# Oil Based Plastic Alternatives: Key Types of Bioplastics [Whitepaper]

Oil based plastics, derived from fossil fuels, regularly provide us with negative headlines. Today's product designers need to be increasingly aware of the plastics in use in components. Consumers are wary of its use, and this trend is increasing together with the public's interest in living in a more sustainable way. One solution may be to use one of the many types of bioplastics instead of their less sustainable petroleum or natural gas-based cousins.

Keep reading the whitepaper, or hit the links below to skip to a particular section:

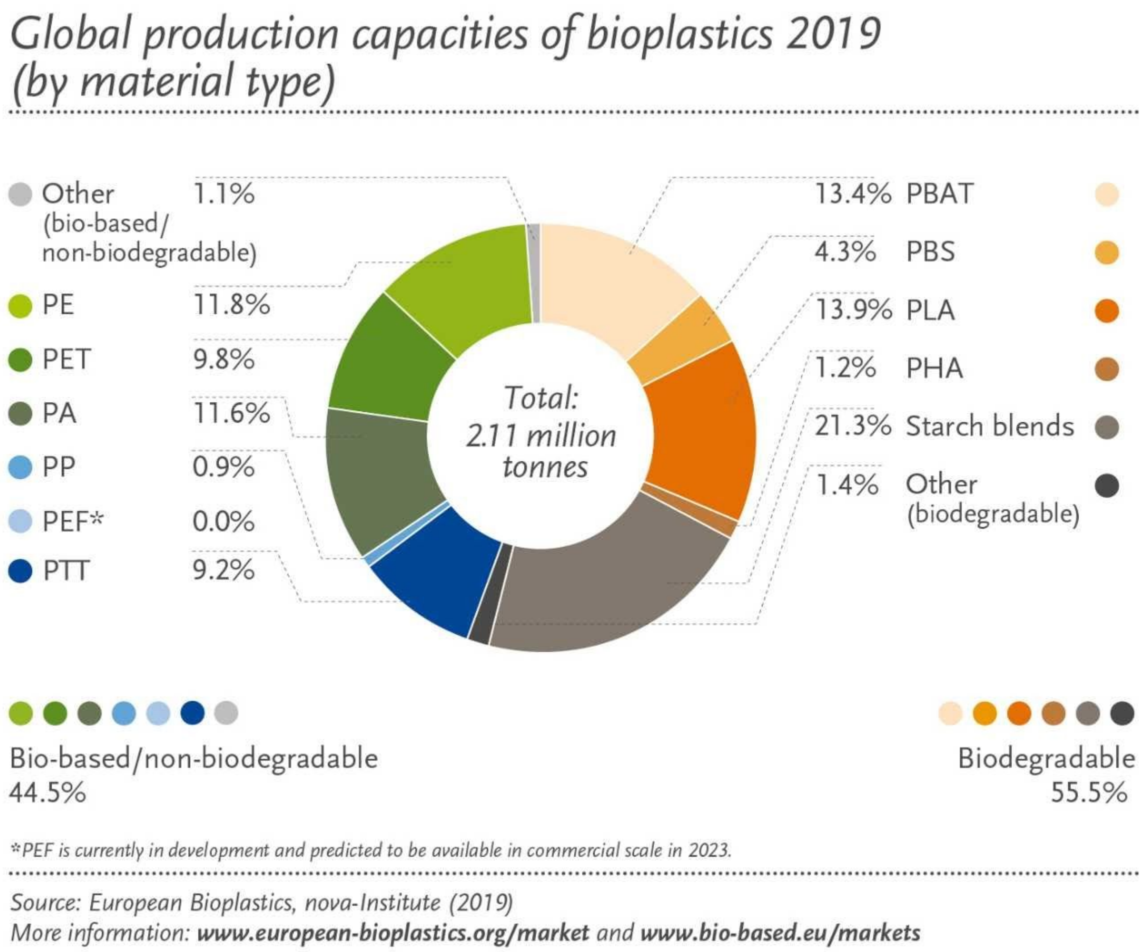

- What are bioplastics?
- How interested are consumers in oil based plastic alternatives like bioplastics?
  - Bioplastics are already used by the giants
    - LEGO
    - Coca Cola
    - YEEZY
- Common materials used as sources of bioplastics
  - Corn, cassava, legume, and sugarcane starch-based bioplastics
  - Bamboo fiber-based bioplastics
  - Hemp-based bioplastics
  - Seaweed (macroalgae) & Algae (microalgae)-based bioplastics
- Different categories of bioplastics
  - Starch-based plastics
  - Cellulose-based plastics
  - Aliphatic polyesters
- In which products and items are bioplastics commonly used, and why?
- Is the bioplastic industry innovating to find even more new materials and products?
- Are bioplastics totally green?
- Are bioplastics cost-competitive with oil based plastics?

## What are bioplastics?

Bioplastics are plastic materials which are made from plant or biological materials instead of fossil fuels. They are either compostable and biodegradable, or recyclable using current plastic recycling facilities.

The most popular type is starch-based plastics. Starch based plastics are complex blends of starch with compostable plastics such as Polylactic acid (PLAs), Polybutylene Adipate Terephthalate, Polybutylene Succinate (PBS), Polycaprolactone, and Polyhydroxyalkanoates (PHAs).

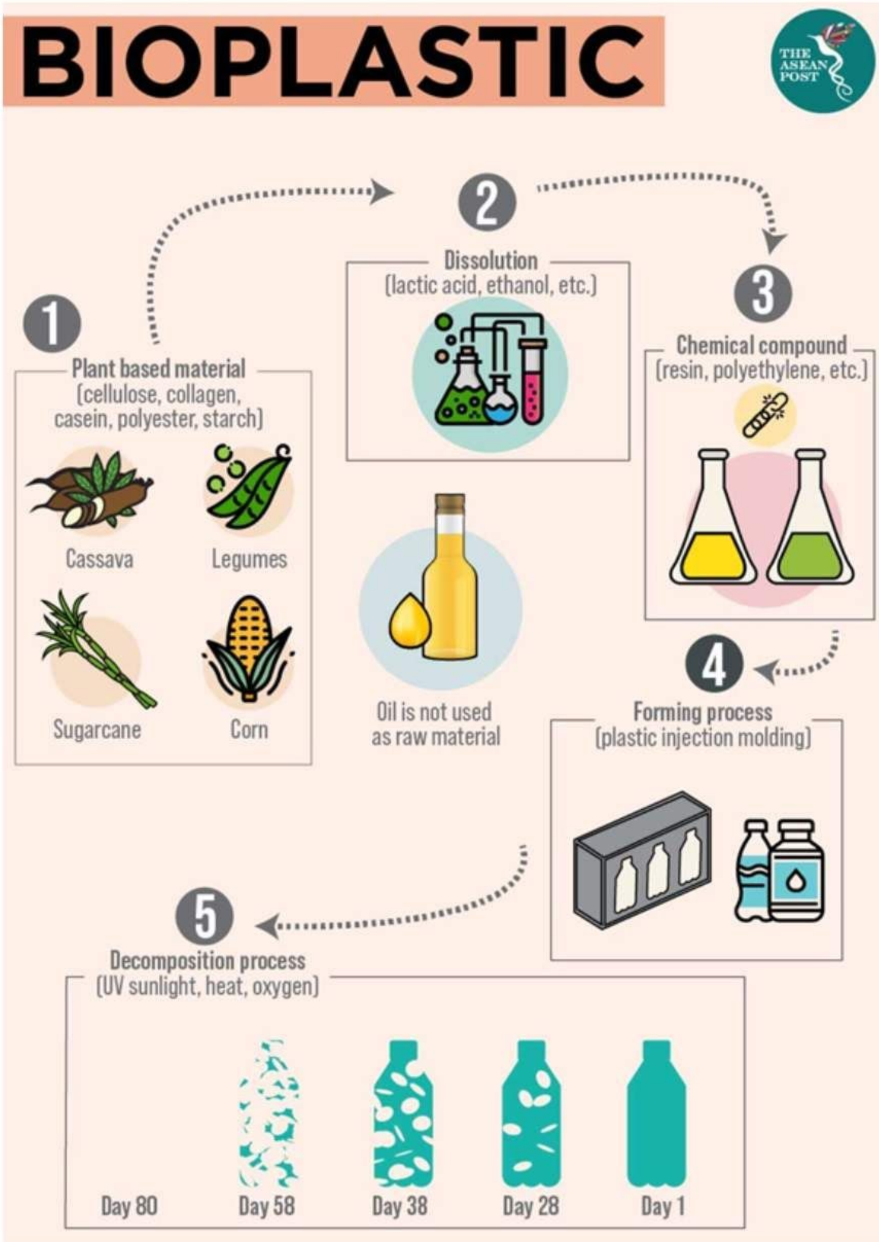
*PLA is...the largest segment, in terms of volume, in 2015 with a market share of more than 45.1% of the total biodegradable plastics market.* (source)




Source: https://www.european-bioplastics.org/market/

The types of bioplastics found today don't always differ a great deal from oil based plastics in behaviour and form, but come from renewable sources as they're derived from plant-based materials in most cases. This alone could be a selling point for manufacturers who have an eco-conscious consumer base.

The creation of plastics from these plant-based materials looks like this:




(source)

## How interested are consumers in oil based plastic alternatives like bioplastics?

Bioplastics currently make up only about 1% of global thermoplastic production capacity, but that still represents a consequential amount and use is growing to the point where production is increasing year on year:

*Hasso von Pogrell, Managing Director of European Bioplastics said in 2018:*
*"The global market for bioplastics is predicted to grow by roughly 15 % over the next five years", "This trend is possible thanks to the increasing demand for sustainable products by both consumers and brands alike, stronger policy support for the bioeconomy, and the continuous efforts of the bioplastics industry to develop innovative materials with improved properties and new functionalities." (Source)*

This is supported by consumers' interest in living a more sustainable lifestyle:

*According to the last Eurobarometer Survey conducted by the European Commission (2013), about 80 percent of European customers want to buy products with a minimal impact on the environment. The fact that biobased plastics display clear advantages over conventional plastics makes them attractive to environmentally-conscious customers. This, of course, means that the use of biobased plastics needs to be explained and marketed transparently: How much biobased content is in the packaging? How much CO2 emissions are saved? And was the biomass grown sustainably? These are questions that need to be answered. (Source)*

No doubt consumers from other areas of the world follow the Europeans' suit here and large companies are already taking heed of this determination.

## Bioplastics are already used by the giants

### LEGO

Lego, a large producer of plastic, has already taken measures to increase its use of bioplastics to greater than the current 2% of its plastic toy pieces. No surprise there given that in a study, 47 per cent of Christmas shoppers worldwide chose not to buy a toy due to sustainability concerns.

At present that only amounts to *'80 of the around 3,600 construction pieces, [being] made of a biosourced material, a sugarcane-based polyethylene.'* Coincidentally these are mainly the trees, leaves, and bushes which tend to be stand alone pieces and don't require the durability of the traditional 'LEGO block' used for building structures.


### Coca Cola

Coca Cola, too, has been producing its 'PlantBottle' since 2009. This is a fully recyclable bottle using 'drop-in' sugar cane residue bio based PolyEthylene (PE) created with lower CO2 emissions which accounts for 30% of the plastic in certain lines which, Coke says, has:

*Eliminated the potential for more than 315,000 metric tons of carbon dioxide emissions – the equivalent to the amount of carbon dioxide emitted from burning more than 743,000 barrels of oil, which has saved more than 36 million gallons of petrol globally. (source)*

The benefit of drop-in plastics like this is that they *'are manufactured from renewable biomaterials such as corn and sugar cane. Through a process called fermentation, the starch* *is extracted from the crops and used to create a "drop-in" replacement polymer for the oil-based polymers used in conventional plastic production...Drop-in or bio-based plastics are not compostable or biodegradable [like PLA, for example]. They are, in fact, fully recyclable and have been designed to "drop-in" to the existing recycling systems without disrupting the quality or financial value of the recycling stream.'* (source)

This 'quiet' innovation has already allowed a more sustainable bioplastic to take the place of its oil-based alternative, providing an environmental benefit that most consumers are probably unaware of.


## YEEZY

Fashion, one of the least eco-friendly industries, is also starting to take note of traditional plastic alternatives, with the rapper-turned-fashion designer, Kanye West, creating a pair of his globally famous 'Yeezy' sneakers from algae-based bioplastic foam.

The algae foam is used in conjunction with oil-based ethylene-vinyl acetate giving the sneakers a more sustainable makeup, and West aims to go further, as he plans to hydroponically grow algae for use in bioplastics for future sneaker lines: *"We're going to be farming and going seed to sole,"* he said.

# Common materials used as sources of bioplastics

## Corn, cassava, legume, and sugarcane starch-based bioplastics

All of these materials are derived from the starch coming from staple foods already grown globally, therefore they're an abundant and sustainable alternative to fossil fuels. Usefully, *they can accommodate a wide range of physical properties that alternative bioplastics lack, such as tensile strength and heat tolerance. Starch composites can also incorporate recycled plastics.* (source)

The starch is converted into a polymer with the addition of heat, a plasticizer (such as glycerol, sorbitol, or glucose) to link the polymer chains, and other additives such as colourings, acids or salts to help the starch dissolve in water, and, when in a liquid form, the resulting bioplastic is formed into its final shape by using plastic injection molding machinery in the same way as other plastics.

*Ozone processing has [also] gained attention due to the demand for methods that meet safety and health standards for both consumers and the environment Consequently, different properties are achieved due to complex relation among molecular modifications on size, charge and chemical affinity. In fact, different starch sources were already modified by ozonation, such as corn, sago, wheat, potato and tapioca/cassava.*

*Biodegradable films were produced by casting technique using native and ozonated cassava starch, glycerol as the plasticizer, and water as the solvent. Films produced with ozonated cassava starch presented higher tensile strength, Young's modulus and lower elongation. The water vapour permeation and the oxygen permeation were increased by increasing the ozonation time.*

*Ozone processing resulted in films with a more hydrophilic surface and lower solubility after 24 h. The ozone processing showed to be a good alternative for starch based packaging production.*

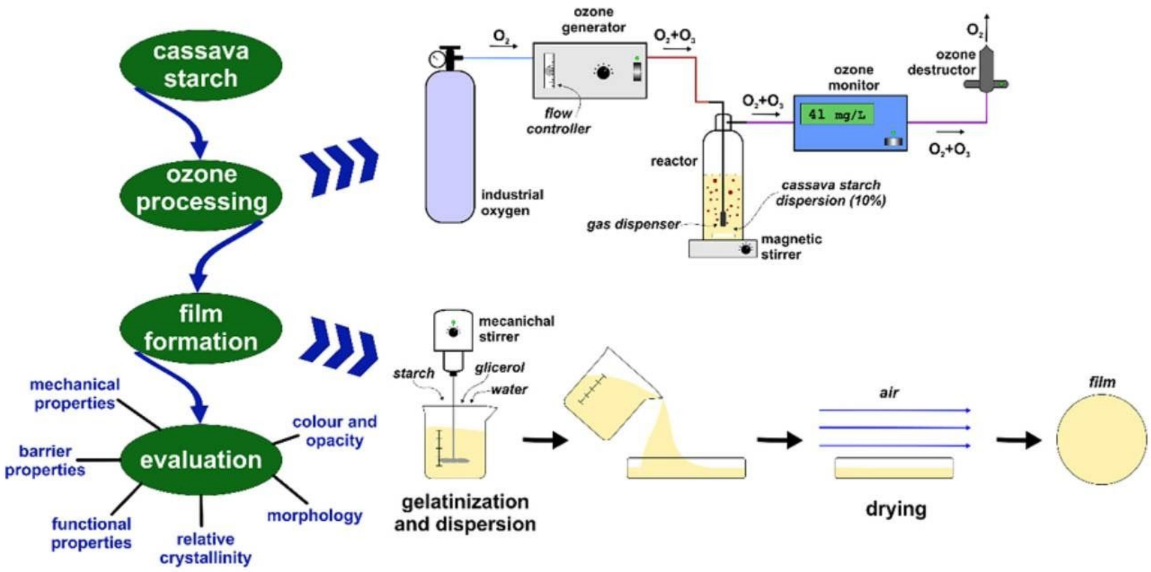



Fig. 1. Schematic representation of the ozone processing system and the film elaboration.

*(Image Source: La Fuente, C. I. A., de Souza, A. T., Tadini, C. C., & Augusto, P. E. D. (2019). Ozonation of cassava starch to produce biodegradable films. International Journal of Biological Macromolecules. doi:10.1016/j.ijbiomac.2019.09.028)*

The green credentials of starch-based bioplastics, like PLA, is that they should be able to compost or biodegrade within about 3-6 months, so that ‘green’ benefit allied with its ability to be used in many of today’s popular products and packaging makes it a very attractive plastic alternative:
*Many industries are using PLA because they are capable of biodegrading at a much faster rate than plastic while still offering the same level of sanitation and utility. Everything from plastic clamshells for food take-out to medical products can now be made from PLA, which drastically reduces the carbon footprint of these industries.* (West, Larry. "Pros and Cons of PLA: Corn-Based Plastic." ThoughtCo, Feb. 11, 2020, thoughtco.com/pros-cons-corn-based-plastic-pla-1203953.)

**How environmentally-friendly is it?**
The increased use of agricultural crops for bioplastic manufacturing does cause concern in some quarters that *‘the mass production of bioplastic could undermine food supplies for people and animals because at least 50% of economic crops like cassava and sugarcane would go to feed the bioplastic industry.’*

This bioplastic is supposed to biodegrade in around 3 to 6 months which is positive. *However, PLA ‘needs high temperature industrial composting facilities to break down and very few cities have the infrastructure needed to deal with them. As a result, bioplastics often* *end up in landfills. If bioplastic contaminates recycled PET (polyethylene terephthalate, the most common plastic, used for water and soda bottles), for example, the entire lot could be rejected and end up in a landfill.'*(source)

## Bamboo fiber-based bioplastics

Bamboo fibre is a 100% natural and renewable material that is already well-known as being a source of single-use cutlery, building material, and more.
When ground bamboo fibres are blended with melamine resin or starch polymers, or heat pressed, they form a bioplastic that can be shaped into products like cups in the same way as traditional plastic is used. Bamboo stalks can also be used a plastic-straw alternative.

Bamboo plastic food containers are becoming more common, as this Thai company has benefited from as they ramp up to produce more of their bamboo/cassava starch disposable food packaging:


In a drive to become more sustainable, bamboo is also used to create some of KFC's iconic buckets in Canada from 2020. (source)

The use of melamine in bamboo plastic is a concern, as when exposed to high temperatures, it can release harmful chemicals like formaldehyde, however *melamine resin is harmless as long as certain conditions are preserved, specifically if products containing it are kept under 70 degrees Celsius (158 Fahrenheit)*. (source)

So as a source of packaging, food utensils, and containers for cool or cold drinks, bamboo plastic would be an appropriate alternative.

**How environmentally-friendly is it?**
As a resource, bamboo is extremely sustainable as it *'holds the record for fastest growing plant in the world. Bamboos can be harvested in 3 to 5 years and new shoots grow continuously allowing them to be harvested consecutively every year or two. Compare this to wood which takes 20–50 years and requires replanting.'*
In addition, bamboo is a natural CO2 sink, as it '*exhibits carbon capture almost 450 times more efficient than trees.'* (source)

Bamboo is natural wood and so is fully biodegradable, but if it has been combined with other substances these may not be so the only way of recycling it may be to burn it for fuel. Bamboo should biodegrade in nature within around 2-4 years.

## Hemp-based bioplastics

Like bamboo, hemp is a fast-growing, renewable source of material for bioplastics which actually removes CO2 from the air when growing. Related to the global cannabis crop, hemp cellulose is a by-product that is used to make the plastic alternative. Hemp is particularly attractive as a source of cellulose (the building block of hemp bioplastic) as it *'contains around 65-70% cellulose compared to wood 40%, flax 65-75%, and cotton up to 90%.'*
*'From seed to harvest (10-15ft tall), hemp plants take just 3-4 months to grow, …[and] are experts at absorbing CO2 from the atmosphere. Hemp plants also require fewer pesticides, fertilisers and water than other bioplastic resources such as cotton and wood, providing a more environmentally friendly, low maintenance crop.'* (source)

With the growing use of CBD and gradual deregulation of cannabis around the world, it seems that hemp use will continue to grow to the extent where a report places the global cannabis packaging industry at $20 billion by 2025.

Hemp plastics (HBP) are said to be 4 times stronger than polypropylene (PP), a commonly used oil-based plastic, as well as being lighter, and it is commonly used in creating film wrap or styrofoam packaging alternatives.

Kanesis, a company based in Sicily is producing a 3D-printer filament made entirely from the waste of hemp production. It is called HempBioPlastic (HBP), it has shown to be more efficient and more aesthetically pleasing than other bioplastics on the market. HBP has shown to be 20% lighter and 30% stronger than PLA – the most common plastic used in 3D-printing filaments. HBP filaments are also seen as favourable to its competitors (ABS and PLA) not only because of its positive eco-footprint, but also due to its favourable weight/volume ratio. (source)

**How environmentally-friendly is it?**
Hemp plastic takes 3 to 6 months to decompose and is able to be recycled indefinitely. In addition, hemp can grow on every continent and requires less water than some crops.

## Seaweed (macroalgae) & Algae (microalgae)-based bioplastics

Algae and seaweed, being plants, can be cultivated in water, dried, milled and chemically treated were used to break the seaweed down into basic constituents. This powdered seaweed is then used as an ingredient for the bioplastic or fermented to produce lactic acid. The lactic acid was also used in the production of bioplastic polymers in the same way as their land-cultivated cousins' starches from corn, cassave, etc, into PLA amongst other bioplastics. (source)

*Harvested microalgae is dried and powdered to be incorporated in a blend with another biopolymer used as a binder, and natural additives. (source)*
Both rigid and flexible packaging can be made and some microalgae and seaweed plastics are even edible.
It is affected by warmer temperatures and so is recommended as packaging for dried goods rather than liquids, especially hot liquids.

**How environmentally-friendly is it?**
This is an intriguing source of sustainable material, as growing water plants doesn't put extra pressure on the earth's already-stretched farmland. They just need sunlight and don't require water, pesticides, and fertiliser in the same way as terrestrial crops do, so this makes seaweed cheap as well as sustainable. (source)

Some can break down naturally after just a couple of months, depending on weather conditions (warmer temperatures will break it down sooner), whereas other types of algae/seaweed-based bioplastics will biodegrade within 12 weeks in soil and 5 hours in water.

It is also one of the few edible plastics:
*'Bioplastics made from cornstarch and sugarcane are sold as more eco friendly—renewable, though not edible—alternatives. But they can be just as bad as petroleum-based plastic for the environment, sitting around for hundreds of years in a landfill or floating in the ocean without breaking down. Edible packaging takes biodegradability to the next level; the same properties that make the materials edible also make them hypercompostable.'*
*'Algopack offers a breakthrough innovation using seaweeds to produce biodegradable granules. Algopack is made entirely from seaweeds. This type of granule is entirely bio-compostable and biodegrades within 12 weeks in soil and 5 hours in water; its*

*permeability can be adapted according to the product lifecycle. Algopack also plays the role of fertilizer for the soil.*

*London-based start-up Notpla creates edible drink pods, containing a sip of a sports drink, called Ooho. The capsules encase liquid in a waterproof film made from seaweed. Users can gulp the drink and swallow the packaging. But if they choose to spit out the film, it will biodegrade in 4–6 weeks without a trace*

*New York–based Loliware is turning alginate from seaweed and agar from red algae into flavored straws that, unlike paper straws that get soggy, behave like plastic for 24 h once they become wet. You can eat them if you like; regardless, they will degrade in the environment within 2 months.'* (source)

# Different categories of bioplastics

Let's categorise some of the types of Bioplastics (source):

## 1) Starch-based plastics

Starch-based thermoplastics make up about 50 percent of the bioplastics market and are widely used. Pure starch possesses the characteristic of being able to absorb humidity, therefore Flexibilizer and plasticizers such as sorbitol and glycerine are added so the starch so that it can be processed into a thermoplastic.

## 2) Cellulose-based plastics

Cellulose bioplastics are mainly the cellulose esters, (including cellulose acetate and nitrocellulose) and their derivatives, including celluloid.

## 3) Aliphatic polyesters

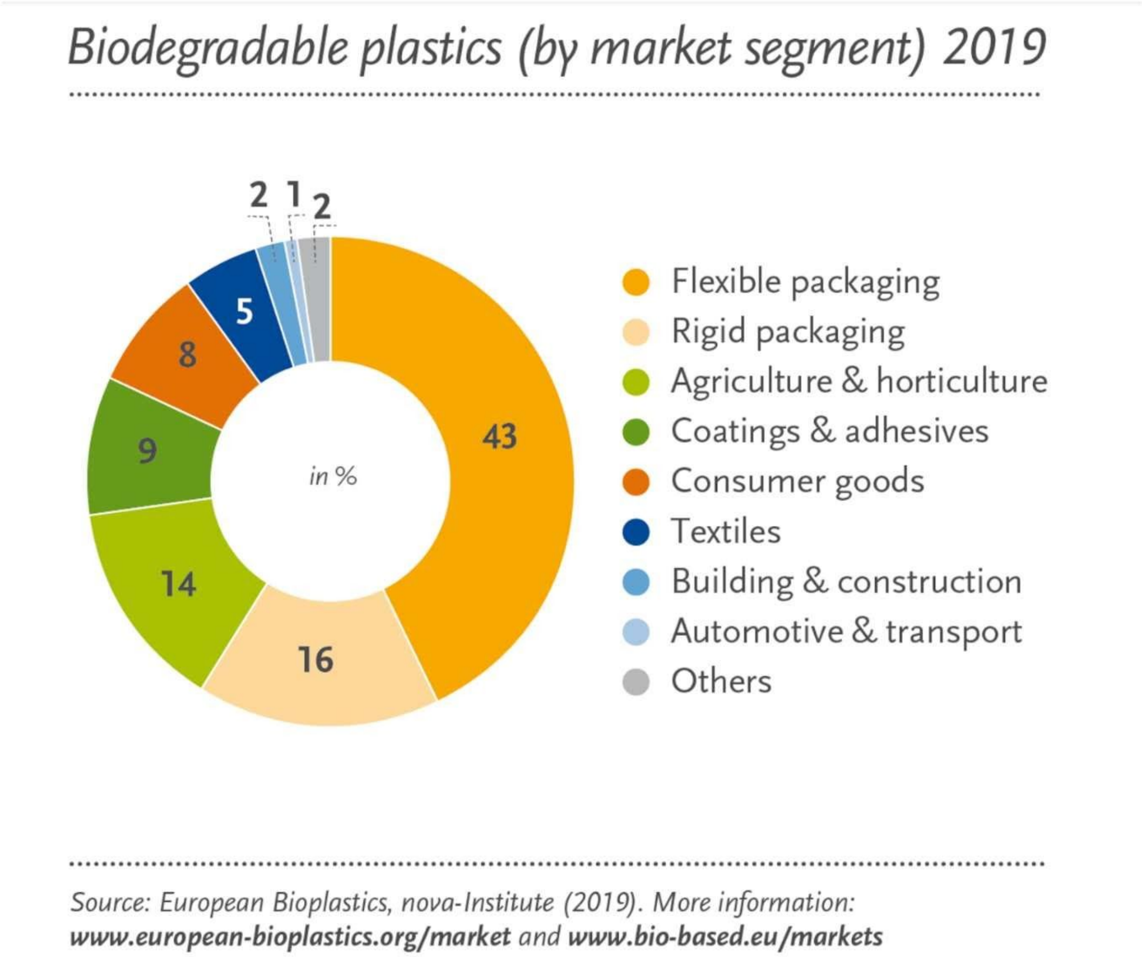
The aliphatic biopolyesters are mainly polyhydroxyalkanoates (PHA), poly-3-hydroxybutyrate (PHB), and Polylactic acid (PLA) plastics.

- **Polylactic acid (PLA)**
  Polylactic acid (PLA) is a transparent plastic produced from cane sugar or glucose from other plant . Enzymes are used to break starch in the plants down into glucose, which is fermented and made into lactic acid. This lactic acid is polymerized and converted into a plastic called polylactic acid. These are used in the plastic processing industry for the production of foil, moulds, cups and bottles.
- **Poly-3-hydroxybutyrate (PHB)**
  The biopolymer poly-3-hydroxybutyrate (PHB) is a polyester produced by certain bacteria processing glucose, corn starch or wastewater. It produces transparent film at a melting point higher than 130 degrees Celsius, and is biodegradable without residue.
- **Polyhydroxyalkanoates(PHA)**
  These are linear polyesters produced in nature by bacterial fermentation of sugar . They are produced by the bacteria to store carbon and energy. In industrial production, the polyester is extracted and purified from the bacteria by optimizing the conditions for the fermentation of sugar. These plastics are being widely used in the medical industry.
- **Bio-derived polyethylene (PE)**
  The basic building block of polyethylene is ethylene. This is just one small chemical step from ethanol, which can be produced by fermentation of agricultural feedstock such as sugarcane or corn. Bio-derived polyethylene is chemically and physically identical to traditional polyethylene – it does not biodegrade but can be

recycled. It can also considerably reduce greenhouse gas emissions. It is used in packaging such as bottles and tubs.

# In which products and items are bioplastics commonly used, and why?

Where are bioplastics commonly used? Packaging is by far the most popular application, accounting for almost 60% of the market (inclusive of both flexible and rigid types) in 2019, however bioplastics are used as alternatives to traditional plastics in almost every business sector.




| Market Segment | Commonly used bioplastic | Typical products & items they're used in | Properties of the bioplastics used that make them desirable for that application |
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| Flexible Packaging | PLA | PLA is currently used in packaging as films, thermoformed and blow molded containers, food service ware, and short shelf-life bottles competing with PS and/or PET [3].<br><br>Example:<br>Clear film overwrap for trays [2].<br> | PLA is a brittle polymer and hence could not be aptly used for thermoforming. However when blended with processing aids and impact<br>modifiers such as starch, Ecoflex etc, we could impart toughness for PLA, making it suitable for such [thermoformed plastic] applications [3]. |
| Rigid Packaging | PLA | PLA is currently used in packaging as films, thermoformed and blow molded containers, food service ware, and short shelf-life bottles competing with PS and/or PET [3].<br><br>Example:<br>Foam trays for meat, fish, etc [2]<br> | PLA has good mechanical and thermal properties similar to poly(ethylene-terephthalate) (PET) or polystyrene (PS) depending on the considered properties [3]. PLA has moderate barrier properties (water vapor permeability and oxygen permeability) as compared to those of polystyrene (PS). However, high density, high polarity, poor heat resistance, and brittleness limit its use [3].<br><br>Foam PLA is targeted to replace Styrofoam, while reducing environmental pollution [2]. |
| | Starch-based bioplastics | Food packaging and edible films are two major applications. The most common applications of starch based polymers are for the packaging industry with applications such as<br>soluble films, films for shopping bags and | From the packaging industry point of view, starch based plastics represent a great potential because of their biodegradability, their combustibility but also the natural abundance and renewability of starch [3]. |

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| | | refuse sacks, and loose fills [3]. | |
| | Aliphatic polyesters (PHA, PHB, PHV) | Food packaging. | Packaging materials made from PHA possess excellent film forming and coating properties. PHAs have properties close to that of polypropylene (PP) [3] and could also replace (PE)[4].<br>PHB materials are suitable materials for storage of liquid acidic and fatty foodstuffs such as orange juice and cream cheese, soured cream, etc [4]. |
| Agriculture | Starch based | 3 major applications in agriculture: polytunnel greenhouses, mulch film and fertilizer controlled release materials [3]. | Sturdy, yet flexible films can be made. Among natural polymers, starch is completely biodegradable, has low cost and is renewable [3]. |
| Coatings & Adhesives | Starch based, PHB | Coating on paper board, Edible coatings for food and pharmaceutical, paper coating, Cassava starch adhesives, plywood/ chipboard adhesive, adhesive for automotive [3]. | The edible films and coatings appear to have potential applications to pack ready to eat foods. For example, an edible film/coating composed of alginate or pectin between the base and sauce component of pizza could reduce the water migration between the sauce and base [3].<br><br>Plasticized PHB employed as continuous polymer matrices for the elaboration of PHB- starch- based films and paper coatings. It is demonstrated that the use of high molecular weight PHB- and PHB-starch -based coatings for paper significantly increases the water vapor permeability of the material. The results testify the that combination of inexpensive water sensitive starch with hydrophobic PHB offers a potential for creating ecologically sound biocomposites for special kinds |

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| | | | of application [3].<br><br>Cassava starch adhesives are more viscous and smoother working. They are fluid, stable glues of neutral pH that can be easily prepared and can be combined with many synthetic resin emulsions. |
| Textiles | PLA, Cellulose based, starch based | Fabric, Fiber cloths [2].<br><br>Cellulose based natural fiber yarns and fabrics from flax, hemp and other natural fibers such as ramie [3]. | PLA is well known for being biocompatible and compostable and has received considerable industrial attention as a replacement for existing petrochemical-based polymers due to its processability and properties which in some circumstances can match or exceed the performance of conventional plastics<br><br>Modified starches such as acid-modified, oxidized, and ethylated are used in the textile industry. These starches are used to treat the cloth as it comes from the loom. The starch removes the impurities of various applied dyes, chemicals, and softener. It is also used for desizing [3]. |
| Constructions | PLA | Thermal Insulation [3]. | PLA foams are excellent thermal insulators, comparable to expanded polystyrene (EPS) which itself is considered an excellent insulator [3]. |
| Automotive | PLA | Toyota (floor mat of Toyota Prius and spare tire cover), Toray (fiber for car mat), etc [2].<br> | The rigidity of PLA is an advantage for external cover applications. Although PLA is biodegradable, the rate of degradation is low and requires high moisture conditions to initiate the hydrolysis process (the depolymerization reaction) [2]. |

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| Others | PLA, Starch based | Rigid covers for consumer and medical goods [2]. | The rigid character of PLA can provide protection to enclosures for highly sensitive products, such as electronics and cosmetics. There are a few grades of PLA on the market specially designed for high-impact and heat-stable applications [2].<br><br>PLA has equally good electrical properties as other common polymers used<br>in the electronics industry [2].<br><br>Due to their good biocompatibility, biodegradability, mechanical properties, [slow] degradation, and being non-toxic, [these bioplastics] find major applications in medical field [3]. |

Sources used in above table:


2. Ebnesajjad, S. (Ed.). (2012). *Handbook of biopolymers and biodegradable plastics: properties, processing and applications*. William Andrew.

3. Pilla, S. (Ed.). (2011). *Handbook of bioplastics and biocomposites engineering applications* (Vol. 81). John Wiley & Sons.

4. https://crimsonpublishers.com/ntnf/fulltext/NTNF.000546.php

# Is the bioplastic industry innovating to find even more new materials and products?

Yes, since the demand for bioplastics is growing there are many new and experimental processes and forms of bioplastics being developed.
They include:

- Casein protein used to make an alternative plastic film for food storage.
- Chitin bioplastics (these are made from the shells of insects and crustaceans, for example, crab shells or shrimp shells)
- Food waste bioplastics, for instance using coffee and orange peel to make 3D printing plastics, or banana peels which provide starch for starch-based bioplastics that are fast to biodegrade and can be pliable or molded to suit the user's application.

The ability to use what would commonly be considered as 'food waste' to create bioplastic is the next frontier of innovation and would seemingly go a step further to allay fears about perfectly good foodstuffs being used for bioplastics which could otherwise be used to feed people.

As bioplastic use increases, so does innovation - we have now reached a point where the key environmentally-conscious plastic innovations are squarely in the bioplastic polymer arena:

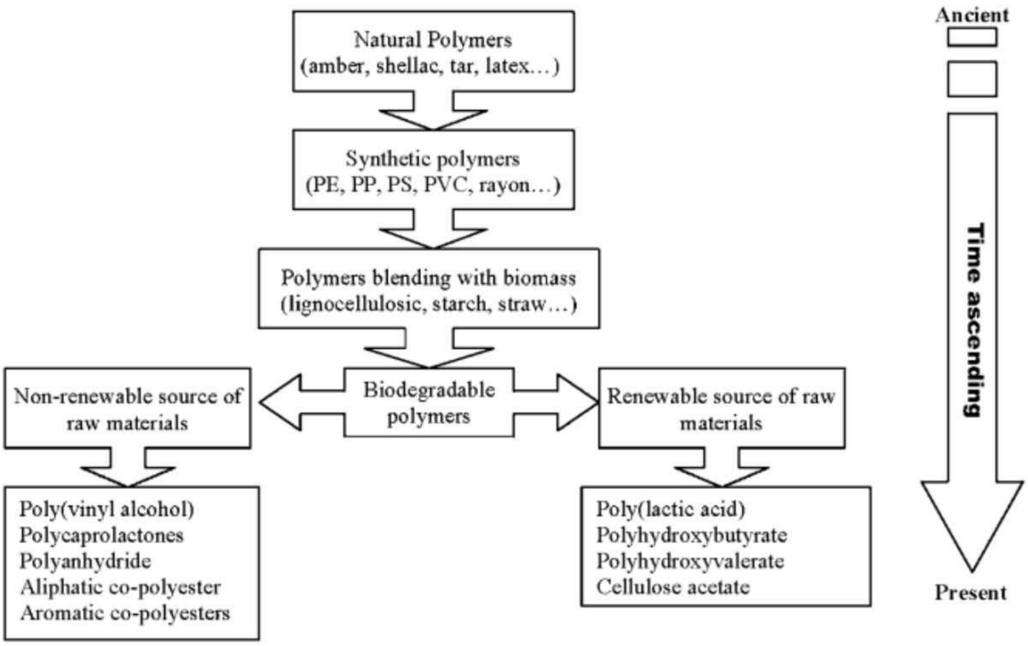


**Figure 1. Trends in polymer development.**

*Source: Ebnesajjad, S. (Ed.). (2012). Handbook of biopolymers and biodegradable plastics: properties, processing and applications. William Andrew.*

## Are bioplastics totally green?

Bioplastics are arguably greener than oil based plastics due to the lower carbon footprint of their production as their basic raw materials are usually totally sustainable and, being plant-based, actively remove CO2 from the environment during their growth. Their production also has a lower CO2 footprint than oil-based plastics.

However, recycling is not easy and it's arguable whether every type biodegrades effectively.

In the case of PLA:
*Discarded bioplastic must either be sent to a landfill, recycled like many (but not all) petroleum-based plastics, or sent to an industrial compost site...If they end up in marine environments, they'll function similarly to petroleum-based plastic, breaking down into micro-sized pieces, lasting for decades, and presenting a danger to marine life. (source)*

Consumers may be aware of the lack of recycling or industrial composting options, and so by choosing bioplastics which are technically greener than oil based options, manufacturers and importers may still be at risk of being accused of 'greenwashing' if the bioplastic in question cannot realistically be disposed of in an eco-friendly method.

# Are bioplastics cost-competitive with oil based plastics?

As long as the cost of a barrel of oil remains fairly low, bioplastics just *can't* compete yet because their commercial manufacturing processes are plagued by low yields and are expensive.

*"In order to be competitive with traditional oil-based material, the price of oil [needs] to be somewhere around $130, $140 a barrel...Clearly, at $50 a barrel, we are far away from being able to compete."*
*The capacity to make all of the world's plastic from non-petroleum sources exists, but to do so would require significant government support.*
*"It will have to be driven by regulation that will force the cost of plastic and the cost of oil to be substantially higher than it is right now." (source)*

Government support *is* effective as the plastic bag ban in France in 2016 did *'not include a ban on those plastic bags that are deemed re-usable or biodegradable'* (source) and a subsequent 2020 *'law was passed...to ensure all plastic cups, cutlery and plates can be composted and are made of biologically-sourced materials.'* (source) Indeed, France is leading Europe by having an objective of NO plastic packaging by 2040.