Scientists point the way to a sustainable circular economy for plastics

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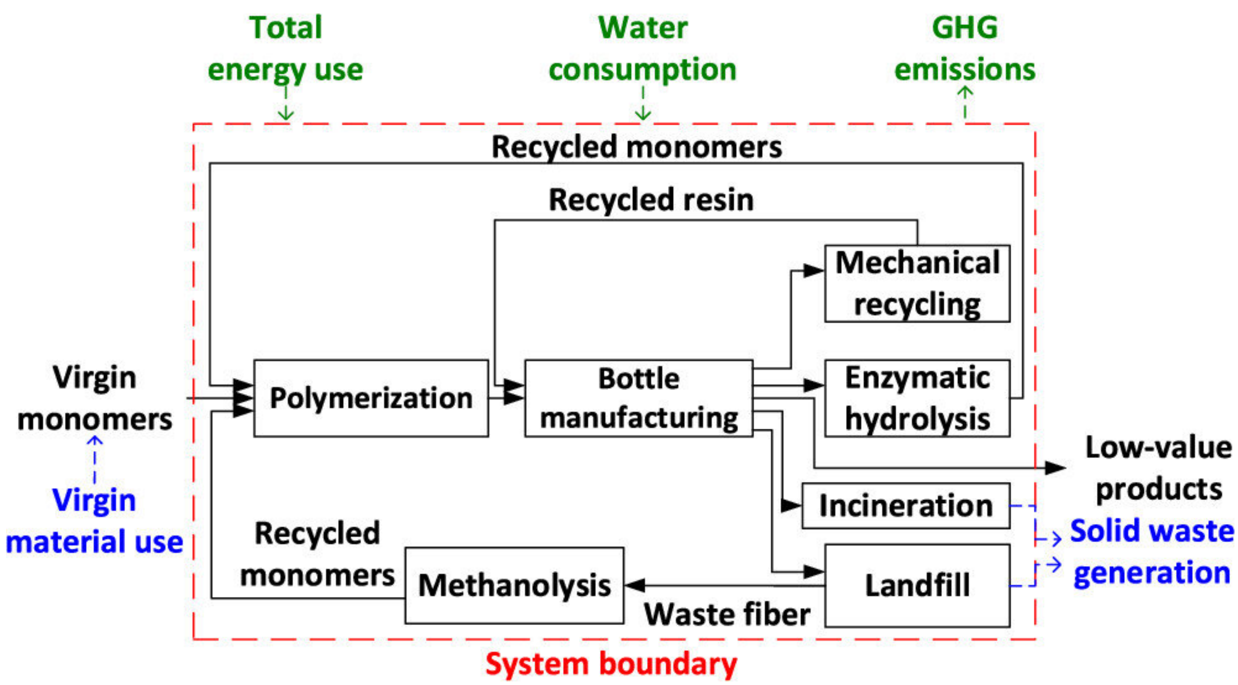

Credit: *ACS Sustainable Chemistry & Engineering* (2023). DOI: 10.1021/acssuschemeng.2c04626

Our society has a love affair with plastic. To take our relationship to the next level—happily ever after in a waste-free future—the path is circular.

Specifically, scientists at the U.S. Department of Energy's (DOE)

Argonne National Laboratory are working to analyze the impact of a circular economy where plastics are reproduced, reused or recycled to prevent them from ending up in landfills.

But how to get there? Plastics have traditionally been produced through a linear take-make-waste model where plastics are disposed after one use. The challenge is finding an effective pathway in which plastic never becomes waste—the goal of a circular economy.

A circular approach considers the entire lifecycle of a product, including end-of-life treatment, at the time of design. Resources in waste streams are reused at the highest level to avoid waste and reduce environmental impact. Still more challenging is finding an approach that holistically evaluates production, use and reuse of plastic.

In line with circular thinking, Argonne scientists created a sustainability analysis framework to evaluate various circular economy strategies for examining sustainability impacts of production, use and remanufacturing for reuse of plastic.

"The long-term sustainability of our planet demands a major shift from a linear economy, where goods are discarded after use, to a circular economy of recovery, recycling and reuse," said Troy Hawkins, leader of Argonne's Fuels and Chemicals Group. "Many products with recyclable content are currently sent for disposal."

In their research, scientists used polyethylene terephthalate (PET), a plastic used extensively in bottles, as an example to apply the circular modeling framework. PET is a light, durable plastic most often used in bottled water and soft drinks.

Argonne's comprehensive analysis framework for circular economy sustainability combines life-cycle analysis (LCA) with material flow analysis. This new approach provides an assessment of the environmental impact of PET bottles over the entire life cycle.

The new research is published in published in *ACS Sustainable Chemistry & Engineering*.

What is the process?

In their analysis, researchers factored in detailed life-cycle metrics of all stages of plastics recycling.

They incorporated data for recovering, sorting and separating valuable material for recycling, which is becoming increasingly complex due to the sheer number of plastics and vast array of uses. By doing this, researchers were able to provide realistic scenarios and results.

Researchers analyzed various pathways for realizing a circular economy. In one scenario, they analyzed supply chain inputs of two conventional routes for producing plastic, as well as mechanical and chemical recycling.

Mechanical recycling is the most common recycling process but has drawbacks. The process recovers plastic by sorting, cleaning, grinding, re-granulating and compounding. Each time plastic is recycled this way, its quality is degraded. The new, lower grade plastic can be recycled a very limited number of times before it becomes too degraded to use.

In a sense, chemical recycling picks up where mechanical recycling leaves off. An emerging technology, chemical recycling breaks plastic down to its original components, creating high-grade material that can be upcycled, or transformed into a product of higher value. In this way, chemical recycling can be used to upcycle waste not suitable for mechanical recycling.

Each has advantages and disadvantages. Mechanical recycling has a smaller carbon footprint. As a newer technology, chemical recycling is costlier, and its energy use and greenhouse gas (GHG) emissions is comparable to new plastic.

What are the results?

In the study, scientists sought to determine how mechanical and recycling work together.

In one scenario, researchers explored the integration of mechanical and chemical recycling in the supply chain. They determined that while integrating mechanical and chemical recycling did not decrease or increase GHG emissions, the solid waste generation was reduced by 44% compared to the current practice.

Researchers found that any given circular pathway can produce pollution and climate impacts that don't happen in parallel. For example, a pathway using mechanical recycling might reduce GHG emissions, but increase dependence on new plastic due to lower recycling rates.

"We determined there may be tradeoffs between improving circularity and reducing other environmental impacts such as greenhouse gas emissions or water consumption," said lead author Gracida Alvarez.

For example, increasing the share of mechanically recycled bottles reduced GHG emissions by 14% while using chemical recycling and upcycling did not impact GHG emissions compared to the current practice. However, using mechanical recycling reduced solid waste generation by 36% compared to the current state, in contrast with the 44% reduction in solid waste generation achieved by integrating chemical recycling and upcycling, as mentioned in the first scenario.

Nevertheless, mechanical, chemical and upcycling will play a critical role in achieving a circular economy.

"Our analysis suggests that as we continue to improve chemical recycling and upcycling to generate lower greenhouse gas emissions and water consumption, mechanical recycling currently provides significant benefits," Gracida Alvarez said.

Why is it important?

Plastic pollution is one of the largest environmental threats to our planet. Plastics Europe estimates that in 2019 alone, the global economy produced 368 million tons of plastic, which is expected to double in the next 20 years. Of the plastic waste generated, only 9% is recycled, while the rest ends up in landfills or is combusted, according to the U.S. Environmental Protection Agency.

There is no silver bullet solution. Hawkins said that using all three recycling processes in tandem, or cascade recycling, is important in a circular economy. The cascade approach keeps materials in circulation at the highest level of quality, economic and environmental value as long as possible.

He likens the cascade approach to a waterfall where the quality of plastic resin decreases as it cascades through uses in the economy.

"The top of the waterfall would be a clear plastic bottle, followed by a colored or opaque plastic container. In turn, this bottle could be recycled into a polyester fiber and used to produce clothing or carpet," Hawkins said. "If fiber is the bottom of the waterfall, we can use chemical recycling to bring the material back to the top."

Why is collaboration critical?

Argonne researchers collaborated closely with public and private sector partners, who provided data and expertise for the project. The publicly accessible model has industry-wide applications, said Hawkins.

"Our stakeholders are interested in having rigorous and credible analysis that helps build consensus around the relative impacts of various circular strategies," Hawkins said. "This is a robust, consistent framework developed through building consensus with stakeholders."

The Argonne framework was built as an expanded version of the Greenhouse gases, Regulated Emissions, and Energy use in Technologies model.

More information: Ulises R. Gracida-Alvarez et al, Circular Economy Sustainability Analysis Framework for Plastics: Application for Poly(ethylene Terephthalate) (PET), *ACS Sustainable Chemistry & Engineering* (2023). DOI: 10.1021/acssuschemeng.2c04626

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