

Voices

Toward a circular economy for plastics

Reversing the extraordinary growth in the production and accumulation of primary plastics in the environment will require collaboration across research disciplines and scales—from the chemical building blocks to product life cycles, producer and consumer incentives, and waste management. After a recent Cell Press LabLinks symposium on the topic, this Voices asks the event participants: what are the major research priorities for moving toward a circular economy for plastics?



Eleni Iacovidou
Brunel University

Do we know enough about plastics?

Plastics are extremely useful materials (e.g., they're lightweight, cheap, durable, tough, and resistant), lending their use in a multitude of applications. But they have flaws too. They are made from crude oil and are pervasive and persistent in the environment. Although these flaws suffice to suggest that plastics cannot promote sustainability per se, their production, use, and end-of-life management represent opportunities to turn plastic's flaws into components of a circular plastic economy.

An excess of studies are now looking for the silver lining in promoting circularity for plastics. This includes replacing petrochemical-based plastics with bio-based alternatives, redesigning plastic packaging components to boost recycling rates, changing collection regimes to improve the quality of plastic waste collected, and introducing new technologies for the management of plastic packaging waste. Are these interventions sustainable though? Can they help us achieve circularity in the plastics system? Most importantly, is circularity the answer to plastic pollution?

Misperceptions, misguided opportunities, and challenges abounding at the production, consumption, and management stages could hinder instead of promote higher collection and recycling rates of plastic waste. Until we understand how these aspects prevent us from designing out waste and recovering maximum value from resources, our ability to plan ahead and craft a sustainable plastics system will be limited. The major research priority for moving toward a sustainable plastic economy is therefore to understand all aspects involved in plastic production, use, and management processes and the context in which circularity can flourish. Only then can we build the knowledge needed to deal with the multi-faceted challenges that currently hamper progress in closing the material, component, and product loops and help us to trigger transformational change.



Roland Geyer
University of California at Santa Barbara

Mostly a behavioral challenge

The reuse and recycling of plastics are certainly not without technical and operational challenges, and it is therefore worthwhile to continue the search for better collection, separation, and reprocessing technologies. Yet, the biggest circular economy challenges by far are of a behavioral nature, be it at the level of the individual or the aggregate market. In the end, whether circular business models succeed or not comes down to the individual and collective decisions we make—whether it is about the goods and services we purchase or the way we manage our end-of-life products. It is thus critically important that we develop a better understanding of the involved decision-making processes and their underlying drivers.

For me, the biggest priority is therefore to get the social sciences more involved in circular economy research. By that I mean not just economics, as sometimes happens, but also the full spectrum of social sciences, from political science to psychology. Here is one pertinent example: together with colleagues, I recently identified the possibility that reuse and recycling could actually lead to an overall increase in consumption and thus environmental impact. We call this effect “circular economy rebound.” Potential mechanisms could be on the individual level, such as moral licensing, or on the market level, such as increased demand due to price reductions spurred by increased

competition. The circular economy will fulfill its environmental promise only if we make the study and avoidance of such behavioral effects a research priority.



Julia Kalow
Northwestern University

Plastic as feedstocks—Not waste

Although I wasn't alive when polyethylene was discovered, as a polymer chemist, I can't help but feel a certain degree of responsibility for the plastic pollution crisis. A large part of my group's program is dedicated to making polymers, but like many other researchers, we have become equally invested in the challenge of un-making and re-making them. When it comes to new polymers derived from non-petroleum feedstocks, poised for degradation and chemical recycling, there have been many exciting advances and rapid progress. However, if we judge success by a decrease in the total production of polymers, it is clear that we cannot only synthesize our way to circularity.

Chemistry has a role to play in both upstream and downstream interventions. We must develop processes that harness existing plastics as a feedstock by capturing the embedded carbon and energy of these materials. Adding value to plastic waste can motivate better collection and recycling processes. Any practically useful process will have to deal with the impurities, additives, and multi-material makeup of plastic waste streams—a significant challenge for translating chemistry out of the lab. We must also engage in dialogue with other disciplines in forums such as LabLinks so our research can work in tandem with policymakers, waste collectors, recyclers, media, consumers, and industry to maximize the benefit to society and, just as importantly, reduce harmful unintended consequences.



James Palardy
The Pew Charitable Trusts

Solution-oriented design

The economics of plastic currently dictate that recyclable does not always mean recycled—that compostable does not always mean composted. Breaking the wave of plastic entering the environment and transitioning toward a circular plastics economy requires identifying and implementing affordable solutions at a global scale.

One way to maintain a solution-oriented focus is to apply co-design principles, where researchers work in collaboration with (1) communities suffering from the burdens of plastic pollution to ensure that solutions are practical and affordable; (2) waste-management practitioners, who understand the specifics of local costs, infrastructure, markets, and available funding; and (3) corporations, which understand the material properties needed to ensure delivery of their goods and services and whose profit motive is likely to drive change.

To be truly effective, these collaborations must occur in locations with limited waste-management infrastructure, including rural communities and across the Global South.

At a global scale, solution-oriented research toward a circular economy will minimize the current cost differences between linear and circular systems. It will most likely focus on the design of low-cost, low-investment, and/or low-technology solutions that remove or replace plastic in the economy or increase the inherent value of plastic waste. Solution-oriented research will also develop appropriate incentives for transitioning away from a linear economy (e.g., by measuring the full human, environmental, and social impacts of plastic waste and by encouraging national and corporate transparency in plastic use and disposal) and translating these incentives into policy tools (e.g., recycled content targets) to drive change.



Jennifer Dunn
Northwestern University

Integration of interdisciplinary expertise

Advancing a circular plastics economy requires insights from science and engineering for the design of materials for circularity. Economics and the social sciences are equally important disciplines in this pursuit. They provide insights into consumer behavior and the potential effects of circular economy policies. Only through combining expertise from all these disciplines can efforts to re-engineer plastics be successful. Through this integration, the interdependencies among plastic's properties, consumer behavior during the use and end-of-life phases, and systems and technologies that can turn the "grave" into a "cradle" will be considered. One major research priority is therefore to identify and evaluate circular economy approaches that reflect the combined expertise of science, engineering, and the social sciences. These approaches should be evaluated holistically through techniques such as life-cycle assessment. Viable approaches that the research community develops and communicates can guide policy, industrial strategies, and consumer behavior. Moreover, we should anticipate that even a circular economy will be leaky and design plastics accordingly. To do that, we need comprehensive public databases that help quantify the human and environmental health hazards of compounds used and produced throughout the plastic supply chain, including microplastics and degradation products that arise at the end-of-life phase. Developing these databases and employing them in plastic development are a second major research priority. Finally, plastics touch nearly every economic sector. Correspondingly, transitions to a circular economy must be evaluated for economic and environmental ripple effects to other economic sectors.



Timothy Hoellein
Loyola University Chicago

Focus on fresh water

"The normative power of the actual" is a fancy way of saying, "you get used to things." Plastic litter is so commonplace and enduring that we have become accustomed to seeing it, and it can fade into the background of our vision. However, ecologists have trained their sights on measuring, counting, and characterizing plastic litter globally. Freshwater environments are a focus area for plastic research because they receive, retain, transform, and transport litter downstream.

Long focused on the oceans, research on plastic in freshwater ecosystems is rapidly emerging and making a major impact. Plastic litter in freshwater environments is unevenly distributed. For example, plastic litter accumulates with organic matter on beaches and in rivers according to well-known particle transport dynamics attributed to particle density and hydrology. Microplastics (i.e., particles < 5 mm) are found in high density in streambeds at sites where fine particulate organic matter collects (e.g., soils and small detritus). Over long timescales, microplastics in freshwater fish specimens have increased since the mid-1900s, when plastic was first industrialized. And in the last 20 years, cigarette-butt litter on the beaches of the Great Lakes has declined along with national smoking rates as a result of public policy and education.

Freshwater ecosystems are a key area of research growth for understanding and preventing plastic litter. Freshwater environments are biologically and chemically reactive, provide key ecosystem services, and are where successful intervention, cleanup, and prevention can be best implemented. Advances in recycling are welcome but represent a single component of a broad spectrum of needed advancements. Solutions will ultimately be generated through collaboration among many fields and include the vision of freshwater ecologists.



Boya Xiong
University of Minnesota

Closing knowledge gaps in plastic degradation

Polymeric materials are an almost irreplaceable component of modern life. However, many plastics are designed to be wasted; roughly 75% of global plastics produced each year are diverted to landfills or the natural environment. Plastics that have degraded into smaller particles, called nano- or microplastics, have been found in all ecosystems, posing unknown ecological and health risks at a planetary scale. To avoid unintended consequences, we need the sustainable selection and design of polymers, which will require us to first establish risk-assessment tools with quantitative environmental and health objectives for current and future plastic materials. But our ability to do so is currently limited by poorly defined and/or unavailable data on exposure and effects. In particular, we are limited by our poor understanding of the complex degradation mechanism of polymer materials in the natural environment. Polymers can leach chemicals, additives, and generate nano- and microplastics as a result of degradation. The size, shape, and surface chemistry of polymeric materials can critically affect toxicity, and all of these properties can be altered during the course of degradation. Furthermore, the lifetime of plastics in the environment is determined by unconstrained rates of degradation. It is critical to have science-based degradation data to inform policy. Our lab aims to develop novel analytical and characterization tools and devices to understand both chemical (e.g., photochemical) and mechanical (e.g., abrasion and fragmentation) degradation of plastics under simulated environmental conditions. With better data on the chemical and physical nature of polymer-degraded products and the rates at which such degradation occurs, we can start to close the gaps in assessing the environmental risks of plastic waste and designing future polymers that reduce environmental consequences.



Eugene Y.-X. Chen
Colorado State University

Addressing the root of plastics problems

Nearly all of today's polymers, including plastics, were historically designed and developed for cost, performance, durability, and disposability rather than for performance and recyclability or degradability. This failure to address end-of-life issues in the design of today's plastics has accelerated the depletion of finite natural resources, caused severe worldwide plastic pollution problems, and resulted in enormous loss of energy and material value to the economy. To address the root of the plastics problem, the design of next-generation polymers must consider their afterlife and establish closed-loop lifecycles toward a circular materials economy.

Preventing plastic pollution is just like preventing any other type of pollution: the best solution is to prevent pollution at the source. Addressing plastic waste is far more costly than developing plastics that will not end up as waste in the long run. Creating intrinsically circular plastics with tunable performance properties is one way to address the root of the plastics problem and should therefore be prioritized and supported by all stakeholders. The arguments that today's plastics are much cheaper and that new plastics contaminate recycling streams neglect environmental, financial, and social triple-bottom-line accountability. It will be critically important for the plastics industry to embrace this new plastics revolution. Sacrificing some short-term profitability in order to transition to a circular plastics economy will require courage, commitment, and strategic planning. Achieving a sustainable plastic future preserving natural resources and the environment for future generations depends on doing so.