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Dos and Do Nots When Assessing the Biodegradation of Plastics

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The increasing pollution of aquatic and terrestrial environments by plastics has fueled discussions on the potential of using biodegradable instead of conventional, nonbiodegradable plastics to mitigate this pollution problem. While we consider these discussions helpful and forward-oriented, we recognized a number of recently published articles that fell short of adequately acknowledging fundamental principles of plastic biodegradation. We assign these articles to two categories. The first category consists of publications that claim to assess plastic biodegradation without providing the required experimental data (i.e., data on microbial assimilation of plastic carbon). Publications in the second category question the biodegradability of certified biodegradable plastics based on findings of insufficient biodegradation of these plastics in environments other than the ones for which the plastic was certified biodegradable. We are concerned that such publications—particularly when attracting significant media attention—misdirect the overall discussion on the role of biodegradable plastics in plastic pollution abatement, lead to misconceptions, and ultimately adversely impact the development of and the research on biodegradable plastics.

In this viewpoint we communicate our view on the "dos and do nots" in assessing and communicating plastic biodegradability. Our aim is to contribute to a constructive and fact-based discussion on the role biodegradable plastics can play in mitigating environmental plastic pollution.

Publications in the first category (i.e., papers that claim to assess biodegradability but provide no direct experimental evidence) highlight the need to emphasize that plastic biodegradation is a multistep process in which microorganisms in a plastic-receiving system metabolically utilize the organic building blocks of that plastic. The plastic is utilized both to gain energy under the formation of carbon dioxide in oxic (aerobic) systems and of carbon dioxide and methane in anoxic (anaerobic) systems and to form new cellular biomass. Therefore, assessing biodegradation of a given plastic first mandates quantitative measurements of the conversion of the plastic's carbon into CO_2 (or CO_2 and CH_4). Second, there must be a rigorous discussion of these respirometric data in the context of specific incubation conditions (e.g., time, temperature, relative humidity) and the key polymer-specific properties.[1] Such respirometric data and its discussion are currently missing for some products for which biodegradability has been claimed, including oxo-"bio"degradable plastics (i.e., formulations containing additives that supposedly render otherwise persistent plastics such as polyethylene completely biodegradable).[2,3] ASTM and ISO standards provide more detailed guidance for conducting and reporting on respirometric analyses in specific environments (Note: For biodegradability in composting environment refer to ASTM D6400 & D6868 (used in Americas-BPI certification), EN13432 (European certifications), ISO 17088, and ISO 18606. EN 17033 provides specifications for soil biodegradable agricultural mulch films. ISO 17556 and ASTM D 5988 provides test method for measuring plastics biodegradability in soil. ASTM D6691, D7991 and emerging ISO Standards provide test methods for measuring plastics biodegradability in marine environments. Most importantly, all these standards require demonstrating microbial utilization of the plastic through respirometric measurements). The analysis of evolved CO_2 (or CO_2 and CH_4) may be complemented by measuring the conversion of the plastic's carbon into microbial biomass. For the latter, we are convinced that the use of carbon isotope-labeled plastics is the best—if not the only valid—option, as recently demonstrated.[4] The experimental rigor of tracking the plastic's

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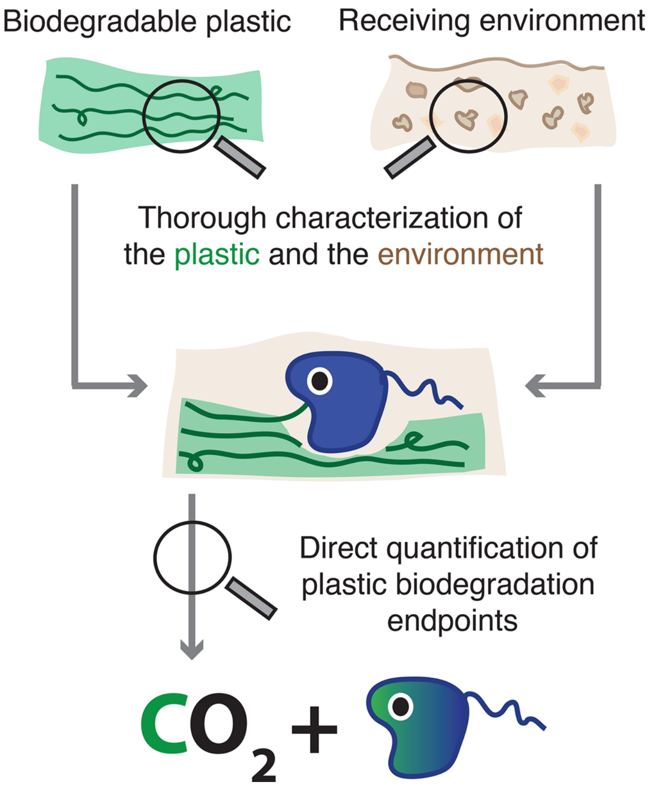
Environ. Sci. Technol. XXXX, XXX, XXX−XXX

carbon during biodegradation is equally required for assessing biodegradation of current as well as of future plastics. Importantly, experimental observations that are not directly related to the above-described microbial conversion of the plastic's carbon, such as visual disappearance of plastic, plastic mass loss, a decrease in the plastic's tensile strength, shortening of the average polymer chain length, or microbial growth, are all ill-suited to assess plastic biodegradation. Unfortunately, such experimental data is often falsely used to assess, report, and even claim biodegradability. Finally, it is crucial to recognize that the biodegradability of a plastic is entirely disconnected from the origin of the carbon in the plastic: while a biobased plastic might be nonbiodegradable, plastics based on fossil carbon may readily biodegrade or vice versa.

Studies that make up the second category (i.e., those that question biodegradability of certified biodegradable plastics based on experiments in receiving environments other than the one for which the plastic is certified biodegradable) ignore the fact that plastic biodegradability is not only a material property but also largely depends on the properties of the receiving environment (Scheme 1). Critical system factors include abundance and activity of microorganisms capable of utilizing the respective plastic, temperature, and oxygen and moisture levels. Therefore, any study assessing plastic biodegradation needs to provide rigorous data on key properties of both the plastic and the environmental system under study. The importance of taking into account system factors implies that claims such as "biodegradable" and "insufficiently biodegradable" are meaningful only when discussed in the context of the specific system in which biodegradation is assessed. This implies that the biodegradability of a plastic that was certified biodegradable in a given system (e.g., industrial compost or agricultural soil) cannot be called into question based on experiments that show that the same plastic insufficiently biodegrades in a different system (e.g., freshwater or the marine environment). The strong dependence of plastic biodegradation on system factors also mandates care when communicating the discovery of novel microorganisms—isolated from specific environments—that are capable of degrading plastics that are nonbiodegradable in most natural environments (e.g., poly(ethylene terephthalate)).[5] It is crucial to avoid the false conclusions that such microorganism will render nonbiodegradable plastics biodegradable in all environments. Instead, we believe that communications of such findings ought to focus on the exciting potential of such newly discovered microorganisms and their plastic depolymerases for plastic recycling in engineered systems.

Scheme 1. Assessing Plastic Biodegradation Demands a Thorough Characterization of Both the Material Properties of the Plastic and the Characteristics of the Receiving Environment, Given That Both Strongly Affect Plastic Biodegradation.[a]



[a]Assessing plastic biodegradation further mandates direct demonstration of microbial plastic utilization by quantifying conversion of the plastic's carbon into CO_2 (or CO_2 and CH_4 under anoxic conditions) using respirometric measurements. Respirometric analyses may be complemented by tracing the plastic's carbon into microbial biomass through the use of isotopically labeled plastics.

Biodegradable plastics are not the silver bullet for alleviating all problems associated with plastic pollution. Yet, for specific applications and end-of-life scenarios, others[6] and we see advantages in replacing nonbiodegradable plastics with completely biodegradable ones as an important step in alleviating environmental plastic pollution. Examples are plastics used as packaging materials that are designed to biodegrade in industrial composts and anaerobic digesters. At their end-of-life, such biodegradable−compostable plastics associated with food, paper, and biowastes can be diverted from landfills and open dumps to managed composting systems. Similarly, we consider the use of biodegradable instead of conventional plastics an environmentally responsible solution for some applications that require the use of the plastics directly in the environment. These applications include plastics used in agricultural food production (such as plastic mulch films covering agricultural soils) and plastics used in the marine environment (such as pots, nets, and buoys). Not only do plastic weathering and physical abrasion in these environments often make it impossible to recover all of the plastic after use, but also the fraction of plastic recovered is so heavily soiled that reuse and recycling are not viable options. Therefore, for all these applications, replacing conventional plastics with biodegradable plastics that completely biodegrade in the respective environments in a specified time is an important step in alleviating environmental plastic pollution.

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Notes
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