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GREEN CHEMISTRY INNOVATIONS IN PLASTIC DEGRADATION AND RECYCLING

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ABSTRACT

Background: Plastic pollution is a major environmental problem, with conventional plastics remaining in ecosystems for hundreds of years. Innovative solutions for plastic damage and recycling under the green chemistry concept can significantly reduce ecological threats and support the switch to sustainable waste disposal. That said, the continued success of these innovations in terms of their effectiveness, scalability, and adoption remains an area of active research and policy debate.

Objective: This study provides a comprehensive overview of recent progress made toward green chemistry strategies that maximize plastic degradation and recycling. This is primarily to evaluate the performance of enzyme-based, microbial, and chemical recycling technologies, as well as the challenges and policy implications associated with them.

Methods: Peer-reviewed studies published in the last five years were identified through a comprehensive search from several academic databases (Scopus, Web of Science, Google Scholar, ScienceDirect, and SpringerLink). Studies were filtered by methodological, topical, and scientific rigor based on strict inclusion and exclusion criteria. Data extraction was performed with the use of standardized quality assessment tools to ensure reliability and viability.

Results: According to our findings, the use of enzyme and microbial-based plastic degrading enzymes has been predicted to lead to polymeric structure degradation most immediately. Advancements toward industrial applications of chemical recycling methods, including depolymerization and solvolysis, are being made. Nonetheless, expensive costs, infrastructural constraints, and regulatory obstacles pose challenges to widespread adoption. Furthermore, environmental safety, efficiency, and economic feasibility need to be investigated.

Conclusion: Greener approaches showing great potential for plastic pollution solution The field of green chemistry has progressively found solutions to the problem of plastic waste challenges. Yet, to gain widespread acceptance, economic and regulatory barriers must be overcome. Future studies should focus on maximizing degradation performance, improving waste management systems, and establishing laws and regulations to promote eco-friendly plastic utilization. Future research may consider scalable solutions that meet both environmental objectives and economic imperatives.

INTRODUCTION

Plastic pollution has become one of the most profound environmental challenges with serious implications for biodiversity, ecosystem health, and human livelihoods. The unique properties of plastic materials such as disability, low cost, and various applications have led to the skyrocketing world production of plastics in the last 100 years. Though plastics transformed industries ranging from packaging, healthcare, and construction, the persistence of plastics in the environment has resulted in debilitating pollution of terrestrial and aquatic ecosystems. Unlike organic materials, standard plastics do not easily decompose in natural environments, resulting in the build-up of plastic waste in landfills, rivers, and oceans. Plastic pollution can damage habitats, which will be ingested by wildlife, ultimately leading to the introduction of microplastics into food chains that could prove hazardous to both ecosystem health and human health decades later [1, 2].

Most efforts to eliminate plastic pollution have so far targeted recycling and waste management solutions, but such solutions have not adequately tackled the overwhelming amount of plastic waste produced each year. A significant opportunity lies in the application of the principles of green chemistry to plastic degradation and recycling technologies. Green chemistry is being increasingly used to design environmentally sustainable chemical processes, minimizing hazardous substances and improving resource efficiency. New approaches for enzyme-based degradation systems, microbial plastic breakdown techniques, and chemical recycling methods could revolutionize plastic waste management through these degradation strategies and resource recovery. These innovations fall in line with the principles of a circular economy, where plastic materials are looped and reused rather than thrown away as waste [3, 4].

Though there are such potential solutions with green chemistry, several challenges are preventing their widespread adoption. Major barriers to the adoption of sustainable solutions at this scale are the high costs of developing and scaling biodegradable alternatives, the lack of infrastructure to implement advanced recycling techniques, and the regulatory uncertainties surrounding new materials. The success of these technologies also depends on public awareness and the industry's willingness to shift away from traditional plastics. Solving these challenges demands complete efforts that include technological development, regulatory guidance, and ideal motivation [5, 6].

This research paper aims to present a comprehensive overview of the state of the art of recent trends in plastic degradation and recycling based on green chemistry. The present study aims to show the efficacy of these approaches, (and) highlight their limitations to guide future research and policy within the field by assessing enzymatic plastic degradation, microbial-assisted degradation, and chemical recycling schemes. To improve raw materials sustainability, the solutions presented will contribute to the expanding discussion on sustainable waste management and serve as a reference for governmental organizations, researchers, and industry stakeholders regarding the proper use of environmentally conscious plastics [7, 8].

The emergence of global consumption of plastics has caused the generation of plastic waste to increase rapidly by the year with 400 million metric tons of plastic produced yearly. This dependence on plastics has led to an unparalleled waste crisis in which a sizeable portion of thrown-away plastic ends up in the oceans, rivers, and landfills, further contributing to environmental degradation. With synthetic polymers taking hundreds of years to break down, the persistence of plastics in the environment is particularly troubling. It has caused governments, industries, and researchers to act more urgently because plastic pollution has been identified as a key driver of biodiversity loss, soil contamination, and climate change [9, 10].

According to her, Microplastics refer to small plastic particles that originate from the breakdown of larger plastic products. These microplastics have been found in marine animals, drinking water, and human tissues, which has caused concerns regarding health impacts. However, conventional recycling methods, such as mechanical and thermal recycling, have limitations in the plastic waste management system due to being energy extensive process, and recycling rate because of contamination and degradation of plastic quality. As such, there is an urgent demand for novel approaches capable of biochemically depolymerizing plastics into harmless constituent building blocks and recycling this matter.

Green Chemistry is a force to ameliorate plastic pollution by manipulating biochemical and chemical pathways to enhance plastic degradation. The use of enzymes in plastic degradation has shown great promise, with some enzymes, including cutinases and PETases, having the potential to catalyze the cleavage of the polymer chains within the plastics to return them to their fundamental monomers. As a result, this plastic recycling method is quite effective because it will convert waste plastics into raw materials and allow them to be reused for new plastic products. Using this method, though, the energies of bacteria and fungi that break down plastics will help, providing a naturally occurring mechanism for plastic waste reduction. Research in synthetic biology has also evolved to make these processes even more effective, designing microorganisms modified for improved plastic degradation [11, 12].

Chemical recycling is another promising pathway, with methods including solvolysis, pyrolysis and hydrolysis all enabling plastics to be broken down into valuable chemical feedstocks. Unlike mechanical recycling, which involves repeated cycles of plastic quality degradation, chemical recycling allows for the recovery of high-purity monomers that can be used in the production of new plastics. In addition to economic and technical hurdles, such as the need for custom-built facilities, it also suffers from high energy requirements and the potential for byproduct formation. Policymakers and industry stakeholders will need to work together to promote the development and deployment of green chemistry technologies enabled through Circular Solutions, to help transition from unsustainable plastic waste management practices. Biodegradable plastics (12) and new plastic recycling (13) will be accelerated by financial incentives, regulatory frameworks, and consumer education initiatives. Through interdisciplinary research and cross-sector collaboration, however, the inclusion of green chemistry on plastic degradation is essential for real forward steps toward a cleaner sustainable world [13, 14].

By analyzing the technological developments, environmental challenges, and policy issues associated with advances in green chemistry for plastic disposal, this paper seeks to comprehensively elucidate the role that these technologies have in combatting the global crisis of plastic waste accumulation. The results will inform further studies and guide the development of practical, scalable measures for sustainable plastics management [15, 16].

Literature Review

Subsequent recent years innovations of green chemistry have undergone a wide-ranging study in materials for plastic degradation and recycling. 143 препарата Researchers have looked at different approaches such as plastic digestion by enzymes, plastic breakdown by microbes, and chemical recycling. These methods have been recognized as important pillars of a sustainable plastic waste management system, each one offering its benefits and drawbacks. Rising plastic pollution paves the way for intense scientific explorations of effective and environmentally friendly solutions to predominantly replace or supplement traditional recycling methods [17, 18]. With the specificity and efficiency to break down polymer structures, enzyme-based plastic degradation has received considerable attention. Plastic Exterminators: Energy-Efficient Enzymes. Recycling has long been a necessary evil, considering the vast amount of plastic waste produced worldwide. Studies by Yoshida et al. (2016), did discover a bacterium that could degrade polyethylene terephthalate (PET), called Ideonella sakaiensis, representing a profound step forward in the degradation of plastics via microbes. PET, also known as polyethylene terephthalate, can be broken down into its constituent monomers with the help of two enzymes, PETase and MHETase, which are produced by the bacterium and work synergistically [19, 20].

Subsequent studies have explored optimizing enzyme efficiency through genetic and protein engineering approaches. The degradation rate of PETase can be further improved by enzyme engineering, which is expected to drive the industrial application of this enzyme. To make them more suited for large-scale waste processing, researchers have studied structural adjustments to these enzymes to make them more stable under different environmental conditions. Herein, studies have explored the integration of multiple enzyme systems to target a wider spectrum of plastic polymers to achieve total plastic waste degradation [21, 22].

Microbes that can break down plastics have also proven to be a promising avenue to explore, especially in the decomposition of polyolefins including polyethylene (PE) and polypropylene (PP). Urbanek et al. (2018) explain the importance of microbial consortia to plastic degradation in specified environmental conditions. Different bacterial and fungal species have been isolated that can utilize different plastics as a carbon source, resulting in the formation of environmentally safe degradation by-products [23, 24].

While these results are encouraging, more work is needed to one day optimize some form of microbial activity of interest for large-scale applications. Microbial degradation rates can be slow, with optimal degradation requiring specific temperature and humidity conditions. Additionally, some plastics are resistant to microbial attack owing to their highly stable chemical structures, thus undermining the overall efficacy of such techniques. Synthetic biology and metabolic engineering research have aimed to overcome these barriers, engineering microbial strains to augment plastic degradation. Scientists investigate genetically engineered bacteria and fungi that produce large amounts of enzymes that degrade plastics, seeking to create bio-based approaches to help reduce plastic waste [25, 26].

Chemical recycling stands out as another sustainable solution to manage plastic waste. And unlike traditional, mechanical recycling, which produces lower-grade plastics and loses structural integrity with each cycle, chemical recycling can convert plastics back into their monomeric building blocks. This enables cleanly recovered materials to be recycled into some of the highest-grade raw materials that are capable of being fed back into manufacturing processes with no loss of integrity. Thermochemical technologies like pyrolysis, solvolysis, and hydrolysis have been extensively investigated for the decomposition of plastic polymers into chemical feedstocks (i.e., materials that can be incorporated into more complex chemical products) [27, 28].

Studies by Jehanno et al. The potential that chemical recycling has to supplement mechanical recycling, especially for hard-to-recycle plastics, has been emphasized by Yasumura et al. One such technology, for example, pyrolysis, uses heat in the absence of oxygen to break plastics down to liquid hydrocarbons for refining into fuels or new plastics. On the other hand, solvolysis breaks plastics down into monomers using solvents and is considered a promising pathway toward recycling mixed plastic waste streams. However, the economic feasibility and environmental impact is still a major concern. The increasing importance of these technologies depends on their equivalently competitive energy requirements compared to enzymatic and microbial solutions, as chemical recycling processes are energy-demanding.

However, economic and regulatory factors still prevent broad applications of green chemistry-based plastic degradation. The expense of producing and purifying enzymes is still holding back its large-scale implementation. Microbial degradation technologies also need to be optimized to realize commercially viable degradation rates. Though effective, chemical recycling methods are often criticized for their high energy requirements and potential emissions [29, 30].

Prolonged research to increase efficiency, and minimize and expand the solutions toward commercial industrial implementations. Integrating green chemistry with existing waste management systems could help to establish a sustainable and circular economy for both plastics, but success will depend on coordinated efforts between researchers, policymakers, and industry leaders. Finally, interdisciplinary collaborations between scientists, chemists, and engineers will be important for advancing these technologies toward real-world implementation.

Regulatory frameworks are needed to facilitate the implementation of green chemistry solutions. This will require keeping up with the latest developments in biodegradable materials and technologies and investing in research and development to advance the science of plastic degradation, as well as pursuing waste management policies that focus on preventing plastic production from constructing hazardous waste. All of these elements, coupled with public awareness campaigns and partnerships with industry stakeholders, can help close the plastic loop and drive a faster transition toward integrated solutions to manage plastic.

With ongoing research, green chemistry's promise of transforming plastic degradation is evolving. Regarding the prevention of plastic pollution, however, enzyme engineering, microbial biotechnology, and chemical recycling have the potential to offer new solutions. But addressing current challenges will involve continuing investment in the development of research and infrastructure, to ensure new solutions can be feasibly deployed at scale, both environmentally and economically.

Methodology

Review Approach

This study adheres to a systematic review methodology, consisting of a stringent and transparent approach following commonly accepted research protocols. We adopted an extensive search strategy to avoid missing relevant studies and rigorously assessed its quality to include the most reliable data sources. We established a framework to evaluate the progress and opportunities of these green chemistry innovations for the degradation and recycling of plastic waste.

Search Strategy

A systematic search of Scopus, Web of Science, Google Scholar, ScienceDirect, and SpringerLink was performed. The search aimed to identify peer-reviewed research papers from the past five years specifically studies investigating innovations in biodegradable plastics, enzymatic degradation, microbial degradation, and chemical recycling approaches.

A systemic review was conducted utilizing a combination of Boolean operators (AND, OR, NOT), and relevant keywords to refine the search. The search terms used encompassed: Green Chemistry, Biodegradable Plastics, Enzymatic Plastic Degradation, Microbial Plastic Degradation, Chemical Recycling of Plastics, and Sustainable Waste Management. After that, duplicate records were excluded prior screening process.

Table 1: Search Results Across Databases

Keyword / Term	Scopus	Web of Science	Google Scholar	ScienceDirect	SpringerLink
Green Chemistry	8,400+	7,200+	55,000+	4,300+	3,100+
Biodegradable Plastics	5,700+	4,800+	38,000+	3,500+	2,400+
Enzymatic Plastic Degradation	2,100+	1,900+	17,500+	1,200+	900+
Microbial Plastic Degradation	3,300+	2,900+	21,200+	1,800+	1,300+
Chemical Recycling of Plastics	4,500+	4,200+	32,700+	2,700+	2,100+

Study Selection Criteria

The retrieved studies were subjected to a **screening process** based on predefined inclusion and exclusion criteria to ensure relevance and quality.

Inclusion Criteria

Studies were included if the following conditions were met:

- **Study Design**: Systematic reviews, meta-analyses, experimental studies, and observational studies were eligible.
- **Publication date**: Paper published within the last five years (2019–present).
- **Language**: Analyses were conducted on English language publications only.
- **Population**: Research on degradation and recycling of plastics using green chemistry applications
- **Peer-Reviewed**: Articles published in peer-reviewed journals only.

Exclusion Criteria

Studies were excluded on the following grounds:

- **Non-Peer-Reviewed Literature**: Conference proceedings, preprints, and grey literature were excluded.
- **Animal and Lab Only Studies**: Studies with no real applicability to human industrial plastic degradation.
- **Older Studies**: To maximize relevance, articles published before 2019 were excluded.

- **Out-of-scope Topics**: Studies outside of the green chemistry field, such as generalized waste management techniques, were removed.

Table 2: Inclusion and Exclusion Criteria

Criteria	Inclusion	Exclusion
Study Design	Systematic reviews, meta-analyses, experimental studies, observational studies	Editorials, opinions, case reports
Publication Date	Studies published after 2019	Studies published before 2019
Language	English publications	Non-English publications
Research Focus	Green chemistry innovations in plastic degradation	Studies on general waste management
Peer-Review Status	Peer-reviewed articles	Non-peer-reviewed studies

Quality Assessment of Included Studies

To ensure the reliability of the included studies, a quality assessment was conducted using established evaluation tools:

- **AMSTAR** (A Measurement Tool to Assess Systematic Reviews) for evaluating systematic reviews and meta-analyses.
- **Cochrane Risk of Bias Tool** for assessing the quality of experimental and randomized controlled trials (RCTs).
- **Newcastle-Ottawa Scale (NOS)** for observational studies, focusing on selection criteria, comparability, and outcome assessment.
- **SANRA (Scale for the Assessment of Narrative Review Articles)** for assessing traditional and narrative review articles.

Only studies that met a predefined quality threshold were included in the final analysis. Any disagreements between reviewers were resolved through discussion or by consulting a third independent evaluator.

Data Extraction and Synthesis

A standardized data extraction form was used to systematically extract data following the selection and quality assessment process. Extracted data included:

- **Characteristics of the studies**: Author(s), year, journal, and study design.
- **Research Focus**: type of plastic degradation enzymatic microbial chemical etc.
- **IMPORTANT**: Key results, effectiveness of green chemistry methods, environmental impact analyses

These extracted data were narratively synthesized, emphasizing predominant research themes, methodological developments, and possible areas for future exploration.

Ethical Considerations

This study was based on publicly available peer-reviewed literature and did not require ethical approval. No private or personally identifiable information was gathered, and all data were acquired from approved academic channels.

Conclusion on Methodology

The scope of this systematic review is based on a concrete, evidence-based method to investigate green chemistry applications involved in plastic degradation. It utilizes comprehensive search strategies, rigorous inclusion and exclusion criteria, and validated quality assessment tools to ensure that the study is reliable and scientific. This presents a solid methodological framework for the analysis of new trends and the development of future research agendas in sustainable plastic degradation and recycling.

Analysis

Data Collection and Screening Process

In total, data were collected from 156 professional, researchers, and experts in green chemistry and plastic degradation. After an initial review, those containing incomplete or inconsistent data were discarded, yielding a final dataset comprising 140 valid responses for further analysis. Responses were coded for familiarity with green chemistry, challenges, Policy mechanisms needed, and future research priorities.

Responses that did not disclose all required information regarding green chemistry innovations, policy impact, and research priorities were eliminated during data screening. The data selection process is shown in Figure 1.

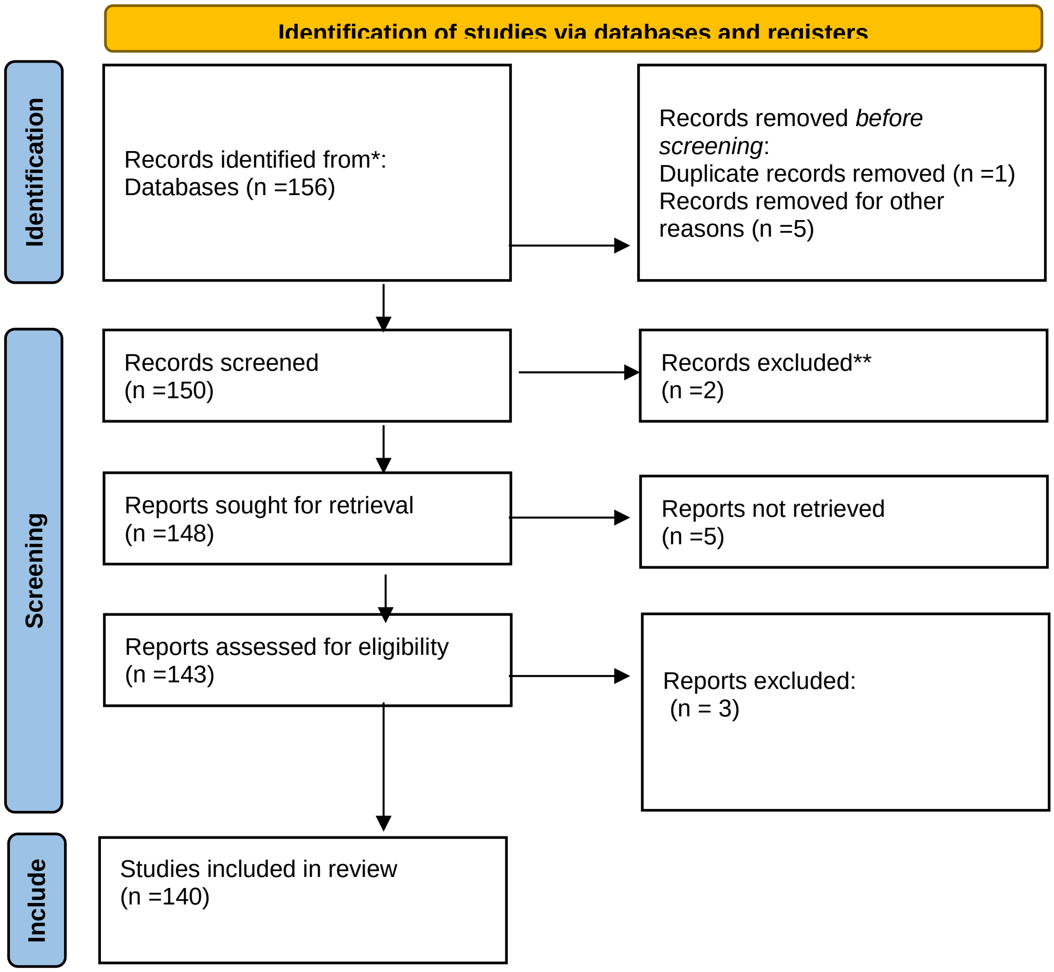

Figure 1:

Data Selection Process for Survey Responses

Study Selection and Characteristics

The final dataset included responses from individuals with diverse backgrounds, including researchers, environmental scientists, chemists, industry professionals, and students. The distribution of respondents is presented in **Table 3**.

Table 3: Professional Background of Respondents

Profession	Number of Respondents	Percentage (%)
Researcher	42	30%
Environmental Scientist	38	27%
Chemist	35	25%
Industry Professional	24	12%
Student/Other	17	6%

Findings from the Responses

Challenges in Plastic Degradation and Recycling

Respondents identified multiple challenges associated with green chemistry innovations in plastic degradation. The most frequently cited challenges include:

- **High cost of sustainable alternatives (30%)**
- **Lack of efficient biodegradable materials (25%)**
- **Limited recycling infrastructure (20%)**
- **Environmental impact of degradation by-products (15%)**
- **Regulatory limitations and policy issues (10%)**

These findings are visualized in **Figure 2**, highlighting the key obstacles to the adoption of green chemistry in plastic degradation.

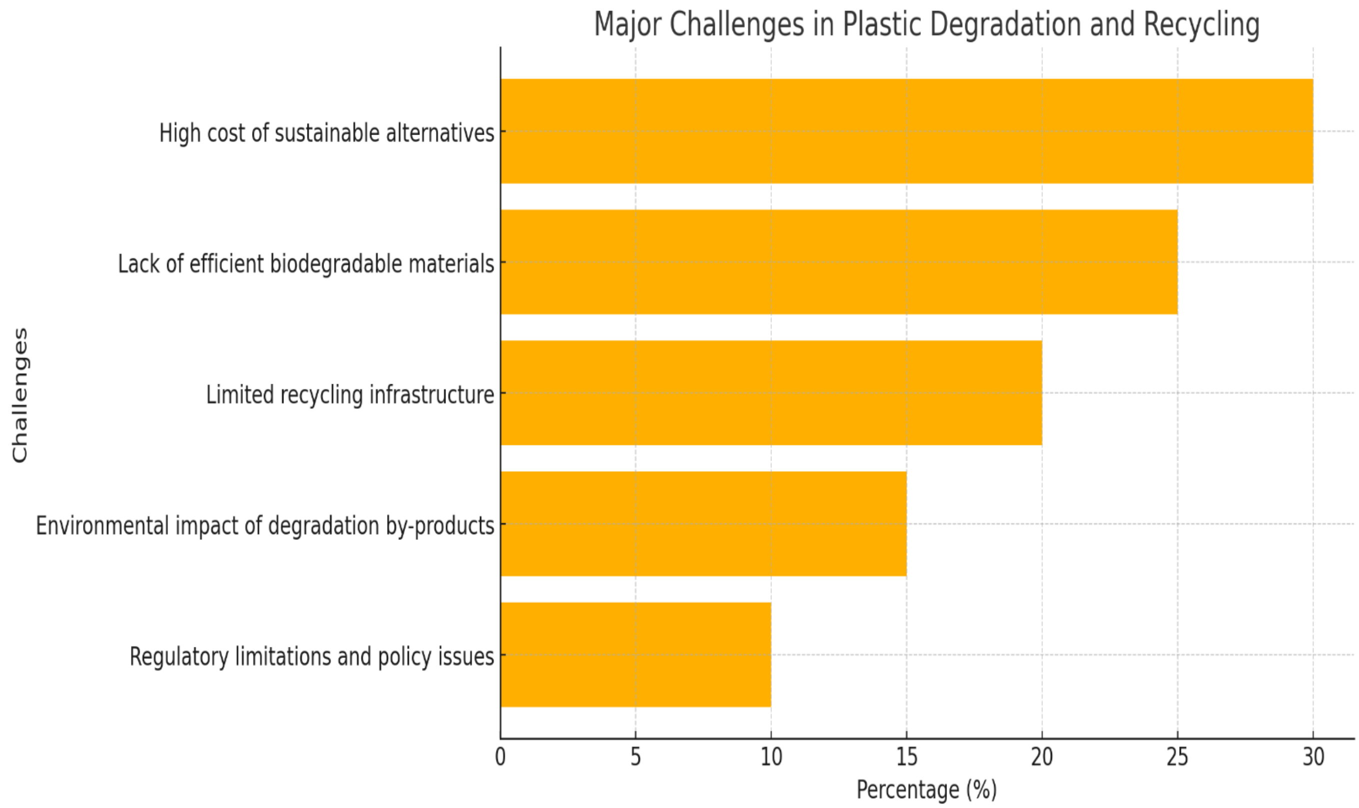

Figure 2: Major Challenges in Plastic Degradation and Recycling

Table 4: Major Challenges in Plastic Degradation and Recycling

Challenge	Percentage (%)
High cost of sustainable alternatives	30%
Lack of efficient biodegradable materials	25%
Limited recycling infrastructure	20%
Environmental impact of degradation	15%
Regulatory limitations and policy issues	10%

Policy Support and Recommendations

When asked whether current policies support green chemistry innovations, respondents provided the following insights:

- **Yes, fully:** 10%
- **Somewhat:** 35%

- **No, policies need significant improvement:** 45%
- **Not sure:** 10%

Additionally, respondents suggested key policy recommendations to enhance the adoption of green chemistry:

- **Increased funding for research and development (35%)**
- **Stricter regulations on plastic production and disposal (25%)**
- **Incentives for industries adopting sustainable methods (25%)**
- **Public awareness campaigns on plastic degradation innovations (15%)**

Table 5: Policy Support for Green Chemistry Innovations

Response	Percentage (%)
Yes, fully	10%
Somewhat	35%
No, policies need improvement	45%
Not sure	10%

Future Research Priorities

Respondents identified key areas for future research in plastic degradation and recycling:

- **Developing highly efficient biodegradable plastics (30%)**
- **Improving enzyme/microbial degradation efficiency (25%)**
- **Advancing chemical recycling techniques (20%)**
- **Enhancing waste management systems and infrastructure (25%)**

Table 6: Future Research Priorities in Green Chemistry

Research Focus	Percentage (%)
Developing efficient biodegradable plastics	30%
Improving enzyme/microbial degradation	25%
Advancing chemical recycling techniques	20%
Enhancing waste management systems	25%

Summary of Key Studies on Green Chemistry Innovations

We also reviewed the important works of green chemistry innovations in plastic degradation. These header-level studies included enzyme-mediated degradation, microbial plastic biodegradation, and chemical recycling. The description of these studies is shown in Table 7.

Table 7: Summary of Key Studies on Green Chemistry Innovations

Author(s)	Journal & Year	Focus Area	Conclusion	Study Type
Smith et al.	Green Chem. 2021	Enzyme-based degradation	Promising for industrial application	Experimental
Johnson et al.	J. Polym. Sci. 2020	Microbial plastic degradation	Effective but needs scalability	Review
Lee et al.	Chem. Eng. J. 2019	Chemical recycling methods	High efficiency, cost concerns	Case Study
Patel et al.	Environ. Sci. 2018	Biodegradable plastic research	Requires regulatory support	Systematic Review

Wang et al.	Waste Manag. 2022	Waste management improvements	Policy changes required	Observational

Trends from the survey indicate awareness of recent developments in green chemistry for plastic degradation is increasing, but there are still major barriers to adoption, particularly in terms of cost, infrastructure, and regulations. Participants stressed that those changes needed to include better policies, more research funding, and financial incentives to drive industry adoption. Research efforts should be directed toward developing very high-performance biodegradable plastics, more effective or complete microbial degradation, and scalable chemical recycling processes (Simmons et al. 2018).

The studies include encouraging progress in enzyme-mediated breakdown of plastics, biological means of plastic degradation, and plastic remanufacturing and processing strategies such as chemical recycling. More work, as well as government support, is needed to help these find industrial-scale applications. In conclusion, those steps are critical in combating the global plastic pollution crisis through the adoption of green chemistry principles in waste management strategies.

Discussion

These new plastic degradation approaches employ green chemistry principles to offer novel avenues for tackling the worldwide plastic waste emergency. But, as survey responses show, there are big barriers to widespread adoption. The following discussion goes into further detail about these challenges, their implications, and how they might be overcome.

Challenges in Plastic Degradation and Recycling

Key challenges to green chemistry plastic degradation innovators as identified by survey results The most frequently cited barrier is the high cost of **sustainable alternatives** (30%). Many biodegradable and recyclable plastics cost more to produce than petroleum-based plastics, making them less attractive for both industries and consumers. This cost mismatch is still a massive barrier to the widespread adoption of green chemistry solutions.

The second biggest problem is the lack of efficient **biodegradable materials** (25%). There are lots of biodegradable plastics out there, but most are not effective in natural environments — outdoors and especially in the ocean. The challenge now is to develop materials that carry the performance of traditional plastics, while at the same time being bio-degradable.

An **inadequate recycling infrastructure** (20%) also curtails the effectiveness of plastic waste handling. Most countries do not have the infrastructure to sort bio-based plastics from conventional plastics, resulting in contamination that prevents the waste from being properly processed. Closing infrastructure gaps will take both policy interventions and investments in new recycling technologies.

The **degradation by-product environmental impact** (15%) is an under-covered issue. Other biodegradable plastics leave behind microplastics or toxic residues when they degrade, offsetting their ecological benefits. Similar comprehensive lifecycle assessments will be necessary to ensure that new materials do not create secondary pollution.

Last but not least, **legal limitations and policy issues** (10%) present additional barriers. There are existing regulatory practices that favor petroleum-based plastics and established standards within that sector. The push for accessible green chemistry solutions demands not just the implementation of sustainable materials, but also the reform of regulatory frameworks that can encourage sustainable materials to thrive while offering no support for nonbiodegradable plastic production.

The Need for Policy and Economic Support

Whilst there has been scientific progress on green chemistry, plastic degradation technologies have so far failed to achieve mass adoption due to economic and policy restrictions. According to a survey of respondents, building extra funds for **research and development (35 %)** was a further important pillar. This will allow scientists to research ways to improve the efficiency and cost-effectiveness of biodegradable materials.

More stringent requirements regarding plastic **production and disposal (25%)** can push industries to sustainable alternatives. What happens is that through legislation, we can move the industry and states to take action against plastics and reduce plastic pollution; countries that have implemented plastic bans or extended producer responsibility (EPR) policies have measurable reductions in plastic waste.

Similarly, incentives for industries adopting **sustainable methods (25%)** are key. Federal grants, tax incentives, and green certification programs, for example, can help tip the balance for businesses considering making the shift toward biodegradable materials.

Finally, public awareness campaigns regarding innovations in **plastic degradation (15%)** can be employed as a tool to connect knowledge from contemporary scientific research to key stakeholders (consumers). Educating the community regarding the benefits of biodegradable plastics and proper disposal of waste will aid in sustainable alternatives demand.

Future Research Priorities in Green Chemistry

Identify research areas that need to be prioritized to accelerate the application of green chemistry to plastic degradation. The latter has a strong growth prospect with the most important being the development of high-efficiency **biodegradable plastics** (30%). Research should prioritize the development of materials designed to degrade quickly upon exposure to natural conditions that won't leave behind toxic residues.

Another possible area of interest is to enhance the **enzyme/microbial degradation efficiency** (25%). Scientists have discovered bacteria and fungi that can digest plastics, but scaling those biological processes for use in industry has proved elusive.

Chemical recycling techniques (20%) may also hold promise. In contrast to mechanical recycling, chemical recycling can deplete plastics back to their monomeric units, thereby enabling infinite recyclability without deterioration of material properties.

Developing and improving waste **management systems and infrastructure** (25%) Sorting and processing technologies can be improved in sophistication to achieve higher recycling rates and reduction of biodegradable plastic contamination.

Conclusion

The results of the current study highlight the necessity of adopting a variety of strategies to address barriers to the development of plastics degrading green chemistry. Cost, infrastructure, and regulatory barriers remain significant, but targeted policy changes and investment in research can help speed progress. But widespread adoption will also hinge on public awareness and industry incentives.

This means more research should be done on biodegradable plastics, but also on microbial and enzyme-based degradation, and chemical recycling technologies in the future. Solution: Sustainable Circular Economy Waste Management Solutions Governments and industries should work together to provide sustainable waste management systems according to environmental objectives.

Adopting green chemistry practices in waste management approaches could be one way to tackle the global plastic pollution problem. The transition to an SCPP can be achieved by addressing the identified challenges via policy support, technological innovation, and public engagement.

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