Guide to biodegradation

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Leveraging biodegradation to divert waste from landfills

Plastic is ubiquitous. It's used in everything from your shampoo bottle to your golf shirt. Unfortunately, traditional petroleum-based plastics are notorious contributors to landfill waste. According to a 2017 study in Science Advances, of the 8.3 billion metric tons of virgin plastics produced since the 1950s, about 6.3 billion metric tons have been disposed of in landfills or the natural environment.

If this trend continues, that number could increase to 12 billion metric tons.

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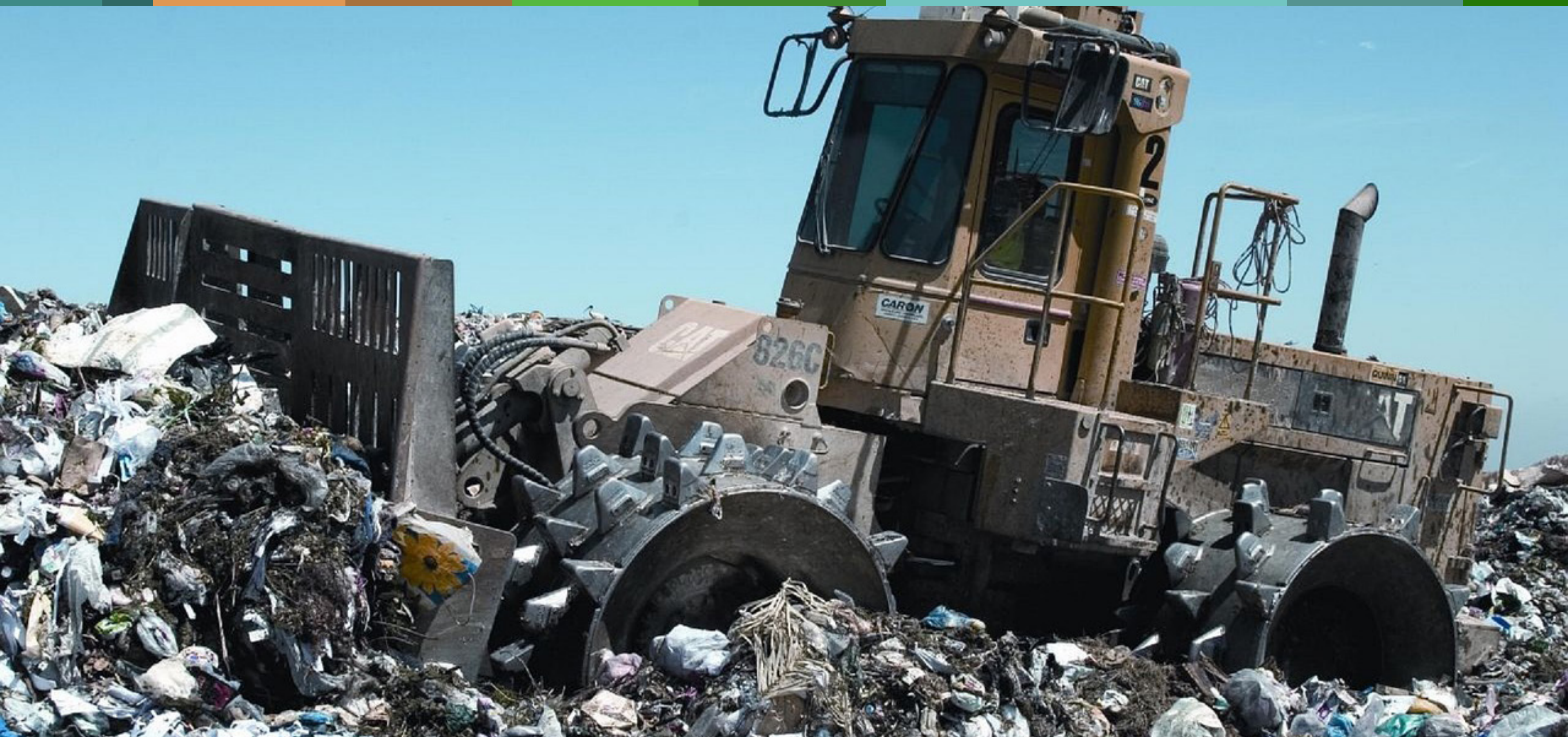


Diverting waste away from landfills with biodegradable plastics

Municipal solid waste landfills (i.e., landfills) are assigned areas of land or excavation that receive household waste. They can only be built in "suitable geological areas away from faults, wetlands, floodplains or other restricted areas." In addition, they need a composite liner (i.e., a geo-membrane) two feet above its compacted clay soil lining to protect groundwater and the underlying soil from leachate releases. Despite the standards in place, disposed products degrade and produce landfill gas composed of methane and carbon dioxide; both gases are highly effective at trapping heat in the atmosphere, especially methane.

> In 2014 alone, 136 million tons of municipal solid waste were landfilled, 18% of which were plastic.

Landfills are only designed to store waste, not break them down. Unfortunately, the rate at which we are producing waste outpaces the rate of natural biodegradation. Consequently, landfills are quickly filling up, which increases air, water and soil pollution. In 2014 alone, 138 million tons of municipal solid waste were landfilled, 18.9% of which were plastic.

The disposal of non-biodegradable plastics is unsustainable because they often follow a linear economic model where virgin products are manufactured, used once and disposed of, accumulating in landfills or the natural environment.

> 9% of plastics made since 1950 have been recycled.

While recycling is one solution to divert waste from landfills and reduce the production of virgin materials, only 9% of plastics made since 1950 have been recycled. Recycling simply delays disposal, which is why biodegradation and composting should also be considered as solutions.

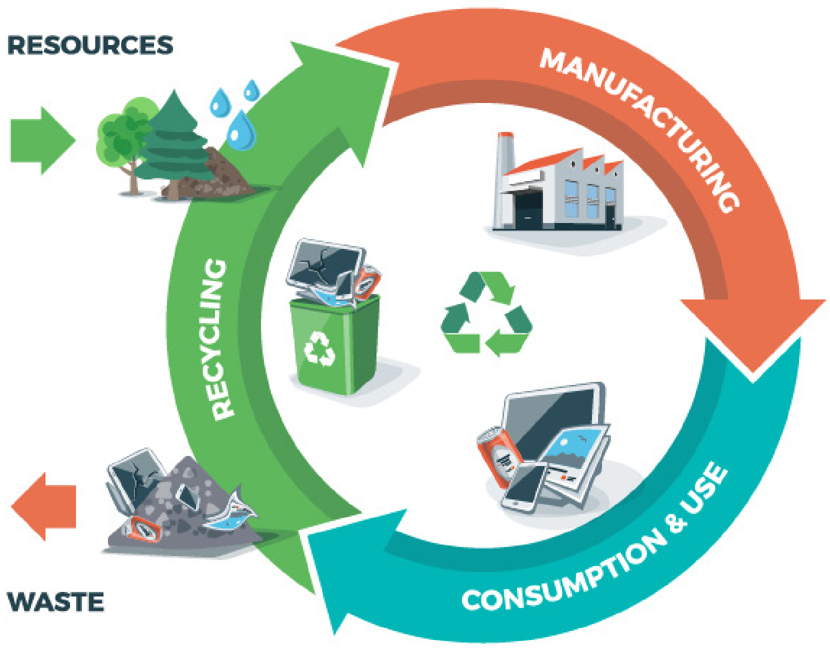
Looking at alternative solutions to recycling will become more important in light of recent global events. For decades, the United States has relied on China to recycle its plastic waste. As of January 2018, China is no longer accepting plastic in an effort to protect their citizens' health. This puts more pressure on domestic recycling infrastructure, forcing the U.S. to further explore alternate waste solutions such as industrial composting.

What is biodegradation?

Biodegradation is a natural process that breaks down everything from yard waste to crude oil. The United States Environmental Protection Agency (EPA) defines it as "a process by which microbial organisms transform or alter (through metabolic or enzymatic action) the structure of chemicals introduced into the environment." The mechanism varies based on the environment, plastic material and biodegradation rate.

When organic waste decomposes in landfills, it does so in an anaerobic environment, resulting in the production of methane, a highly flammable greenhouse gas that is 23 times more potent than carbon dioxide. As such, aerobic biodegradation, which produces carbon dioxide and organic materials, is desired. In fact, a 2014 EPA report noted that recycling or composting 89 million tons of municipal solid waste reduced carbon dioxide emissions in the atmosphere by 181 million metric tons.

Many bioplastics will biodegrade when composted. They follow a circular economy where sustainable plastics are manufactured from renewable resources. These plastics can be returned to nature when their useful life has ended. In short, a circular economy takes landfills out of the equation. Over the past decade, the plastic industry has been evolving. The number of options for compostable bioplastics has increased, along with the volume of material produced.



Biodegradable plastics vs. compostable plastics

Businesses and consumers misconstrue what biodegradation means and how it differs from composting and recycling, which creates issues with labeling and ultimately disposal. All compostable plastics are biodegradable. However, not all biodegradable plastics are compostable. In order to be labeled as compostable, bioplastics must biodegrade in a specified time period leaving no toxins in the soil. Some traditional plastics claim to be oxo-degradable; however, these materials are designed to degrade into smaller and smaller fragments of plastic, which can contaminate soil and waters for years.

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Truly biodegradable plastics undergo biodegradation by naturally occurring microorganisms, which help the material degrade into organic matter. Biodegradation refers to anaerobic or aerobic degradation of materials by microorganisms. Depending on the environmental factors (i.e., moisture and temperature), the process will result in carbon dioxide, water, biomass, minerals salts and / or methane. Anaerobic biodegradation occurs without oxygen, meaning that anaerobic microorganisms are dominant, resulting in the production of methane. Conversely, aerobic biodegradation occurs with oxygen, meaning that aerobes are present and use cellular respiration, which produces oxygen and carbon dioxide.

Composting is a specific process for biodegradation where aerobes digest organic waste to create compost. We will specifically discuss composting in industrial facilities where the process is carefully controlled because the proper levels of heat, water and soil need to be present, so the proper microorganisms can digest the materials at a consistent rate without leaving toxic residue.

Biodegradation

Bioplastics, as a general category, are plastics that are made from renewable biomass or can biodegrade at the end of their lifecycle. Some bioplastics have both attributes, some only one. For example, there are bio-based plastics that are not biodegradable (e.g., bio-based PET) and petroleum-based plastics that are (e.g., PBAT, PCL).

To be truly labeled biodegradable, the plastic must degrade into carbon dioxide, water, biomass and / or mineral salts when exposed to air, moisture and microbes. The materials should not be toxic to the environment. Bio-based materials may also be used as fillers, reinforcements for other biodegradable plastic polymers.

In the United States, the plastic needs to be certified compostable, meaning that it needs to comply with ASTM D6400 as certified by a third party organization such as the Biodegradable Products Institute.

Thus, the term "certified compostable" is more specific than "biodegradable." All materials are biodegradable given enough time, but claiming a product is "compostable" denotes that it meets requirements of ASTM D6400 or will degrade 90% in 180 days under the specific humidity, temperature and aeration conditions of an industrial composting facility.

The mechanism for biodegradation

Biodegradation can occur under aerobic or anaerobic conditions. Carbon dioxide is produced under aerobic conditions while the same materials will produce methane under anaerobic conditions (i.e., landfills). The environment or medium in which a plastic is disposed of will affect the possibility and rate of biodegradation.

A biodegradable plastic contains polymers that can be broken down and digested by polymer-degrading microbes in (ideally) aerobic environments where methane isn't a byproduct. If key environmental factors such as temperature and moisture align, then enough microorganisms can adhere to the surface of the plastic, ingest it and enzymatically degrade it.

The mechanism varies between aerobic and anaerobic processes and where the process takes place (e.g., landfill, marine environment or backyard). In general, enzymatic digestion is facilitated by hydrolysis, a two-step process where an enzyme first binds to the ingested polymer to catalyze hydrolytic cleavage. The polymer is then "cleaved" down to molecules with lower molecular weights that are then mineralized to carbon dioxide, water and biomass.

Rates of biodegradation

Biodegradation rates are influenced by the bioactivity of the location, temperature and moisture levels. The disposal site needs to have an environment conducive to the microorganisms needed to break down the plastic, as most biodegradable polymers degrade faster in significantly hot and wet environments.

However, for a biodegradable plastic to properly break down into environmentally friendly components, it needs to be disposed properly. For example, a biodegradable plastic bag thrown into a hedge will take years to properly degrade and even a banana peel needs a minimum of one year. Unfortunately, many biodegradable plastics are improperly discarded in areas that have undesirable environmental conditions, meaning that the products either slowly or never degrade.

A product made with a biodegradable plastic should be designed to biodegrade or compost according to its function. Fortunately, it is possible to create formulas with different biodegradable polymers with various bio-based materials to elongate or shorten biodegradation (or composting) rates, depending on the application. Consider how quickly compostable products should compost in a backyard after use (remember that composting is a specific form of biodegradation that results in compost). For example, Green Dot Bioplastics developed a compostable horticultural pot. The compostable plastic material was made to compost slowly so the pot could retain its structural integrity on store shelves but compost in a backyard when used.

Rate of biodegradation of a horticultural pot

Biodegradable plastics

All materials will eventually break down, but what we call “biodegradable plastics” break down into organic components in months or years as opposed to decades or centuries. Each plastic has a chemical composition and material characteristics that dictate which microbes can consume it and ultimately its degradation rate.

Biodegradability as a property does not depend on whether the plastic is sourced from renewable materials. Rather, it depends on the chemical properties of the polymer itself — not whether it is bio-based or petroleum-based. In fact, there are many petroleum-based plastics which are certified compostable.

Terratek® Flex

The line of Terratek® Flex bioplastics —the market's first biodegradable elastomer— is a good example of a biodegradable plastic which is not fully bio-based. Changing the ratio of natural and synthetic biodegradable polymers can generate a wide variety of properties, allowing for customization of the elastomer to fit the needs of the application.

Terratek® WC

Also, alloying biodegradable polymers with additives —such as fine wood particles in the Terratek® WC line of bioplastics— can imbue enhanced physical qualities. By altering the ratio of wood and type of biodegradable plastic, different performance (i.e., flexibility, rigidity) and aesthetic (i.e., color variations, smoother textures) can be achieved.

Regardless of source, any biodegradable plastic aids in directing waste away from landfills and to composting facilities. This not only decreases the burden placed on landfills but also lowers methane emissions.

Still, chronic issues with labeling and the system itself keep biodegradable plastics from properly degrading. However, composting facilities are an example of how biodegradable plastics can be systematized to not only divert waste but also renew it.

Composting

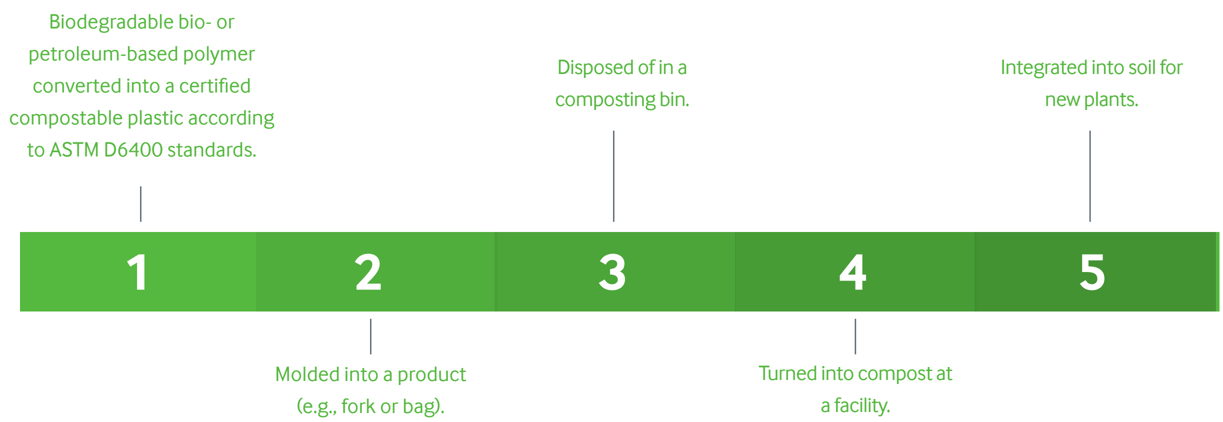
Composting is a method of biodegradation that can occur in a backyard or industrial composting facility. More specifically, it is the controlled process of breaking down yard waste, food scraps and compostable plastics into compost, a humus-like product that can be integrated with soil. On a molecular level, it is the microbial digestion of materials under optimal levels of heat, water and oxygen to create compost. Because compost is the end product of the composting process, it can be sold to generate revenue for facilities. However, to claim that a product is fully compostable in an industrial facility, it must meet all the requirements for ASTM D6400.

Composting plastics in an industrial facility can divert waste from landfills. Municipal governments along the West and East Coasts grapple with land space and are quickly learning that strategically located composting facilities can decrease waste in landfills.

Beyond diverting waste away from landfills, composting organic and food waste can also contribute to lower methane emissions, a harmful greenhouse gas.

The benefits of compost

Single-use items are generally thrown away after use and remain in landfills or the natural environment. However, if composted, they follow this renewable lifecycle:



Adding compost to soil can modify its pH levels, increase cation exchange capacity for nutrient retainment, bind contaminants and suppress plant diseases. In fact, the US Composting Council notes that it is highly versatile and "has the unique ability to improve the properties of soils and growing media physically (structurally), chemically (nutritionally) and biologically."

The mechanism of composting

The composting process in an industrial facility is carefully controlled but is only successful if customers understand how to properly dispose of waste. Although each composting facility tailors its process to the community it serves, the one used by St. Louis Composting is insightful:

St. Louis Composting process

1. Compostable plastics are mixed with organic scraps and picked up in 21- to 64-gallon bins.

2. The bins are then brought to a warehouse, where they are examined for contaminants and subsequently placed into large compactors.
3. The compactors are transported to a composting facility, where the compacted waste is placed into a mill with a windrow.
4. The windrow is then covered and sits for about two weeks before it's turned (mixed materials take about six months to form into compost).
5. Finally, the compost is sold to homeowners, landscapers and landscape architects.

Microbial digestion

Once the waste is in the windrow, it is converted into compost under aerobic conditions, which provides the necessary oxidative environment for aerobic microorganisms to digest organic materials and turn it into compost. There are three stages: The mesophilic or moderate-temperature phase, the thermophilic or high-temperature phase and the maturation phase.

In the mesophilic phase, the initial stages of decomposition occur. Mesophilic microorganisms secrete specialized enzymes that break down the materials into smaller organic molecules. Once the molecules have formed, the microorganisms absorb them for cellular respiration, which causes the temperature of the forming compost to rise above 40° C.

The rise in temperature signals the start of the thermophilic phase, where high-energy compounds —mainly proteins, fats and complex carbohydrates— are broken down. The temperature of the compost will gradually decrease as these compounds break down.

Once the temperature lowers enough, maturation can begin. Mesophilic microorganisms can function again under the lower temperatures and "cure" the remaining organic matter into compost.

Certified compostable plastics

While there are a variety of plastics on the market that claim to be biodegradable, composting facilities only accept certified compostable plastics, which is why understanding the various certifications is critical before beginning manufacturing.

Products and packaging that are certified compostable won't impede commercial composting operations or contaminate the compost. Common certifications include ASTM, BPI and CMA.

ASTM D6400

ASTM D6400 certifies that plastics and products have been developed to compost in municipal and industrial aerobic composting facilities. The certification ensures that products will biodegrade at a proper rate in a facility.

Biodegradable Products Institute (BPI)

For a product to be certified by BPI, it must first be certified ASTM D6400-12. BPI testing is conducted by independent labs that will ensure products can biodegrade at a comparable rate to other compostable materials so that large plastic fragments don't need to be screened out.

Composting manufacturing alliance (CMA)

The CMA field testing program specifically certifies that food service-ware (e.g., bags, utensils, plates and wraps) is compostable in facilities. CMA will provide insights on how well these products will break down in a composting facility. Ultimately, the program strives to divert food waste from landfills and "minimize contamination in urban feedstocks."

The challenges of systematizing composting

Ken Powell, the Public Service Executive at the Kansas Bureau of Waste Management said the key driver for bringing composting facilities to a city is policy and access but cautions that "cost, education and infrastructure are needed to get people composting." More specifically, Sarah Ryan, the Marketing Coordinator at St. Louis Composting, notes that some challenges include educating consumers and companies about the differences between bio-based, biodegradable, recyclable and compostable plastics as well as implementing a universal labeling system to prevent contaminants from entering composting facilities.

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>
> - Ken Powell, Public Service Executive at Kansas Bureau of Waste Management

Addressing contamination

Contamination is a key challenge for composting facilities. Improperly sorted plastics can contaminate recycling streams or feedstock and get buried in landfills. Most contamination results from petroleum-based plastics entering facilities due to:

1. Inaccurate labeling.
2. Confusion on disposal instructions.
3. Ignorance of best waste management practices.

Not all bioplastics are compostable, which is why inconsistencies in labeling and definitions puzzle customers. Although contamination is avoidable, a systematic solution will be needed to eliminate the issue entirely, which could include:

1. Educating customers.
2. Implementing fines for improper disposal.
3. Rejecting contaminated loads.

Diverting waste away from landfills

Governmental incentives and consumer expectations need to first shift towards composting and biodegradation. Doing so will influence the plastic industry to value biodegradable and compostable plastics over traditional plastics. The current waste management system affords consumers and companies with convenience. However, it took decades for it to come to fruition. As such, implementing a circular economy, where plastic is biodegraded, recycled or composted, and systemizing it to become convenient like the current system, will take time.

Schedule a consultation with our team if you are curious about the possibilities offered by biodegradable or compostable plastics.

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