Perspective

Neuroscience

Is There Hope to Switch Traditional Plastics into Sustainable?

Leonie Schäfer*
Freie Universität Berlin, Kaiserswerther Straße 16–18, 14195 Berlin, Germany
*: All correspondence should be sent to: Dr. Leonie Schäfer
Author's Contact: Dr. Leonie Schäfer, Ph.D., E-mail: lschafer1@gmail.com
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Plastics, once hailed as revolutionary materials, have become one of the greatest environmental burdens of modern society. The global reliance on petroleum-based plastics, driven by durability, affordability, and versatility, has fueled exponential growth in production but also intensified ecological damage. Microplastics pollute ecosystems, greenhouse emissions accelerate climate change, and waste management systems are overwhelmed. Yet, a paradigm shift is emerging: the pursuit of sustainable alternatives. From bioplastics derived from renewable biomass to recyclable and biodegradable polymers, innovation is accelerating. Governments are enacting stricter regulations, industries are investing in circular economy strategies, and consumers are increasingly demanding greener choices. Still, challenges persist, including scalability, cost competitiveness, infrastructure readiness, and the real environmental trade-offs of "green" plastics.

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PLASTICS represent both the marvel and menace of human innovation. Born in the early twentieth century, synthetic polymers promised an era of lightweight, durable, and versatile materials that could transform industries (Sohn et al., 2020). From medical devices to packaging, construction to electronics, plastics became embedded in modern civilization. Global plastic production surged from 2 million tons in 1950 to over 400 million tons in 2022, a figure projected to triple by 2060 if current trends continue (Liu et al., 2025). Yet the very properties that make plastics indispensable—resilience, low cost, and durability—also make them environmentally destructive. Single-use plastics dominate waste streams, oceans are littered with microplastics, incineration releases toxins, and fossil fuel extraction feeds a vicious cycle of emissions (Iroegbu et al., 2021). The world now confronts a pressing question: can humanity switch from traditional plastics to sustainable alternatives before the damage becomes irreversible?

To understand the urgency of finding alternatives, one must first acknowledge the scale and severity of plastic's environmental footprint. Traditional plastics, derived from petrochemicals, are engineered to resist degradation (Samir et al., 2022). A plastic bottle discarded today may persist for 450 years, fragmenting into microplastics that infiltrate soils, oceans, and even the human bloodstream (Helm et al., 2022). Scientific studies have identified microplastics in placental tissue, lung samples, and blood plasma, raising concerns about long-term health risks (Lotter et al., 2022). Plastics are also a carbon and energy burden. Nearly 99% of plastics are manufactured from coal, oil, or natural gas. Their life cycle—from extraction to production, transportation, and disposal—contributes significantly to greenhouse gas emissions (Jambeck & Walker, 2023). Plastics could account for up to 13% of the global carbon budget by 2050 if left unchecked. Waste management systems further illustrate the crisis (Xayachak et al., 2023). Only about 9% of global plastics are recycled, while the rest are incinerated, landfilled, or leaked into the environment (Saleem et al., 2023). Recycling is hindered by contamination, mixed polymer streams, and the economics of sorting and processing. Moreover, downcycling, where plastics are turned into products of lesser quality rather than being reused for the same purposes, reduces their utility (Vats & Rissanen, 2016). Finally, the crisis is not just environmental but social. Plastic production facilities are often located near marginalized populations, exposing them to carcinogenic pollutants. Developed nations frequently export waste to less developed countries, exacerbating environmental injustice and creating global inequities.

The quest for sustainable plastics is driven by three major pathways: bioplastics derived from renewable biomass, biodegradable polymers, and circular economy approaches. Bioplastics are polymers derived from renewable resources such as corn starch, sugarcane, or algae (Lin et al., 2025). Polylactic acid (PLA), produced from fermented plant sugars, is already widely used in packaging and disposable utensils. Polyhydroxyalkanoates (PHA), generated by microbial fermentation, stand out because they can biodegrade even in marine environments. Other bioplastics, such as bio-PET and bio-PE, are chemically identical to conventional plastics but partially derived from renewable feedstocks, reducing reliance on fossil fuels (Altman, 2021). While these innovations lower carbon footprints and open new avenues for sustainable production, they also raise concerns. The use of agricultural feedstocks competes with food crops, strains water resources, and may drive deforestation (Zaimes et al., 2015). Production costs remain higher than for petrochemical plastics, limiting market competitiveness.

Another avenue is the development of biodegradable and compostable plastics. These materials are engineered to break down in industrial composting facilities and, in some cases, natural environments. However, biodegradability is highly context-dependent. Plastics that degrade under controlled composting conditions may persist in oceans or landfills (Choe et al., 2021). Mislabeling and consumer confusion about disposal often exacerbate waste problems rather than solve them. Parallel to these material innovations is the idea of circular economy strategies, which do not rely solely on replacing plastics but on redesigning systems to keep materials in circulation longer (Polyportis et al., 2022). Advanced recycling technologies such as enzymatic or chemical depolymerization can break plastics down to their basic monomers, allowing them to be reused at near-original quality (Vora et al., 2021). Deposit-return systems for beverage bottles, refill models for consumer goods, and packaging designed for recyclability are all part of a systemic rethinking of plastic's role.

Several powerful drivers support this transition. Governments worldwide are enacting stricter regulations, such as the European Union's Single-Use Plastics Directive, Canada's ban on plastic bags and straws, and California's packaging laws requiring reduced virgin plastic use (Hohn et al., 2020). Corporations are also pledging sustainability goals. Companies like Nestlé, PepsiCo, and Unilever are committing to fully recyclable, compostable, or reusable packaging by 2030 (Bocken et al., 2022). Start-ups are experimenting with alternatives such as seaweed-based wrappers, mushroom-based foams, and bacterial cellulose films. Scientific breakthroughs are accelerating progress as well. Enzymes capable of degrading polyethylene terephthalate (PET), algae-derived polymers, and even carbon dioxide–based plastics are moving from laboratory to pilot projects (Nikolaivits et al., 2021). Equally important is consumer behavior. Younger demographics are particularly eco-conscious, fueling demand for green alternatives and supporting zero-waste movements. Public awareness campaigns and grassroots initiatives are reshaping cultural norms about plastic use.

Despite the momentum, several challenges hinder a complete shift away from traditional plastics. Scalability and cost remain significant barriers. Conventional plastics are cheap and efficient, produced on a massive scale with decades of infrastructure backing (Shah & Gangadeen, 2023). Sustainable plastics often cost more, limiting adoption unless subsidies, incentives, or regulations intervene. Infrastructure is another major gap. Biodegradable plastics often require industrial composting facilities to realize their environmental benefits, but such facilities are scarce (Bos et al., 2024). Without appropriate waste management systems, biodegradable plastics end up in landfills where oxygen deprivation slows decomposition, or in recycling streams where they cause contamination. Even when biodegradable, plastics do not always break down harmlessly, as additives or residual fragments may persist (Geyer et al., 2017). Life-cycle analyses also reveal trade-offs. While bioplastics may reduce reliance on fossil fuels, their agricultural feedstocks demand land, water, and fertilizers, raising questions about biodiversity loss and food security. In some cases, the environmental footprint shifts rather than shrinks.

Performance limitations must also be considered. Certain applications demand properties not yet matched by sustainable alternatives. Medical devices, aerospace components, and electronics require extreme durability, chemical resistance, or heat tolerance (Totorica & Li, 2022). Substituting these with currently available bioplastics is impractical. Meanwhile, consumers face confusion over labels like "compostable," "biodegradable," and "bio-based." Greenwashing by corporations worsens the problem, creating a false sense of sustainability while actual benefits remain minimal. Without standardized definitions and transparent communication, consumer behavior may undermine waste management rather than improve it.

Case studies from around the world provide insight into both progress and limitations. PLA has been widely adopted in food packaging, but its reliance on corn competes with agriculture, and its inability to degrade outside specialized composting facilities reduces its ecological benefit (Moraczewski et al., 2025). PHA shows strong potential for marine applications given its true biodegradability in aquatic environments, but scaling microbial fermentation remains expensive and energy-intensive (Villano et al., 2013). Deposit-return schemes in Europe have demonstrated extraordinary success, with countries like Germany and Norway achieving more than 90% recycling rates for PET bottles, proving that well-designed systems can close loops even with conventional plastics (Pinter et al., 2021). Meanwhile, Coca-Cola's PlantBottle™, incorporating up to 30% bio-based PET, represents an incremental but significant improvement (Welle, 2011). While it is chemically identical to conventional PET, thus ensuring recyclability, critics argue that such partial measures cannot solve systemic issues without broader transformation.

So is there hope to switch traditional plastics into sustainable ones? The answer requires nuance. A wholesale replacement of petrochemical plastics is unlikely in the near future, given their entrenched role, economies of scale, and performance advantages. Yet there is hope in pursuing a multi-pronged strategy. Rather than expecting one sustainable material to replace all plastics, the future likely involves diversification. Different sustainable polymers will find their niches—PHA in marine applications, PLA in compostable packaging, bio-based PET in beverage containers—while traditional plastics remain in use but within stricter recycling frameworks. Government policies must continue to level the playing field, introducing taxes on virgin fossil-based plastics, subsidizing greener alternatives, and expanding waste management infrastructure. Corporations must accept extended producer responsibility, designing products with end-of-life in mind and investing in true closed-loop systems rather than symbolic greenwashed projects. Scientific and technological innovation must be continuously supported, pushing the boundaries of biotechnology, green chemistry, and waste-to-resource technologies. At the same time, cultural attitudes must shift. The plastic problem cannot be solved by materials alone. A society accustomed to convenience and disposability must learn to value reuse, minimalism, and collective responsibility.

The plastic crisis is one of the defining challenges of our century. Traditional plastics cannot continue unchecked without catastrophic ecological and social consequences. Yet the world is not without hope. Sustainable plastics are no longer a fantasy but a growing reality, propelled by scientific innovation, political will, market pressure, and cultural change. The transition will not be absolute or immediate but gradual, sector-specific, and systemic. The greatest hope lies not in a single new material but in the transformation of the systems through which humanity produces, consumes, and disposes of materials. The question is no longer whether humanity can afford to make the switch, but whether it can afford not to.■

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References

Altman, R. (2021). The myth of historical bio-based plastics. Science, 373(6550), 47–49. DOI: https://doi.org/10.1126/science.abj1003

Bocken, N. M., Harsch, A., & Weissbrod, I. (2022). Circular business models for the fastmoving consumer goods industry: Desirability, feasibility, and viability. Sustainable Production and Consumption, 30, 799–814. DOI: https://doi.org/10.1016/j.spc.2022.01.012

Bos, P., Ritzen, L., Van Dam, S., Balkenende, R., & Bakker, C. (2024). Bio-Based plastics in Product Design: the state of the art and challenges to overcome. Sustainability, 16(8), 3295. DOI: https://doi.org/10.3390/su16083295

Choe, S., Kim, Y., Won, Y., & Myung, J. (2021). Bridging three gaps in biodegradable plastics: Misconceptions and truths about biodegradation. Frontiers in Chemistry, 9. DOI: https://doi.org/10.3389/fchem.2021.671750

Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use, and fate of all plastics ever made. Science Advances, 3(7). DOI: https://doi.org/10.1126/sciadv.1700782

Helm, L. T., Murphy, E. L., McGivern, A., & Borrelle, S. B. (2022). Impacts of plastic waste management strategies. Environmental Reviews, 31(1), 45–65. DOI: https://doi.org/10.1139/er-2021-0117

Hohn, S., Acevedo-Trejos, E., Abrams, J. F., De Moura, J. F., Spranz, R., & Merico, A. (2020). The long-term legacy of plastic mass production. The Science of the Total Environment, 746, 141115. DOI: https://doi.org/10.1016/j.scitotenv.2020.141115

Iroegbu, A. O. C., Ray, S. S., Mbarane, V., Bordado, J. C., & Sardinha, J. P. (2021). Plastic Pollution: A perspective on matters arising: Challenges and opportunities. ACS Omega, 6(30), 19343–19355. DOI: https://doi.org/10.1021/acsomega.1c02760

Jambeck, J. R., & Walker-Franklin, I. (2023). The impacts of plastics' life cycle. One Earth, 6(6), 600–606. DOI: https://doi.org/10.1016/j.oneear.2023.05.015

Lin, J., Jaiswal, A. K., & Jaiswal, S. (2025). A critical review of consumer perception and environmental impacts of bioplastics in sustainable food packaging. Sustainability, 17(4), 1358. DOI: https://doi.org/10.3390/su17041358

Liu, C., Zhuo, Q., Ishimura, Y., Hotta, Y., Aoki-Suzuki, C., & Watabe, A. (2025). Regional insights on the usage of Single-Use plastics and their disposal in five Asian cities. Sustainability, 17(10), 4276. DOI: https://doi.org/10.3390/su17104276

Lotter, B., Konde, S., Nguyen, J., Grau, M., Koch, M., & Lenz, P. (2022). Identifying plastics with photoluminescence spectroscopy and machine learning. Scientific Reports, 12(1). DOI: https://doi.org/10.1038/s41598-022-23414-3

Moraczewski, K., Stepczyńska, M., Raszkowska-Kaczor, A., Szymańska, L., & Rytlewski, P. (2025). PLA/PCL Polymer Material for Food Packaging with Enhanced Antibacterial Properties. Polymers, 17(9), 1134. DOI: https://doi.org/10.3390/polym17091134

Nikolaivits, E., Pantelic, B., Azeem, M., Taxeidis, G., Babu, R., Topakas, E., Fournet, M. B., & Nikodinovic-Runic, J. (2021). Progressing Plastics Circularity: A Review of Mechano-Biocatalytic Approaches for Waste Plastic (Re)valorization. Frontiers in Bioengineering and Biotechnology, 9. DOI: https://doi.org/10.3389/fbioe.2021.696040

Pinter, E., Welle, F., Mayrhofer, E., Pechhacker, A., Motloch, L., Lahme, V., Grant, A., & Tacker, M. (2021). Circularity Study on PET Bottle-To-Bottle recycling. Sustainability, 13(13), 7370. DOI: https://doi.org/10.3390/su13137370

Polyportis, A., Magnier, L., & Mugge, R. (2022). Guidelines to Foster Consumer Acceptance of Products Made from Recycled Plastics. Circular Economy and Sustainability, 3(2), 939–952. DOI: https://doi.org/10.1007/s43615-022-00202-9

Saleem, J., Moghal, Z. K. B., Shakoor, R. A., Luyt, A. S., & McKay, G. (2023). Non-Wettable microporous sheets using mixed polyolefin waste for Oil–Water separation. Polymers, 15(14), 3072. DOI: https://doi.org/10.3390/polym15143072

Samir, A., Ashour, F. H., Hakim, A. a. A., & Bassyouni, M. (2022). Recent advances in biodegradable polymers for sustainable applications. Npj Materials Degradation, 6(1). DOI: https://doi.org/10.1038/s41529-022-00277-7

Shah, K. U., & Gangadeen, I. (2023). Integrating bioplastics into the US plastics supply chain: towards a policy research agenda for the bioplastic transition. Frontiers in Environmental Science, 11. DOI: https://doi.org/10.3389/fenvs.2023.1245846

Sohn, Y. J., Kim, H. T., Baritugo, K., Jo, S. Y., Song, H. M., Park, S. Y., Park, S. K., Pyo, J., Cha, H. G., Kim, H., Na, J., Park, C., Choi, J., Joo, J. C., & Park, S. J. (2020). Recent advances in sustainable plastic upcycling and biopolymers. Biotechnology Journal, 15(6). DOI: https://doi.org/10.1002/biot.201900489

Totorica, N., & Li, F. (2022). Signal and power integrity challenges for high density System-on-Package. Semiconductor Science and Information Devices, 4(2), 1–9. DOI: https://doi.org/10.30564/ssid.v4i2.4475

Vats, S., & Rissanen, M. (2016). Parameters affecting the upcycling of waste cotton and PES/CO textiles. Recycling, 1(1), 166–177. DOI: https://doi.org/10.3390/recycling1010166

Villano, M., Valentino, F., Barbetta, A., Martino, L., Scandola, M., & Majone, M. (2013). Polyhydroxyalkanoates production with mixed microbial cultures: from culture selection to polymer recovery in a high-rate continuous process. New Biotechnology, 31(4), 289–296. DOI: https://doi.org/10.1016/j.nbt.2013.08.001

Vora, N., Christensen, P. R., Demarteau, J., Baral, N. R., Keasling, J. D., Helms, B. A., & Scown, C. D. (2021). Leveling the cost and carbon footprint of circular polymers that are chemically recycled to monomer. Science Advances, 7(15). DOI: https://doi.org/10.1126/sciadv.abf0187

Welle, F. (2011). Twenty years of PET bottle to bottle recycling—An overview. Resources Conservation and Recycling, 55(11), 865–875. DOI: https://doi.org/10.1016/j.resconrec.2011.04.009

Xayachak, T., Haque, N., Lau, D., Parthasarathy, R., & Pramanik, B. K. (2023). Assessing the environmental footprint of plastic pyrolysis and gasification: A life cycle inventory study. Process Safety and Environmental Protection, 173, 592–603. DOI: https://doi.org/10.1016/j.psep.2023.03.061

Zaimes, G., Vora, N., Chopra, S., Landis, A., & Khanna, V. (2015). Design of sustainable biofuel processes and supply chains: challenges and opportunities. Processes, 3(3), 634–663. DOI: https://doi.org/10.3390/pr3030634