Shaping a sustainable future for a common plastic

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Credit: AI-generated image (disclaimer)

Polyurethane is one of the world's most widely used plastic materials, but it's often overlooked in our daily lives. Yet whether you're at home, at work or in your vehicle, it is usually not far away, with common end uses ranging from mattresses and furniture cushioning to building insulation, car parts and even the soles of shoes.

But as with other plastics that go largely unrecycled, the widespread use of polyurethane is generating concerns about its environmental impact. To better understand the opportunities for recovering polyurethane for recycling and for replacing the chemicals used in its production with plant-based alternatives, researchers from the U.S. Department of Energy's (DOE) Argonne National Laboratory, Northwestern University and The Dow Chemical Company joined together to conduct the first comprehensive assessment of "Material Flows of Polyurethane in the United States." The study was recently published in the journal *Environmental Science & Technology*.

"The goal was to understand how linear versus how circular is our use of polyurethanes in the United States," explained co-author Jennifer Dunn, who is the associate director of Northwestern's Center for Engineering Sustainability and Resilience and a member of the Program on Plastics, Ecosystems and Public Health at the Institute for Sustainability and Energy at Northwestern (ISEN). "We also wanted to see if there are opportunities to enhance circularity and increase the bio-based content of polyurethanes."

A linear economy is one in which raw materials are used to make products and then are typically thrown away at the end of their lives. In a circular economy, those same materials are recovered and reused. This limits the need to extract additional natural resources, like fossil fuels, while reducing the amount of waste sent to landfills.

Dunn, who is also an associate professor of chemical and biological engineering at Northwestern's McCormick School of Engineering, said that while researchers expected to find a largely linear system for polyurethanes, "seeing it through a materials flow perspective, from the starting materials to the end of life, it was just blatantly linear."

According to co-author Troy Hawkins, who leads the Fuels and Products

Group in Argonne's Systems Assessment Center, the study highlighted a number of complexities that affect how and when polyurethanes can be recovered and recycled.

"Polyurethanes exist in various forms, from rigid to flexible, and each of these applications look and act differently. The use of polyurethanes has expanded rapidly in the last 50 years, and many uses are long-lived. So what's going in now may not come out of use for another 10, 20 or 30 years. And there's an issue with the concentration of polyurethane in various applications. For example, an adhesive or sealant is much harder to separate and recover compared to a mattress or carpet padding," he said.

Additionally, the supply chains for polyurethanes have long been known to involve toxic materials called diisocyanates, and the study identified how and where they are used.

"Having this complete picture allows us for the first time to see opportunities for recovering and recycling polyurethane, and for replacing some of the inputs to polyurethane production that have environmental and safety concerns with safer, low carbon bio-based chemicals," Hawkins said.

One of the unique aspects of the study was the involvement of Dow, which Dunn said allowed the researchers to incorporate detailed data and technical insight based on actual industry practices.

"Dow was integral to this study. The experience of the Dow co-authors grounded the analysis in real-world knowledge about how polyurethanes are made and used," she said. "They are also very interested in increasing the circularity of their systems and staying at the forefront of best practices for incorporating cleaner materials."

Hawkins said there was a strong collaboration between Argonne and Northwestern as well, with each bringing to bear a broad range of capabilities and resources that have been built up over many years. "It really offered synergies and an opportunity that we may not have each had independently," he said. "And it allowed us to incorporate new elements that we don't typically track in life cycle assessments."

The project took about a year to complete. It was sponsored by the DOE Bioenergy Technologies Office within the Office of Energy Efficiency and Renewable Energy and administered by ISEN, as part of the collaborative three-year Responsible Innovation for Highly Recyclable Plastics initiative.

For next steps, Dunn said the team would use the study to help steer the development of new chemistries that could lead to more recyclable, bio-based polyurethanes.

"It's going to be necessary for us and other researchers to keep contributing to this body of knowledge about these supply chains if we want to design a circular economy," she said. "We have to understand the state of things today if we're going to create technologies that are cost-effective and produce recycled plastic materials that have as high or higher performance than what we are used to now."

Hawkins added that the end goal isn't to do away with plastics, but rather to make sure they are being used in a responsible and sustainable way.

"Plastics are incredibly useful and have a lot of benefits for society. If we were to get rid of plastics there would be all kinds of other problems we would have to deal with, which might cause more environmental harm than the plastics themselves," he said. "So we have to keep looking for ways to intervene in the current system and change things for the better."

More information: Chao Liang et al, Material Flows of Polyurethane in the United States, *Environmental Science & Technology* (2021). DOI: 10.1021/acs.est.1c03654

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