Volume 4, Issue 3, 2026

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

PLASTIC-EATING BACTERIA AND WORMS: FROM POLLUTION TO SOLUTION

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DOI: https://doi.org/10.5281/zenodo.23834246

Keywords

Mealworms, waxworms, superworms, PETase, MHETase, gut microbiome, enzyme engineering, bioremediation, circular economy, plastic pollution, biodegradation, and plastic-degrading bacteria

Article History

Received: 01 January 2026
Accepted: 17 March 2026
Published: 31 March 2026

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Abstract

Because the chemical structures that give plastics their durability also make many of them resistant to biological degradation, plastic has emerged as one of the most enduring types of anthropogenic pollution. Recycling is still insufficient to stop plastic waste from building up in landfills and natural ecosystems, despite a sharp rise in plastic production and waste generation worldwide (Geyer et al., 2017). The variety and persistence of plastic waste cannot be adequately addressed by traditional methods like mechanical recycling, incineration, and landfilling, which has sparked interest in biological alternatives (He et al., 2024). Because certain species can colonize plastic surfaces, oxidize polymer chains, depolymerize particular polymers and use degradation products as sources of carbon and energy, microorganisms particularly bacteria have drawn increasing attention (Pérez-García et al., 2025). A significant area of study in enzymatic plastic recycling was sparked by the discovery of Ideonella sakaiensis and its PET-degrading enzymes, PETase and MHETase, which showed that microbial enzymes could directly attack polyethylene terephthalate (Palm et al., 2019). More recently, research has focused on insect larvae that consume plastic, such as mealworms, superworms, and waxworms, whose digestive systems and related microbes can change polymers like polystyrene and polyethylene (Sanluis-Verdes et al., 2022). Nonetheless, biological plastic degradation is still polymer-specific and frequently proceeds far more slowly in real-world environments than in ideal lab settings. Therefore, rather than serving as a stand-alone substitute for prevention, reuse, and traditional recycling, the available data points to biological degradation as a promising part of future plastic waste management. The variety of bacteria and insects that break down plastic, the molecular mechanisms of degradation, gut microbial interactions, significant enzymes, recent developments in enzyme engineering and metagenomics, the limitations of the available data and opportunities for translating biological discoveries into useful circular economy technologies are all examined in this review.

1. INTRODUCTION

Plastics are essential in packaging, agriculture, medicine, construction and consumer goods because they were made to be strong, lightweight, chemically stable and reasonably priced (Tokiwa et al., 2009). However, because

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

many conventional plastics are resistant to biological attack and can linger for a long time after disposal, these same characteristics pose a serious threat to the environment (Zhang et al., 2022). The issue is massive on a global scale: only a small portion of the 6.3 billion tons of plastic waste that had already been produced by 2015 had been recycled (Geyer et al., 2017). More recent evaluations highlight the inadequacy of current waste-management systems and continue to demonstrate rising plastic production and waste generation (Fletcher et al., 2023). Polymer chemistry is where the biological challenge starts. While PET has hydrolysable ester bonds that are relatively more accessible to specialized enzymes, plastics like polyethylene, polypropylene and polystyrene have extremely stable carbon-carbon backbones (Zhang et al., 2022). Microbial accessibility is also significantly influenced by polymer crystallinity, molecular weight, hydrophobicity, surface area and the presence of additives (Ghatge et al., 2020).

Therefore, treating "plastic" as a single biodegradable material is misleading from a scientific standpoint. Because of this chemical diversity, biological degradation is being studied more and more as a group of polymer-specific processes rather than as a general microbial ability. Microbial attachment and colonization, polymer deterioration or oxidation, depolymerization into smaller molecules and assimilation or mineralization of those products are the four general stages identified by recent reviews (Wang et al., 2026). The scientific question has shifted from whether plastics can interact with microorganisms to how these interactions can be comprehended, optimized and transformed into practical technologies due to the discovery of organisms capable of carrying out some of these processes.

2. What Does "Plastic-Eating" Actually Mean?

Although the term "plastic-eating organism" is appealing from a scientific standpoint, it may be deceptive. Consuming a plastic film does not prove that the polymer has undergone biological degradation. During chewing, an organism may physically break up plastic, increase its surface area, chemically alter the polymer, partially depolymerize it, absorb some degradation products, or fully mineralize a portion of the carbon (Vital-Vilchis & Karunakaran, 2025). Thus, several lines of evidence are needed for a compelling proof of biodegradation. Because plastic particles can physically disappear from experimental systems or change into smaller particles without biological mineralization, weight loss alone is insufficient (Ghatge et al., 2020).

Techniques like Fourier-transform infrared spectroscopy, scanning electron microscopy, gel-permeation chromatography, thermal analysis, molecular-weight measurements, isotope tracing and chemical identification of degradation products are combined in more compelling studies (Reddy et al., 2023). Because some recent research indicates that microbial erosion can actually produce microplastics and nano plastics during the degradation process, this distinction has become especially crucial. Degradation and fragmentation can happen at the same time, as evidenced by the fact that marine bacteria that can break down polystyrene have been shown to produce a lot of smaller plastic particles during polymer erosion (2024). Because of this, the most significant outcome is the transformation of polymer carbon into recognizable, biologically assimilated or recoverable products rather than just the disappearance of a plastic mass. When assessing bacteria and insects that break down plastic, this distinction should continue to be crucial.

Volume 4, Issue 3, 2026

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

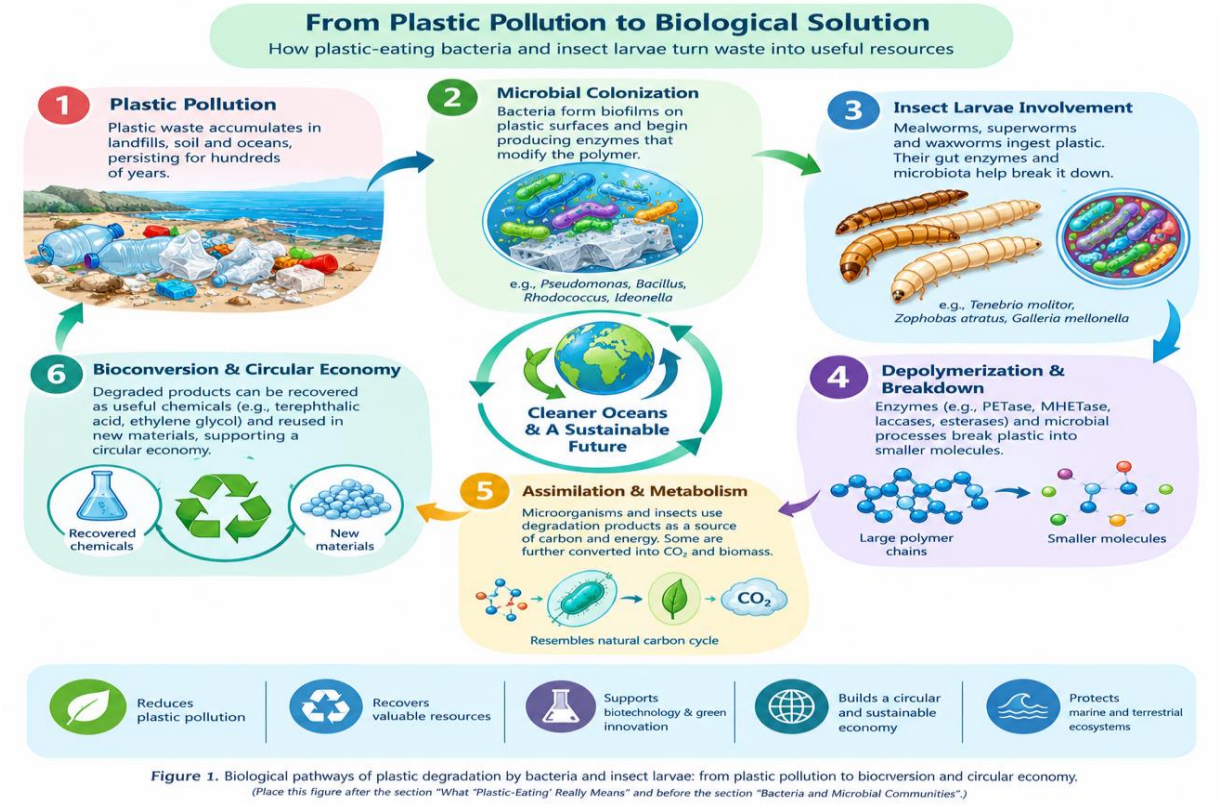


Figure 1. Biological pathways of plastic degradation by bacteria and insect larvae: from plastic pollution to bioconversion and circular economy.

3. Plastic-Degrading Bacteria: The Microscopic Workforce

Numerous plastic polymers such as PE, PP, PS, PET and polyurethane have been linked to bacterial degradation. Pseudomonas, Bacillus, Rhodococcus, Acinetobacter, Streptomyces, Sphingomonas, Alcanivorax, Halomonas and other genera have been reported (Wróbel et al., 2024). Nevertheless, a bacterial species' ability to utilize plastic as a carbon source is not always implied by its presence on the material. The goal of contemporary research is to use genomic, chemical, and metabolic evidence to differentiate between true degradation and simple colonization. Biofilm formation is one of the most significant mechanisms. Microorganisms can colonize the hydrophobic interfaces provided by plastic surfaces, creating extracellular polymeric compounds that aid cells in adhering to the polymer (Bocci et al., 2024). Different organisms may carry out distinct metabolic tasks within these communities. The polymer surface may be oxidized by one microbe; smaller fragments may be attacked by another and soluble intermediates may be metabolized by a third. This suggests that rather than being the result of a single "super bacterium," plastic degradation may be a community process. This theory is supported by recent research. Certain taxa may become enriched under plastic exposure and bacterial communities enriched on plastics may differ compositionally from surrounding communities (Bai et al., 2024). Although the degree of actual biodegradation varies greatly among polymers, exposure to plastic in marine environments can quickly attract bacteria linked to polymer transformation (Abelouah et al., 2025).

The challenge is best illustrated by research on PE. Measurable PE modification was observed in a Rhodococcus strain isolated from naturally weathered plastic, including modifications in molecular weight and the emergence of functional groups containing oxygen (Tao et al., 2023). Similarly, Bacillus species have demonstrated LDPE degradation under laboratory conditions (Yao et al., 2022). More recent research has identified additional candidates, including Paenarthrobacter nitroguajacolicus, highlighting the continuing

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ISSN: (e) 3007-1607 (p) 3007-1593

discovery of new microbial resources for PE remediation (2025).

Using microbial consortia instead of individual isolates is a significant new trend. Compared to individual methods, a consortium comprising Bacillus and Acinetobacter strains isolated from mealworm larvae was more successful in reducing the mass of polyethylene mulch film (Yang et al., 2020). Similarly, communities containing Bacillus, Sporosarcina and Brevibacillus can modify LDPE under controlled conditions, according to recent soil-enrichment studies. These results imply that collaboration among microorganisms might be more beneficial for challenging polymers than dependence on a single strain.

Microorganisms that break down plastic can also be found in marine environments. Bacterial succession during PE degradation has been found in studies of marine sediments and plastisphere communities and it has been suggested that environmental elements like iron and available nutrients can affect degradation pathways. Rapid bacterial recruitment to PET, PS and PP surfaces has also been shown in recent marine experiments, though the polymer changes that resulted varied depending on the material (Abelouah et al., 2025). These results lead to a crucial conclusion: bacteria are more than just plastic eaters. They are intricate microbial systems that can colonize surfaces, oxidize, depolymerize and metabolize certain compounds derived from plastic; their effectiveness is highly dependent on the chemistry of the polymer and the surrounding environment.

4. Worms That Eat Plastic: When the Gut Becomes a Bioreactor

The field was significantly broadened by the finding that insect larvae can eat plastic. Because they can consume polymers that are extremely resistant to traditional biodegradation, mealworms, superworms and waxworms have drawn special attention (Vital-Vilchis & Karunakaran, 2025). One of the first organisms to garner significant scientific interest was the mealworm, as studies showed that its larvae could eat polystyrene and turn some of it into carbon dioxide. Crucially, mealworms capacity to depolymerize and mineralize polystyrene was significantly diminished when gut bacteria were suppressed, offering compelling proof that the insect was not operating in isolation (Yang et al., 2015).

Superworms exhibit a similar phenomenon. Expanded polystyrene can be consumed by Zophobas atratus larvae and studies have shown significant microbial involvement and depolymerization in the gut (Yang et al., 2020). Another study isolated a Pseudomonas strain from super worm guts that demonstrated PS-degrading activity, illustrating the connection between insect feeding behaviour and microbial biotechnology (Kim et al., 2020). Mealworms, waxworms, and superworms have different capacities for consuming and transforming polystyrene, according to comparative studies. Superworms were observed among the three insects, and the three insects (Jiang et al., 2021). These variations are significant because they show that the phrase "plastic-eating worm" refers to multiple different biological systems rather than a single, all-encompassing mechanism.

One particularly intriguing example is the greater wax moth. Waxworms can consume polyethylene, a polymer substantially more resistant to biodegradation than PET. Initially, studies showed that larvae could consume and change PE, but subsequent research revealed that their saliva has the ability to oxidize plastic (Bombelli et al., 2017). This discovery was particularly important because it suggested that the first difficult step in PE biodegradation oxidation of the chemically inert polymer could be initiated by animal-derived enzymes. Thus, the gut of an insect can be thought of as a natural bioreactor. When plastic enters the digestive system, it is subjected to host enzymes, oxygen-reactive processes, digestive chemicals, mechanical fragmentation and a dense microbial community. Microorganisms may find polymer fragments more accessible in the ensuing chemical environment.

This idea has been extended beyond PS and PE in recent research. It has been demonstrated that mealworm larvae can change PET, and that gut microbes can aid in the metabolism of intermediate products and that the size of the polymer chain affects degradation. Research has also investigated melamine-formaldehyde foam and other less commonly studied polymers, suggesting that plastivore insects may have

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ISSN: (e) 3007-1607 (p) 3007-1593

broader biochemical capabilities than initially recognized.

However, there may be physiological costs associated with plastic feeding. Because most conventional plastics don't offer a nutritionally balanced diet, eating only plastic may hinder growth, development and survival (Vital-Vilchis & Karunakaran, 2025). Therefore, understanding the biological mechanisms underlying polymer transformation and transferring those mechanisms into controlled biotechnological systems should be the practical goal rather than raising insects solely on plastic.

5. The Molecular Machinery: From Polymer Surface to Metabolic Pathway

Plastic degradation generally begins outside or at the surface of the microbial cell. Because most polymers are too large to enter cells directly, microorganisms must first modify the polymer or break it into smaller molecules (Zhang et al., 2022). Oxidation is the first significant problem for carbon-carbon backbone polymers like PE and PP. Thus, enzymes like oxygenase, laccases, oxidases and peroxidases have been studied as potential contributors to initial polymer modification (Santo et al., 2013). By adding oxygen-containing functional groups to the polymer chain, oxidation may improve hydrophilicity and increase the likelihood of enzymatic or microbial attack. Oxidative enzymes and hydrocarbon metabolism-related pathways have been connected to PE degradation. While more recent proteomic studies have identified potential oxidases, esterases and lipid-associated proteins during bacterial PE transformation, a classic study showed a role for laccase in PE degradation by Rhodococcus rubber (Tao et al., 2023).

PET is chemically different and therefore provides a clearer enzymatic pathway. The Idea bacteria is a source of energy that can serve as a source of energy and that can serve as a bacterium, and that bacterium, and that can serve as a bacterium, can serve as a bacterium, can serve as a bacterium, can serve as a bacterium (Yoshida et al., 2016). The organism produces two important enzymes: MHETase, which hydrolyzes MHET into ethylene glycol and terephthalic acid and PETase, which attacks PET and produces soluble intermediates like MHET (Palm et al., 2019).

The recognition and hydrolysis of PET by PETase have been demonstrated by structural studies. The enzyme is a member of the α/β-hydrolase family and has structural characteristics that allow it to work with the relatively stiff PET substrate (Chen et al., 2018). Researchers can now rationally engineer better enzymes thanks to more recent mechanistic studies that have provided comprehensive information about the chemical processes involved in PETase catalysis (Burgin et al., 2024). Because PET degradation was no longer limited to environmental phenomena, this discovery revolutionized the field. It might develop into an industrial process that is engineered.

6. From Natural Enzymes to Engineered "Plastic-Eating" Machines

For industrial use, natural plastic-degrading enzymes are frequently too slow, unstable or substrate-specific. Enzyme engineering has therefore become one of the most rapidly developing areas of plastic biotechnology (Lu et al., 2022). An essential model for PET recycling is the LCC enzyme, a cutinase that was first discovered in Thermobifida and related microbes (Tournier et al., 2020) engineered a PET hydrolase capable of achieving high PET depolymerization under optimized conditions, demonstrating that enzymatic recycling could approach practical processing rates.

Computational protein engineering has further (Cui et al., 2021) used a computational restructure strategy to improve PETase performance under ambient conditions while (Lu et al., 2022) demonstrated that machine learning could help identify combinations of mutations producing significantly improved PET-degrading enzymes. Other studies have investigated fusion proteins, surface display and enzyme immobilization. To increase access to highly crystalline PET, PETase has been displayed on engineered cells or combined with hydrophobin (Chen et al., 2022). Additionally, cross-linked enzyme aggregates have been studied to improve PETase degradation performance, stability and reusability (Lee et al., 2024).

More recently, scientists have created PETase that can operate in environments more similar to actual plastic waste. A thermostable PETase that was discovered from a geothermal

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ISSN: (e) 3007-1607 (p) 3007-1593

metagenomic resource and demonstrated activity toward post-consumer PET at high temperatures was reported in a 2025 study. Enzymes that can withstand temperature, crystallinity, impurities and repeated processing cycles are necessary for industrial PET recycling, which makes these advancements crucial. These days, the field is expanding beyond traditional protein engineering to include directed evolution, metagenomics, machine learning, immobilization and synthetic biology. The goal is now to create a biological system that can process plastic quickly, selectively and repeatedly rather than just finding a microbe that consumes plastic.

7. What Happens Inside the Insect Gut?

The gut of an insect offers a unique setting for the interaction of microbial metabolism and host physiology. Chewing plastic can increase its surface area once it enters the stomach and digestive processes may cause chemical changes that increase the polymer's accessibility to microbes (Vital-Vilchis & Karunakaran, 2025). In mealworms and superworms, the significance of the microbiome is especially evident. The composition of gut microorganisms in mealworms can be quickly altered by plastic feeding and new research suggests that microbial communities linked to plastic may form within hours of exposure (Zhang et al., 2024).

Metagenomic analysis has shown alterations in the microbial community in superworms after Styrofoam feeding and identified functional genes potentially associated with polymer transformation (Sun et al., 2022). These results imply that insects might serve as ecological selectors, enhancing microbial populations that can endure or thrive in the presence of plastic. The waxworm is one particularly fascinating example. Research has shown that the gut mellant antibiotics. However, the discovery that waxworm saliva itself can oxidize PE demonstrates that microbial metabolism is only one component of the system (Sanluis-Verdes et al., 2022).

In the gut of waxworms, bacteria like Enterococcus, Pseudomonas and Bacillus have been linked to PE and PS transformation, according to recent research (2025). These findings are consistent with a model in which microbial communities metabolize smaller oxidized products while host enzymes initiate or facilitate polymer modification. The most intriguing implication is that the insect might not have to be the last organism involved in waste treatment. Alternatively, insects can serve as biological discovery platforms for the identification of microbial consortia, metabolic pathways and enzymes that can be isolated and modified for industrial use.

8. Different Plastics Require Different Biological Solutions

It is never appropriate to assume that all plastics can be broken down by microbes or insects. The strongest biodegradation currently represents the strongest biodegradation. PET contains hydrolysable ester bonds and the PETase MHETase pathway provides a relatively well-characterized route toward its monomers (Palm et al., 2019). Major research challenges now involve improving activity against highly glassy PET, increasing thermostability and processing real post-consumer materials (Ermis, 2025). Because its carbon-carbon backbone lacks easily hydrolysable bonds, PE is still far more challenging. Oxidation is an essential initial step, according to evidence from Rhodococcus, Bacillus, insect-associated bacteria and waxworm enzymes (Tao et al., 2023).

However, the mineralization of mineralization of mineralization of mineralization of mineralization of mineralization of mineralization is still remains. Because expanded polystyrene can be consumed by mealworms and superworms, PS has drawn a lot of attention. Studies have shown the involvement of gut microbes and the isolation of PS-transforming bacteria like Pseudomonas and Exiguobacterium (Kim et al., 2020). Recent work has also identified bacterial isolates from mealworm guts capable of introducing hydroxyl groups into PS and producing quantifiable weight loss (Lin et al., 2024).

PP is another challenging polyolefin because of its chemically stable carbon backbone. Recent reviews specify that PP biodegradation remains considerably less understood than PET degradation (Dhali et al., 2024). Nevertheless, bacterial studies have stated measurable PP transformation, including recent work with mangrove-derived bacteria (Zhong et al., 2024). Because chlorine-containing chemistry produces

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ISSN: (e) 3007-1607 (p) 3007-1593

potentially hazardous intermediates and makes biological treatment more difficult, PVC poses additional difficulties.

However, bacterial degradation of PVC microplastics under controlled conditions has been reported in recent metagenomic research, indicating that even highly persistent polymers may be biologically transformable under specific conditions. Because polyurethane is chemically diverse, the presence of ester, ether or other linkages has a significant impact on biodegradation. Bacterial and fungal enzymes including esterases, proteases and urethanes have been investigated, but complete degradation of many commercial polyurethane materials remains difficult (Bhavsar et al., 2023).

9. From Laboratory Discovery to Real-World Solution

The transition from laboratory experiments to environmental applications represents the greatest contest for this field. Pure plastic films, comparatively high microbial densities, regulated temperature, plenty of oxygen and carefully chosen culture conditions are all used in numerous published experiments. Genuine plastic waste is far more intricate. Polymers, pigments, plasticizers, stabilizers, food residues, metals, biofilms and other impurities are mixed together in it. Crystallinity of polymers is also important. Enzymes are much less active against highly crystalline material, but they can attack amorphous PET quickly (Lu et al., 2022). In a similar vein, weathering might increase PE's chemical accessibility, so laboratory tests utilizing artificially oxidized plastic might not accurately reflect untreated waste.

An additional issue is measurement. A decrease in plastic mass does not necessarily demonstrate mineralization. Plastic may be made of plastic. Given the evidence that bacterial erosion of PS can produce microplastic and nano plastic particles during degradation, this issue is particularly crucial. For these reasons, before claims of plastic biodegradation are deemed definitive, recent systematic evaluations have demanded standardized procedures, more robust controls, isotope tracing, molecular-weight analysis and improved mass-balance measurements (2025). Environmental factors are also important. Degradation can be significantly impacted by temperature, pH, salinity, oxygen concentration, nutrients, and microbial competition. In soil, saltwater, or landfills, a bacterial strain that thrives in a nutrient-rich lab flask might not do well.

Therefore, rather than focusing on the question "Can this organism degrade plastic?" future research should consider more pertinent questions like: How quickly does it operate? What proportion of carbon in polymers is truly absorbed? What products are produced? Are hazardous intermediates created? Does the realistic degradation under realistic degradation continue under realistic degradation? Is it possible for the organism? Can mixed plastic waste be handled by the process? Is it possible to recover the products and turn them into new materials? Whether biological degradation becomes biotechnology or just an intriguing observation in the lab depends on these questions.

10. The Most Promising Future: Microbes + Enzymes + Synthetic Biology

It is unlikely that releasing large populations of organisms that consume plastic into the environment will be necessary for biological plastic management in the future. Finding their biochemical machinery and transferring it into controlled systems is a more practical approach. This process is already being accelerated by metagenomics. Instead of culturing every microorganism individually, researchers can sequence entire microbial communities and search for genes encoding potential plastic-active enzymes (Wang et al., 2026). This approach is especially useful because many environmental microorganisms cannot easily be cultured under standard laboratory conditions.

Machine learning can then predict promising enzyme sequences and identify mutations that may improve catalytic performance (Lu et al., 2022). While synthetic biology can integrate enzymes into synthetic pathways, directed evolution can experimentally select improved variants. Microbial consortia designed as division-of-labor systems are one potential future tactic. One organism could oxidize PE, another could metabolize the resulting short-chain compounds, while a third could convert the carbon into useful products. Forcing such systems may be more than one single step.

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Another option is cell-free enzymatic recycling, which uses immobilized or purified enzymes to directly process plastic waste. Because enzymes may be recovered and reused, lowering processing costs, immobilized PETase are especially appealing (Lee et al., 2024). Destroying plastic shouldn't be the ultimate goal. The optimal result in a circular economy is the recovery of valuable chemical building blocks after depolymerization. For instance, it is theoretically possible to transform PET into ethylene glycol and terephthalic acid, which can be utilized to create new polymers instead of producing low-value waste. This distinction shifts the idea of plastic biodegradation from destroying plastic to resource recovery and biological depolymerization.

11. Environmental Safety and the Problem of "A Biological Solution"

It is not always the case that biological degradation is safe for the environment. Microorganisms may increase the concentration of smaller particles if they break up plastics without fully mineralizing them. Secondary environmental risks could arise from the treatment process if degradation releases additives or toxic intermediates. This is why the bacteria should be evaluated; bacteria should be discovered. Microbial communities linked to plastic can affect polymer transformation, but they can also interact with metals, additives and other environmental pollutants, according to recent research (Wróbel et al., 2024).

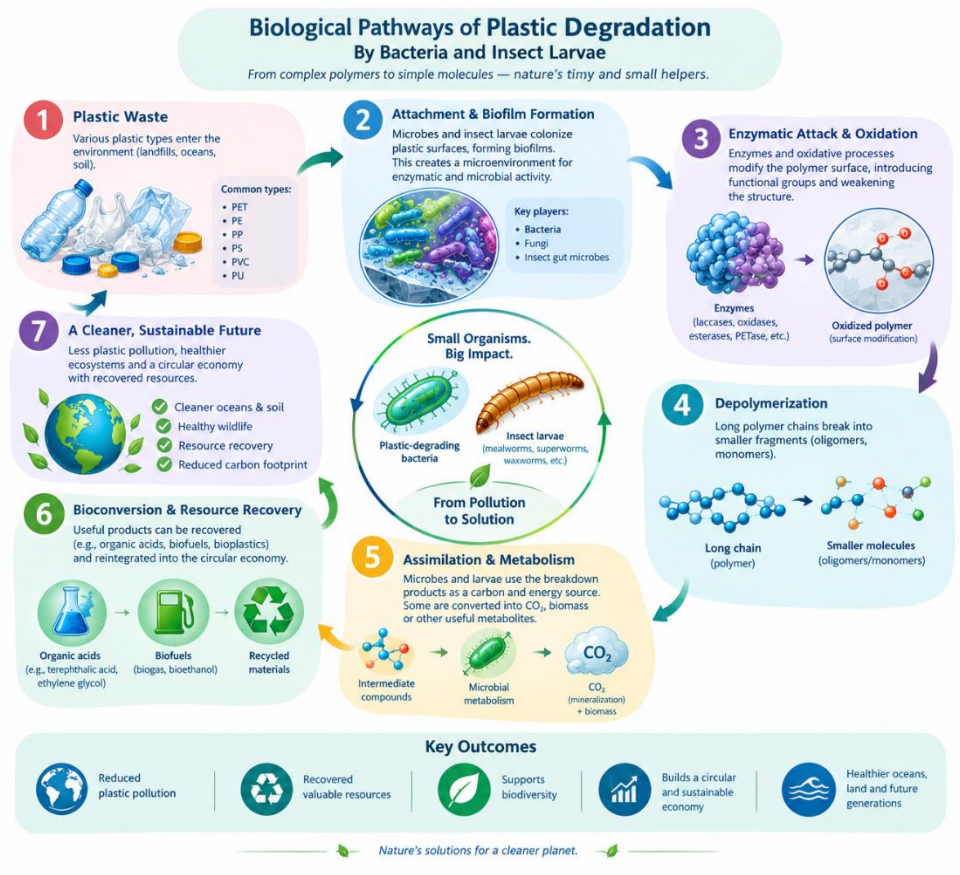


Figure 2. Biological pathway of plastic degradation.

Another concern is biosafety. Rather than being purposefully released into ecosystems, highly effective engineered microorganisms should typically be utilized in contained treatment systems. Because purified enzymes do not proliferate or spread like living things, enzyme-based therapy may eventually offer a safer option. Therefore, the biological solution should supplement rather than replace the most crucial actions, which include cutting back on needless plastic use, creating recyclable products, enhancing collection systems, boosting reuse and creating efficient mechanical and chemical recycling (Fletcher et al., 2023).

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ISSN: (e) 3007-1607 (p) 3007-1593

12. Future Perspectives

The future of plastic biodegradation will depend on moving from individual plastic-degrading organisms toward integrated biological systems that combine microorganisms, enzymes, insect microbiome interactions and advanced biotechnology. The use of insect larvae as biological models to identify host enzymes and gut microbes involved in polymer transformation is becoming more and more supported by recent research (Lin et al., 2024). Metagenomics, transcriptomics, proteomics and metabolomics can help identify previously unknown microorganisms, enzymes and metabolic pathways associated with plastic transformation. However, before their roles in plastic degradation can be established, many candidate genes found using omics approaches still need to be directly validated biochemically (Wang et al., 2026).

PET is one of the most likely to continue to continue to be one of the most important directions. Enzymes with increased catalytic activity, stability, and resistance to industrial conditions can be created by combining machine learning, directed evolution, protein structure prediction and computational screening (Burgin et al., 2024). Additionally, since the molecular mechanisms underlying the biological degradation of challenging polymers like polyethylene and polypropylene are still far less understood than those of PET, future research should concentrate more heavily on these polymers (Pérez-García et al., 2025).

The creation of microbial consortiums and enzyme combinations that can carry out sequential degradation steps is another top priority. Instead of searching for one microorganism capable of completely degrading a complex plastic, researchers may develop biological systems in which different microorganisms or enzymes perform complementary stages of polymer oxidation, depolymerization and metabolite conversion (Wróbel et al., 2024). Additionally, rather than focusing primarily on clean laboratory polymers, research should shift toward realistic plastic waste. Future research should examine aged materials, mixed plastics, additives, pigments, environmental pollutants, and actual post-consumer waste at pH, salinity, temperature, and nutrient levels that are relevant to the environment (Wang et al., 2026).

Equally crucial are standardized techniques for quantifying biodegradation. To prevent fragmentation from being mistakenly interpreted as full biodegradation, future research should incorporate polymer mass loss with molecular-weight measurements, chemical analysis of degradation products, isotope tracing and evidence of carbon assimilation (Pérez-García et al., 2025). The possibility of using insect larvae as controlled bioreactors also deserves investigation. The digestive enzymes and gut microorganisms of plastic-eating insects could be separated and added to contained treatment systems instead of releasing them into their natural habitats (Lee et al., 2024).

Ultimately, rather than being viewed as a stand-alone solution, biological plastic degradation should be combined with mechanical recycling, chemical recycling, waste reduction and circular economy tactics. Therefore, hybrid systems that combine biological depolymerization with downstream recovery and reuse of valuable chemical building blocks may be the most promising future strategy.

Conclusion

One of the main environmental issues brought on by contemporary material consumption is plastic pollution. Biological systems can interact with materials that were previously thought to be extremely resistant to natural degradation, as evidenced by the discovery of bacteria and insect larvae capable of changing particular plastic polymers. One of the best examples of how microbial enzymes can break down a persistent polymer into chemical components that can be recovered is found in research on Ideonella sakaiensis, PETase, and MHETase. Further research on mealworms, superworms, and waxworms has shown that mechanical processing, host-derived enzymes, and gut microbes can all work together to transform plastic. However, the data examined in this article demonstrates that plastic biodegradation is neither a universal nor an instantaneous process. Different polymers possess different chemical structures, and the mechanisms that work efficiently for PET cannot simply be transferred to polyethylene, polypropylene, polystyrene or PVC. Numerous documented

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ISSN: (e) 3007-1607 (p) 3007-1593

degradation processes may be significantly less effective in natural settings and also take place in highly regulated laboratory settings. Therefore, the most significant scientific opportunity is not just to discover more organisms capable of consuming plastic, but also to comprehend how they do so. Natural plastic-degradation phenomena can be turned into controllable biotechnology by combining microbial ecology, insect physiology, gut microbiology, enzyme discovery, structural biology, metagenomics, multi-omics, protein engineering, and synthetic biology. Long-term biological degradation could support a circular plastic economy, where challenging plastic waste is transformed into chemical resources that can be used again instead of just being moved from one environmental compartment to another. However, prevention, reduction, reuse, and traditional recycling will continue to be crucial elements of managing plastic waste. Therefore, the main takeaway from recent research is that plastic-eating organisms shouldn't be seen as a straightforward biological solution to plastic pollution. They provide biological knowledge, enzymes, and metabolic pathways that could help turn plastic waste from an ongoing environmental burden into a resource that can be recovered.

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Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

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