Researchers say accounting for plastic persistence can minimize environmental impacts

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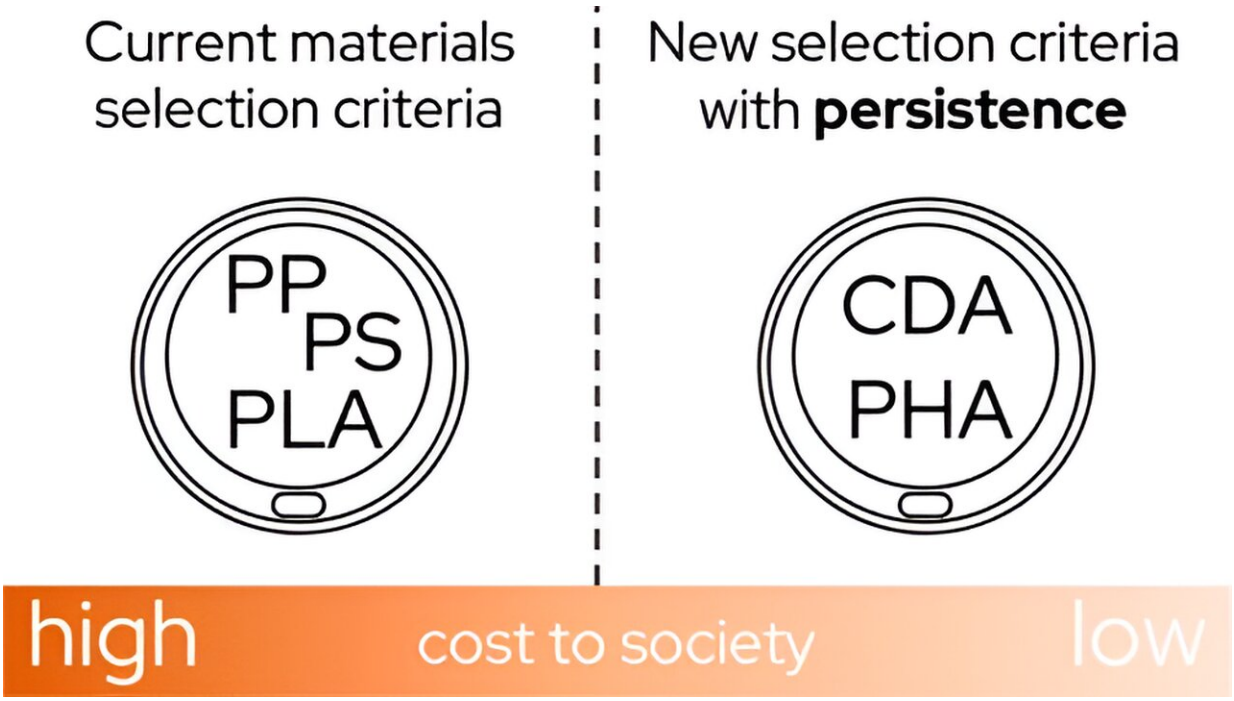

Abstract. While plastic pollution threatens ecosystems and human health, the use of plastic products continues to increase. Limiting its harm requires design strategies for plastic products informed by the threats that plastics pose to the environment. Thus, we developed a sustainability metric for the ecodesign of plastic products with low environmental persistence and uncompromised performance. To do this, we integrated the environmental degradation rate of plastic into established material selection strategies, deriving material indices for environmental persistence. By comparing indices for the environmental impact of on-the-market plastics and proposed alternatives, we show that accounting for

the environmental persistence of plastics in design could translate to societal benefits of hundreds of millions of dollars for a single consumer product. Our analysis identifies the materials and their properties that deserve development, adoption, and investment to create functional and less environmentally impactful plastic products. Credit: *ACS Sustainable Chemistry & Engineering* (2024). DOI: 10.1021/acssuschemeng.3c05534

With plastic pollution posing a significant threat to ecosystems and human health, various strategies to lessen this type of pollution include reducing the production of plastic, decreasing the generation of plastic waste, and improving the material and product design of plastic items.

Now, researchers have developed a sustainability metric for the ecological design of plastic products that have low persistence in the environment. Adhering to this metric could provide substantial environmental and societal benefits, according to a new study led by researchers at the Woods Hole Oceanographic Institution (WHOI), and published in the journal *ACS Sustainable Chemistry & Engineering*.

"While plastic pollution threatens ecosystems and human health, the use of plastic products continues to increase. Limiting its harm requires design strategies for plastic products informed by the threats that plastics pose to the environment. Thus, we developed a sustainability metric for the eco-design of plastic products with low environmental persistence and uncompromised performance," according to the study.

Designing single-use plastics using this approach can have a substantial impact. Analyses in the study say switching to alternative materials for single-use coffee cup lids, such as cellulose diacetate and polyhydroxyalkanoates, could reduce the environmental costs to society by hundreds of millions of dollars.

In general, products are designed to be environmentally friendly primarily by balancing the trade-offs between various environmental concerns, such as greenhouse gas emissions and resource depletion, because there are some frameworks and data sets to estimate these types of impacts.

Selecting one kind of plastic over another is often used to accomplish this goal. However, to date, no material selection framework has considered or quantified environmental persistence, or the time that a plastic item remains in the environment as pollution, as a key environmental concern.

"What's important to determine is how can we design functional, sustainable, and benign materials, products, and processes that embody all of the principles of green materials engineering into the future world that we are going to live in," said lead author Bryan James, a materials scientist and engineer who is a postdoctoral investigator in WHOI's Marine Chemistry & Geochemistry Department.

"What are the next set of strategies and tools that engineers, product designers, and even the average consumer can use to make the best choices for the environment while not having to sacrifice product performance?"

To develop the sustainability metric, the researchers "integrated the environmental degradation rate of plastic into established material selection strategies, deriving material indices for environmental persistence. Our analysis identifies the materials and their properties that deserve development, adoption, and investment to create functional and less environmentally impactful plastic products," the study notes.

Establishing and implementing a sustainability metric for persistence has been challenging because of insufficient data for the wide range of

plastics used in consumer goods. Only recently have scientists had sufficient data on realistic environmental degradation rates of different types of plastic so that they can better consider different types of plastic properties and implement them in design.

With this data, the researchers now show that while switching one plastic material for another can reduce a product's cost and embodied greenhouse gas emissions, that switch could provide a far greater benefit in terms of minimizing environmental lifetime and persistence.

For example, if a product designer only considered cost and greenhouse gas emissions, polylactic acid would be a good choice. Yet, this material persists in the ocean. Comparatively, cellulose diacetate and polyhydroxyalkanoates, while currently only a bit more expensive than polylactic acid, can have lower greenhouse gas emissions and do not persist in the ocean.

"Ninety-nine percent of the papers that have been published on plastic pollution tell us how bad it is. This paper is looking at the issue in a much more forward-thinking way, about how do you address a problem in a meaningful scientific way that's attainable, achievable, and economically viable," said co-author Christopher Reddy, senior scientist in WHOI's Marine Chemistry & Geochemistry Department.

As an example, the researchers applied the metric to the redesign of an everyday single-use plastic item, coffee cup lids. Currently, billions of disposable coffee cup lids are used each year, accounting for about five percent of all plastic debris collected by coastal cleanup efforts worldwide.

With three different coffee cup lids currently in use—including lids made from polylactic acid, polypropylene, and polystyrene—researchers evaluated which on-the-market lid material reduces the environmental

impact the most.

"Which is better: a lid that has a bit more greenhouse gas emissions but persists less in the environment or a lid that has fewer greenhouse gas emissions but will persist for a longer time? To answer this, we put a dollar value on both options in terms of cost to make the product and cost to the environment and ecosystem services," said James.

"Simply making products that persist less by virtue of not being there, or going away faster, reduces that cost to society tremendously."

"When you are charged with making a new coffee cup lid that needs to be sustainable and green, and you have to figure out which polymer is best for the environment, currently, green might take into consideration how much energy is used to make the plastic or how much greenhouse gases are emitted."

"However, the current calculus for a designer does not consider what the lid's persistence is. What Bryan has done with the development of this metric is groundbreaking," added Reddy, who co-advises James along with co-author Collin Ward, associate scientist in WHOI's Marine Chemistry & Geochemistry Department.

"What's important about this study is that it helps shift the narrative away from defining the problem of plastic pollution to arriving at solutions to the problem. Plastics are extremely useful materials—they're not going anywhere anytime soon. But everyone agrees the amount of plastic leaking into the environment is a problem."

"The framework presented in this study represents an important first step towards solving this problem by designing materials that simultaneously meet the needs of consumers and do not persist if incidentally leaked into the environment," said Ward.

James noted that through thoughtful strategies to make good design decisions, "scientists, engineers, and designers have an opportunity to make a significant impact in the plastic pollution crisis. The metrics and methods developed in this study can direct design decisions and research priorities to reach this goal."

More information: Bryan D. James et al, Minimizing the Environmental Impacts of Plastic Pollution through Ecodesign of Products with Low Environmental Persistence, *ACS Sustainable Chemistry & Engineering* (2024). DOI: 10.1021/acssuschemeng.3c05534

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