based plastic continues to be the norm and is likely to remain that way for some time, a focus on recycled plastic is an important sustainable strategy that can help elongate the life of this plastic and keep this material out of the ocean and out of landfills.

Recycled Paper or Corrugated

There are many situations where a traditional paper-based product works beautifully for packaging.

For e-commerce, a box or paper-based mailer can almost always serve as a viable packaging solution.

For consumer products retail packaging, paper can work well as an outer layer of packaging (such as a cereal box) or even as the main packaging (for either a shelf stable food product such as pasta or a toy / electronic, etc).

When paper-based is a viable option, recycled (traditional, tree-based) paper should be considered.

Americans use more than 90 million short tons of paper and paperboard each year. Utilizing recycled paper as a source material ensures that there are strong markets for this waste, allowing the raw materials to be used as many times as possible before they reach their true end-of-life.

Recycled paper produces lower emissions and pollution than virgin paper. Producing recycled paper reduces energy consumption by 28 to 70 percent (because the vast majority of energy and water used in paper production is from the process of turning wood into paper). For the same reason, manufacturing recycled paper reduces air pollution by 95 percent, in addition to significantly reducing other pollutants as well. Recycled paper is not usually re-bleached and where it is, oxygen rather than chlorine is usually used. This reduces the amount of chlorinated compounds which are released into the environment as a by-product of the chlorine bleaching processes.

According to Katherine Guerin, Executive Director of the Maine Resource Recovery Association, for every 1 ton of scrap paper we recycle, we save: 17 trees, 4200 kilowatt hours of electricity, 7000 gallons of water, and 3 cubic yards of landfill space. In addition, 60 pounds of effluents are not emitted into the air.

Like plastic above, recycled paper can be "post consumer" or "post industrial". Luckily, however, for paper-based / corrugated packaging, high percentages of post consumer waste is typically feasible.

Additionally, the beauty of recycled paper is that when the material does reach the end of its usable life (say as tissue paper or paper towels), they can be composted in either an industrial facility or backyard compost bin. It would also completely biodegrade in an ocean or litter environment.

Additionally, the virgin paper that ultimately creates recycled paper comes from a renewable, and often sustainable managed resource. When virgin paper is made from sustainably managed forests, such as SFI or FSC certified producers, they actually are a net positive for the environment. Forests are being planted, maintained and managed in a way that preserves the land (ensuring it does not get utilized for industrial agriculture or real estate development), with soil enriching, carbon sequestering plants that improve flood and drought resistance across a landscape.

All paper, including recycled paper, does have some setbacks. The material is heavy and requires more weight and material per square inch of the equivalent packaging that would be made of plastic.

For example, EcoEnclose stocks recycled poly mailers and recycled kraft mailers. While none of them are exactly the same size, we have comparable ones, such as a 14.5"x19" poly mailer and a 12.5"x19" kraft mailer.

A single poly mailer of this size weighs 0.8 oz. versus the comparable kraft mailer, which weighs in at 2.2 oz. A case of 250 poly mailers is 768 cubic inches (16"x12"x4"), while a case of 200 kraft mailers is 2990 cubic inches (23"x13"x10"). A single 48"x48" pallet can hold 30,000 poly mailers versus just 4,800 kraft mailers.

Largely due to this discrepancy in weight and material per square inch of packaging, plastic (whether it is petroleum based plastic or bioplastic) almost always has a lower carbon footprint than an equivalent paper-based counterpart. As such, a lifecycle analysis based approach in which a company chooses optimal packaging based on its carbon footprint is typically likely to preference plastic over paper.

Paper is also less functional than plastic. It is less flexible, it is gas and water permeable, and more likely to puncture.

Finally, the actual manufacturing of paper (of converting wood into pulp for paper) is relatively dirty work; more so than plastic.

At a paper mill, trees are de-barked, cut into wood chips, and then fed into large pressure boilers called digesters. 20 percent of toxic waste in the air in the U.S. is due to the pulp and paper industry, and wastewater pollution is a very big problem as manufacturing discharges contain pollutants such as lignin, chlorates, transition metals, nitrogen, phosphorus, to name just a few of the toxins that should not be spreading into our rivers and oceans. Boustead Consulting & Associates Ltd. conducted a study comparing traditional plastic grocery bags (also made with LDPE #4, similar to poly mailers) to paper bags and found that manufacturing 1,000 paper bags requires 3.4 times more energy than traditional plastic, and manufacturing compostable plastic bags requires 2.7 times more energy than traditional plastic.

It is important to note that a paper mill that has a comprehensive water reuse system, utilizes wind and solar energy, scrubs air emissions and water before release, offsets its carbon emissions, and obtains reputable certifications to prove these action can drastically reduce its negative impact. In fact, a great paper mill can actually have a positive impact, such as taking in dirty water from a river and releasing clean water.

Other Renewable Fibers

When paper-based packaging is an option, many sustainable packaging fans look to sources of paper outside of trees. There are a number of interesting renewable, "non-tree" fibers "emerging." Emerging is referenced in quotations because many of these crops were being used for paper well before tree-based paper became the norm. A few examples of non-tree fibers include hemp, kenaf fiber, bamboo, straw and bagasse.

Many of these fibers have interesting characteristics, especially from a sustainability perspective. For example, alternative fibers can often be bleached without chlorine. Crops like hemp are known to grow quickly and don't require high amounts of fertilizer or pesticides to grow. However, no single alternative fiber is a silver bullet, and collectively, this category of options has benefits and important downsides to understand.

The benefits of tree-free paper (as compared to paper-based) packaging include:

- Quicker growth and cultivation, typically three to five months from seed to harvest, versus 20 years for wood-based paper.
- For most of these alternative fibers, fewer chemicals appear to be required to convert plants into pulp for paper.
- Many alternative crops have other important

uses or come from waste that already exists in agricultural production. For example, hemp production generates not just paper, but also hemp oil and hemp milk. The U.S. wastes an estimated 150 million tons of straw annually, which could go into paper production.
- Several alternative papers, such as hemp paper, have longer, stronger fibers and are therefore more durable than traditional paper, and can be recycled more times.

The challenges of tree-free paper packaging include:

- For crop-based paper to become mainstream, the U.S. and the world would need ample dedicated industrial agricultural land for these crops. This would require that we either convert cropland currently dedicated to food production or convert other land (such as carbon sequestering prairieland or forests). This downside can be alleviated in part by systematically utilizing fallow crop land, such as abandoned tobacco farms, for alternative fiber production instead.
- Often, the argument is made that by switching to alternative sources of paper, we'd save our trees. There are some major holes in that logic. In fact, if we switched from wood to alternative fiber sources at a large scale, it could cause the world to lose trees. Buying sustainable certified paper (including recycled paper, which ultimately relies on the production of recycled paper) helps strengthen forests in the U.S., because it ensures that sustainably managed forests can remain, versus being converted into real estate or agricultural land. As plants, trees are better for the environment than alternative paper crops. Trees sequester carbon long-term, they strengthen soils, alleviate land against the perils of floods and droughts, and create thriving ecosystems and animal habitats. Monocrop agricultural production is typically known to make soil less healthy, less capable of sequestering carbon, and less able to manage lands against floods and droughts.

Combination and/or Layered Materials

As per the CPCB, "multi layered packaging" means any material used or to be used for packaging and having at least one layer of plastic as the main ingredients in combination with one or more layers of materials such as paper, paper board, polymeric materials, metalized layers or aluminium foil, either in the form of a laminate or co-extruded structure.

A simple version of this would be a padded mailer envelope that is made with paper exterior and a plastic bubble interior. Disposable paper coffee cups are lined with polyethylene, a type of plastic.

Energy bars (like Clif Bars) are packaged with a thin foil of aluminium, which is sandwiched, or laminated in a matrix of paper and/or plastic layers. Fruit juices and wines can be kept for extended periods of time at room temperature in containers made from paper, aluminium foil and polyethylene film.

Multi-layers materials are used for their functionality, particularly in food packaging and disposable beverage cups. They preserve food well, often lead to beautiful printing and branding, and they can be waterproof and lightweight.

However, they are almost always unrecyclable, or at the very least, are extremely difficult to recycle and must be sent to a program like TerraCycle to be recycled. They are typically not compostable (with the one exception being compostable bioplastic lined paper coffee cups). Sophisticated ML packaging such as foil and plastic energy wrappers typically have no recycled content. However, simple multi-layered content (such as paper / plastic padded mailers and plastic lined coffee mugs) sometimes has recycled content in the paper portion of the material.

ECOENCLOSE RECOMMEN-DATIONS

When to Use What

ECOENCLOSE

WHEN TO USE PLASTIC, PAPER OR BIOPLASTIC.

There is no silver bullet material when it comes to sustainable packaging. There is also no perfect way to measure the sustainability of a material. Read on to compare different materials and learn which use case makes the most sense for each.

RENEWABLE, COMPOSTABLE BIOPLASTIC

Most commonly made from PLA, derived from corn. Compostable in industrial facilities. Not recyclable.

YARD TRIMMING BAGS

HIGH RESIDUE FOOD PACKAGING

RESTAURANTS WITH ON SITE COMPOSTING

Best when contents remain in packaging after use should be (and likely will be) composted. Avoid when you're not packaging food or organic materials, and when users don't have access to industrial composting.

Remember: Compostable bioplastic typically doesn't biodegrade in the landfill, ocean or as litter

RENEWABLE, RECYCLABLE BIOPLASTIC

Most commonly made from bio-PET, derived from sugarcane Curbside recyclable with other PET. Not compostable.

BEVERAGE BOTTLES

MILK JUGS

Best for food or beverage packaging formats that require long-term resistance to moisture and air permeability and that have high rates of recycling.

Remember: All things equal, recycling is preferred over composting for end of life.

RECYCLED, RECYCLABLE PLASTIC

Post-consumer and post-industrial recycled petro-based plastic. Typically is recyclable (curbside or grocery drop off). Not compostable.

SOAP DISPENSERS

ECOMMERCE PACKAGING

Best for non-food uses where packaging is clean at end of use, and when slight quality degredation of recycled plastic is acceptable.

Remember: Without markets for recycled content, the recycling process cannot function.

RECYCLED, RECYCLABLE PAPER

Post-consumer and post-industrial paper. Recyclable, compostable and naturally biodegradable.

CPG PACKAGING

ECOMMERCE PACKAGING

Best when functional benefits of plastic aren't needed (flexibility, moisture resistance, etc) and heavier, thicker, and more expensive material is acceptable.

Remember: Paper packaging typically has a higher carbon footprint than plastic.

Overall carbon footprint | Ability to use recycled content | Ability to use readily renewable inputs | Ability to be recycled or composted | Ability to biodegrade as ocean or land litter

EcoEnclose Recommendations For Ecommerce Packaging

We believe the optimal, most sustainable ecommerce packaging solutions are made with recycled poly and recycled tree-based paper. "Alternative" materials - including alternative papers and bioplastic - are interesting and have an important place in the world of packaging, but are not as relevant or beneficial to ecommerce.

If a lightweight, cost effective, flexible packaging option is what you need, opt for 100 percent recycled flexible plastic and strongly motivate your customers to reuse their packaging if possible, and then recycle packaging at the end of its useful life.

If you're looking for the most eco-friendly, renewable, recyclable, compostable and naturally biodegradable (i.e. will biodegrade in the ocean and backyard compost) stick with 100 percent recycled paper. Ask your customers to responsibly dispose of packaging, optimally by recycling it (though composting is an option).

Most importantly, be a thoughtful buyer. As this white paper illustrates, the world of bioplastic is complex and confusing, and largely unregulated in terms of what companies are allowed to convey on their products.

If you see bioplastic packaging that claims to be recycled, recyclable, and biodegradable, ask the supplier for verified information. There is a high probability that these claims are untrue, or are at least unverifiable. Ask for:

- A breakdown of source materials in the packaging
- Exact percentage of material in the packaging that is recycled
- What makes the material biodegradable
- Any certifications related to biodegradability or compostability they can share
- Any verification related to the recyclability of the material they can share
- Information on where the raw material and final packaging is manufactured

If you don't get answers to the above, proceed with caution. Be thoughtful about how you present this packaging to your customers, so you don't mislead them or cause them to dispose of this packaging irresponsibly.

ABOUT ECOENCLOSE

EcoEnclose is the world's leading provider of environmentally friendly packaging and shipping solutions. EcoEnclose is committed to bringing eco innovation and transparency to the world of ecommerce packaging, and to helping ecommerce companies improve the environmental footprint of their products and operations.

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