THE PLASTIC INDUSTRY'S MUDDLED MATH: AN INTRODUCTION TO FAKE NUMBERS AND MISLEADING STATISTICS ABOUT PLASTIC RECYCLING

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Increasing plastic recycling has been presented as a solution to the plastic crisis, but the projected recycling numbers are often based on incorrect assumptions and misleading statistics. These are often intentionally presented to oversell the capacity and promise of plastic recycling. In this research brief, we will summarize the science on the limitations of plastic recycling and the skewed statistics that are often used to oversell its potential.

PHYSICAL LIMITATIONS OF PLASTIC RECYCLING

Plastic materials consist of a mix of different chemicals and contaminants, including polymers, monomers, additives, and non-intentionally added substances (NIAS). Plastic products are often an even more complicated mix of various materials, and studies have shown that products have become increasingly complex, further limiting their recyclability (Gutowski 2011; Shen & Worrell 2024). Combining these chemicals and materials is irreversible and separating them back into their building blocks is impossible. Suggesting that such separation is possible contradicts the second law of thermodynamics (Gutowski 2011) and ignores and undermines the laws of physics.

Industry claims there can be closed-loop plastic recycling, but since it is not possible to recycle plastics continually without reducing the quality of the polymer material to the point where it cannot fulfil its function, the concept of closed-loop recycling is based on an incorrect premise.

There are plastics where less quality is lost during recycling. These plastics may be recycled for a limited number of times into lower-grade plastics. These are typically thermoplastics that are made into simple materials, with one type of polymer and a limited number of additives. Thermoplastics can be remelted and reformed but lose quality during each recycling round (Gutowski 2011). Most recycling statistics only include thermoplastics since the other types of plastics, such as thermosets or thermoelastomers, are difficult or impossible to recycle. However, excluding these plastics from the data contributes to overestimated recycling rates.

PLASTIC RECYCLING TECHNIQUES AND FAKE PROMISES

Plastics recycling can roughly be divided into two different types:

- **Mechanical recycling** – which includes sorting, cleaning, and shredding of waste plastics, followed by remelting and extrusion. This has been assessed as Environmentally Sound Management (ESM), but only a small percentage of plastics can be recycled this way (see section on recycling percentages).
- **Chemical recycling** (also known as "advanced recycling") is not considered ESM and has two main technology groups:
    1. using pyrolysis to produce a hydrocarbon oil that, after expensive cleaning, can be blended in small amounts with virgin petrochemicals to make new plastics.
    2. using solvolysis to break waste plastics down to monomers/polymers, remove contaminants, and use the monomers/polymers to create new plastics (requiring the use of new chemical additives).

Both of these chemical recycling techniques have been shown to be inefficient and energy-intensive, contribute to climate change, and create large amounts of toxic wastes and toxic emissions while producing few recycled plastics or any other useful products (Bell 2023). Such technologies are not considered appropriate for developing countries due to hazardous waste management challenges (Quicker 2023). Other studies show that

only three of eight chemical recycling technologies have achieved the Technology Readiness Level (TRL) 9 (Solis & Silveira 2020; Manning, 2023).

Additionally, there are several techniques that the industry calls recycling that are not recycling, such as "cryogenic recycling" (chopping plastics up into smaller pieces) and plastics that are downcycled as "Refuse Derived Fuels" or "Waste-to-energy." Both of these are methods of burning plastic wastes for fuel, which releases massive amounts of CO2 and toxic compounds. Converting plastics into fuel is not recycling. Burning plastic does not contribute to a circular economy as it is a linear process. Fossil fuel is extracted, turned into plastic, used, disposed of, and then burned. The resource is lost and converted to carbon emissions. For this reason, many countries explicitly state that converting plastic to fuel cannot be claimed as recycling (for example, see the EU Waste Framework Directive).

LAWSUITS EXPOSE INDUSTRY'S RECYCLING LIES

For decades, the plastics industry told consumers that we can recycle our way out of the plastic waste problem.

But it turns out **they were lying (Allen et al. 2024)**.

In September 2024, California filed a lawsuit against ExxonMobil charging that the petrochemical/plastics/oil and gas corporation lied for decades about plastic recycling, calling the company's marketing a "decades-long campaign of deception" (**Zraick and Gelles 2024**). Previous lawsuits by governments, consumer groups, and environmental nonprofits have targeted consumer brands engaged in fake claims about the recyclability of their plastic packaging, but the California lawsuit is the first aimed at a major plastic producer.

Even after their fake claims have been exposed, the industry continues to plan a massive increase in plastic production, projecting to triple production by 2060 – and they continue to claim that recycling will save the day, this time through phony schemes like **chemical recycling (Bell 2023)**.

Several lawsuits have uncovered information from the industry's own records showing that they knew that plastic recycling would never come close to managing the massive waste problem they were creating. Below are a few highlights from some of the **recent lawsuits (Plastic Litigation Tracker 2024)**.

YEAR FILED	DEFENDANT	PLAINTIFF	GROUNDS	STATUS	EXCERPTS FROM ALLEGATIONS	LINK
2024	Exxon Mobil	California	False advertising, pollution, public nuisance	Pending	ExxonMobil, the largest producer of plastic polymers used to manufacture single-use plastics...has deceived Californians for almost half a century by promising that recycling could and would solve the ever-growing plastic waste crisis. All the while, ExxonMobil has known that mechanical recycling, and now "advanced recycling," will never be able to process more than a tiny fraction of the plastic waste it produces.	https://oag.ca.gov/system/files/attachments/press-docs/Complaint_People%20v.%20Exxon%20Mobil%20et%20al.pdf
2024	Exxon Mobil	Surfrider Foundation, the Sierra Club, Heal the Bay, and San Francisco Baykeeper	Public nuisance, unfair competition (false claims)	Pending	Exxon profited by claiming plastics are safe and recyclable. But we know better now—our environment and health were being sacrificed just to protect Exxon's bottom line	https://www.cpmlegal.com/news-Surfrider-the-Sierra-Club-Heal-the-Bay-and-San-Francisco-Baykeeper-Sue-Exxon-for-Hiding-the-Truth-About-Plastic-
2024	PepsiCo, Coca Cola, Frito Lay, and plastic manufacturing companies	City of Baltimore	False advertising re: "recyclable" plastic packaging	Pending	Defendants have been on notice for decades about the dangers of their products and their effects on the environment and public. They also know how to stop the pollution. They simply refuse to do so....None of [their] plastic packaging is reusable, and only a tiny fraction is recycled.	https://stateimpactcenter.org/files/Mayor-and-City-Council-of-Baltimore-v-PepsiCo.pdf

YEAR FILED	DEFENDANT	PLAINTIFF	GROUNDS	STATUS	EXCERPTS FROM ALLEGATIONS	LINK
2023	Reynolds Consumer Products, Inc. and Walmart Inc.	State of Minnesota	False advertising re: "recyclable" plastic trash bags	As of 8/24, a pending settlement would require Reynolds to label semi-transparent blue bags sold in Minnesota with the text: "these bags are not recyclable," pay back its profits from bags, and carry out anti-greenwashing training for staff.	Reynolds hold themselves out to Minnesota consumers and to the public as leaders in the recycling movement and as educators of the recycling process....eynolds have a duty to disclose the facts that the bags cannot be recycled at any Material Recovery Facility (MRF) in Minnesota, that the otherwise recyclable items placed into the bags do not get recycled, and that the bags themselves are not recyclable anywhere (at any MRF in the country) when contaminated by waste residue.... by failing to disclose [this] information, Reynolds did not say enough to prevent the representations made to Minnesota consumers from being deceptive and misleading.	https://stateimpactcenter.org/files/Reynolds_Walmart_Complaint-1.pdf
2023	PepsiCo, Frito Lay	New York State	False advertising, pollution, public nuisance	Pending	PepsiCo is aware of the acute limitations of recycling as a solution to the harms caused by plastic pollution.... Recycling cannot provide a solution for the multi-layered plastic packaging used by PepsiCo for its Lay's potato chips, Doritos, Cheetos, Tostitos tortilla chips or other snack foods. Even as to PepsiCo's beverage bottles made from PET, the vast majority are not recycled. In 2020, only 26.6% of PET bottles were recycled in the US, with the rest incinerated, sent to landfills, or discarded directly or indirectly into the environment.	https://stateimpactcenter.org/files/pepsico-complaint.pdf
2022	Reynolds Consumer Products	State of Connecticut	False advertising re: "recyclable" plastic packaging	Pending	Despite Defendants' representations, the Hefty "Recycling" trash bags are not recyclable at Connecticut materials recovery facilities ("MRFs") and are not suitable for the disposal of recyclable products at Connecticut MRFs...the bags and all of the otherwise recyclable items contained within them are dive1ied to landfills or incinerators. Connecticut MRFs do not recycle either Hefty "Recycling" trash bags or the recyclable items they contain.	https://stateimpactcenter.org/files/Connecticut-v.-Reynolds-Consumer-Products-Inc-No.-HHD-CV-22-6156769-complaint.pdf
2022	7-Eleven	Consumers (class action)	False advertising re: "recyclable" plastic	Pending	"Defendant's store brand "24/7 Life" plastic Foam Cups, Foam Plates, Party Cups and Freezer Bags, feature deceptive labeling that they are recyclable. While Defendant has labeled its 24/7 Life plastic products as recyclable, the truth is that Defendant's 24/7 Life plastic products are not recyclable because they are made out of plastics that are not recyclable in any municipal recycling facilities that consumers have access to.... the products are ultimately not recycled and end up in the landfill."	https://stateimpactcenter.org/files/Curtis_v._7-Eleven__Inc.-Amended-Complaint-1-Filed-in-December-2022.pdf

YEAR FILED	DEFENDANT	PLAINTIFF	GROUNDS	STATUS	EXCERPTS FROM ALLEGATIONS	LINK
2021	Coca-Cola	Earth Island Institute (public interest org)	False advertising re: "recyclable" plastic packaging	As of 9/24, the appeals court remanded the case for further review.	...recycling has proven overwhelmingly insufficient in addressing global plastic pollution. A mere 9 percent of all plastic that has been produced since the 1950s has been recycled, while 79 percent has ended up in landfills or the natural environment. Coca-Cola has done relatively very little to address the immense problem of global plastic pollution and has even actively opposed legislation proven to improve recycling rates...	https://drive.google.com/file/d/10nAzgOVlDIUfuv_0-qThtS2noaDY_R1u/view
2021	Coca-Cola, Bluetriton Brands, and Niagara Bottling (plastic bottle producers)	Consumers (class action)	False advertising, fraud, violation of the Environmental Marketing Claims Act	Pending	"Defendants' continued use of misleading and deceptive recyclability claims on their products serves to defraud the public about plastic water bottles. It falsely informs consumers that they are making an environmentally responsible choice when they purchase and dispose of Defendants' plastic water bottles in a municipal recycling bin. In truth, Defendants' single-use plastics are damaging the environment even when consumers properly dispose of the bottles in a recycling bin... Defendants' representations that the Products are recyclable are material, false, misleading, and likely to deceive members of the public. These representations also violate California's legislatively declared policy against misrepresenting the environmental attributes of products."	https://stateimpactcenter.org/files/Swartz-v.-Coca-Cola-No.-3-21-cv-04643-complaint.pdf
2020	Crystal Geyser Water	Earth Island Institute (public interest org)	False advertising re: "recyclable" plastic packaging	Pending	...much of the purportedly "recyclable" plastic sold to consumers is not actually recycled. Rather than switch to more sustainable materials in their products, or educate the public on the realities of plastic recycling, Defendants have engaged in a decades-long campaign to deflect blame for the plastic pollution crisis to consumers.	https://stateimpactcenter.org/files/PUBLIC_Earth_Island_FAC.pdf
2018	Keurig Green Mountain	Consumers (class action)	False advertising re: "recyclable" plastic packaging	Settlement filed	"the Settlement will prohibit Keurig from labeling, marketing, advertising, or otherwise representing that the Products are recyclable (through use of the word "Recycling" or any variation thereof or through the conspicuous use of the Chasing Arrow symbol or any variation thereof) without clearly and prominently including a revised qualifying statement, "Check Locally – Not Recycled in Many Communities." Settlement § III.A.2. This new qualifying language clearly puts consumers on notice that the Products are not recyclable in many communities. "	https://stateimpactcenter.org/files/Smith-v.-Keurig-Green-4-18-cv-06690-motion.pdf

RECYCLING PERCENTAGES

It has been estimated that only 9% of all the plastics ever produced until 2015 have been recycled (Geyer et al. 2017). This number is likely an overestimation as it is based on reported data which, in turn, does not account for all plastics and is often based—as is the case for reported data from the EU—on how much plastic is sent to recycling (European Parliament 2024), not how much is actually recycled.

Data shows that globally 460 million tonnes (MT) of plastics were produced in 2019. That plastic is used in a multitude of different sectors and applications, with 31% (143 MT) going to packaging, 17% (77 MT) to building and construction, 14% (62 MT) to transportation, 10% (47 MT) to consumer and institutional products, 10% (44 MT) to textiles, 4% (17 MT) to electronics, and 16% (68 MT) to other applications (Our World In Data/ OECD 2022). If we look at EU recycling data, the EU claims to recycle 41% of their plastic wastes (European Parliament 2024), but that number is likely a significant overestimation.

First, the data is only based on packaging (European Parliament 2024; Eurostat 2024) and does not take other types of plastics into account. EU plastic use numbers are focused on plastic products produced in the EU (presented as "converter demand") (Plastics Europe 2023) and do not seem to account for imports. Assuming that the plastic use, including imported plastic products, is similar to the global numbers, less than a third of the plastics (31%) that are produced are used as packaging (Our World In Data/OECD 2022).

That means the 41% recycling rate includes less than a third of plastics. If we look at all plastics produced, and not just plastic packaging, only 13% - not 41% - of plastics are sent for recycling (0.41x0.31x100=13%).

Some waste composition numbers indicate a higher percentage of plastic packaging in waste than in production volumes because plastic packaging has a shorter lifespan (Shen & Worrell 2024). OECD data on plastic wastes suggests that 42% of the plastic wastes in 2019 were plastic packaging (OECD 2019). However, it is important to note that those numbers do not include textiles or plastics that are not collected. But even if this larger number is used, where 42% of the plastic wastes are reported as plastic packaging, the percentage of plastics sent to recycling would still be only 17% (0.41x0.42x100=17%).

Which brings us to the second part of the problem. The recycling data is based on the percentage of plastic packaging wastes that are sent to recycling (European Parliament 2024; Eurostat 2024), not plastics that are actually recycled. Of those 13-17% of plastic wastes that are sent to recycling, half are exported outside of the EU where they are often dumped, landfilled, or incinerated (Karlsson et al. 2023, Schmidt & Ciesla 2023), meaning we cannot assume they are actually recycled. This means that when compared to the production volumes of plastics or to waste generation across sectors, after adjusting for waste exports, the actual recycling rates may be closer to 6-9% (Figure 1). This is also more in line with OECD data that shows that only 6% of the plastics that are produced are made from recycled plastics (OECD 2022).

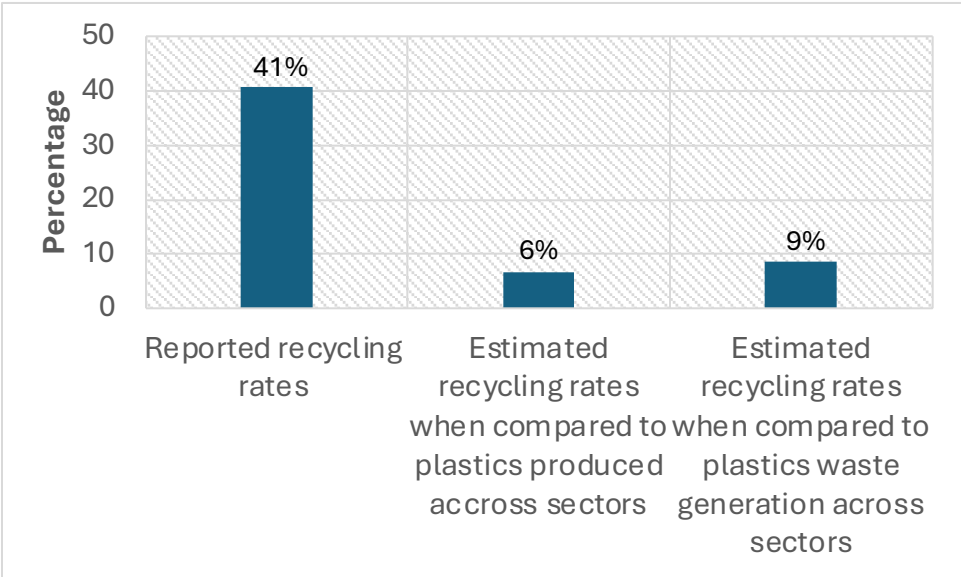


Figure 1 Recycling rates that the EU claims to have for plastics compared to estimated recycling rates when compared to production volumes and waste generation across sectors and adjusted for waste exports.

The estimated 6-9% also comes with several uncertainties. One uncertainty is that it is unknown how much of the plastics that are "sent to recycling" within the EU are actually recycled. Another uncertainty is that it is unclear what amount of thermosets and thermoelastomers are covered in this data. A third uncertainty is that some of the plastics that are used in other sectors may be recycled to some extent, albeit at lower rates than that of packaging (Ljungkvist Nordin et al. 2019). A fourth uncertainty is that some of the wastes exported outside of the EU might end up being recycled.

However, it is clear that the recycling numbers that are currently used are an overestimation, since they only refer to data from less than a third of the applications of plastics and only account for plastics that are sent to recycling, not plastics that are recycled. Similar inconsistencies in recycling percentages have been reported for data from the US (Allen et al. 2024; Bonta 2024; Fraser 2022).

PLASTIC CREDITS

Another system that is used by some companies to appear more sustainable is known as "plastic credits." Companies use plastic credits to meet their commitments to reduce pollution in the supply chain, similar to the carbon credits mechanism used to offset carbon emissions – schemes that have been widely criticized as frauds (Kijewski 2024), including many "certified" by Verra, the company certifying many plastic credit schemes.

Proponents claim that plastic credits function as a market mechanism to incentivize waste collection and recycling by assigning a monetary value to these activities. As mentioned previously, collection does not always equate to actual recycling. However, unlike carbon credits, plastic credits do not benefit from a globally standardized regulatory framework (Monast & Virdin, 2022). Moreover, the focus for the credits is often at the end of the life cycle, instead of throughout the supply chain.

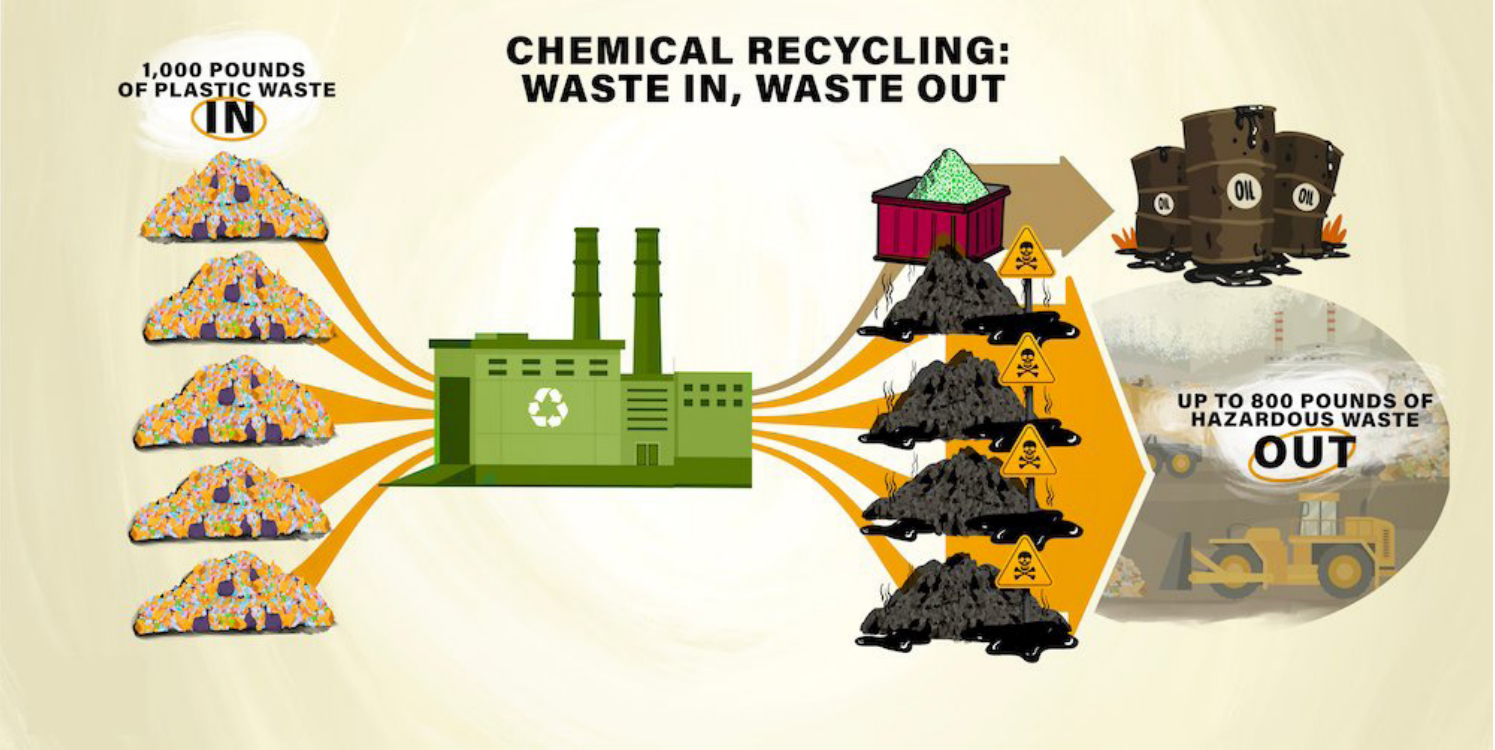
Companies earn credit by collaborating with organizations that collect a certain amount of plastics on their behalf, which are then reported on a plastic credit platform (Verra, 2021; PCX, 2024). The organizations that are involved, including waste pickers and local and coastal communities, do not necessarily benefit from the plastic credit setup, and the reporting mechanisms often lack due diligence. This lack of due diligence has allowed companies to earn and trade plastic credits for projects that directly harm local communities (Howard & O'Donnell 2024).

Plastic credits for recycling thereby allow companies, manufacturers, and retailers to continue to produce low-recycling-value materials while running greenwashing campaigns to appear more responsible than they are. In fact, several sources and evidence have shown that most plastics collected for plastic credits are not recycled but instead burned for fuel (BFFP & GAIA 2023; Nexus3 2024; Lee, 2021), which releases toxic chemicals and poisons local communities. Furthermore, plastic waste that is recycled and claimed for plastic credits does not consider the toxic chemicals that leach, contaminate food chains, release into the environment, and accumulate in recycled products.

MASS BALANCE AND RECYCLED CONTENT

In an attempt to prevent mandatory production cuts, plastic producers are now pushing for chemical recycling facilities to be allowed to use a free allocation, mass balance accounting system. This would allow them to claim large amounts of recycled content in new plastic where there may be very little recycled plastic or even none at all.

This misleading practice is especially beneficial to chemical recycling and designed to benefit pyrolysis plants. The output of pyrolysis plants is contaminated oil that must be heavily cleaned (meaning filtered and diluted with 98% virgin petrochemical/naphtha) to be used in new plastic production since it would otherwise damage the production system (specifically the steam crackers). Aside from the oil, pyrolysis also produces gas, waxes, and a hazardous solid waste called char. Pyrolysis operators want to be able to claim "recycled content credits" for all these outputs, even though only a small amount of the outputs can ever be used for plastic production, and most may be burned as fuel. Worse still, they want to be able to allocate these "credits" to any product they make whether or not that product actually contains recycled content. Plastic lobbyists are even calling for the bogus credits to be traded between facilities, companies, or even across borders to boost recycled content claims

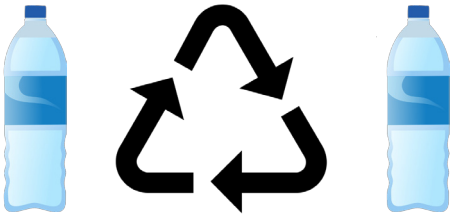


in consumer goods companies' most popular and expensive products. This approach destroys truth in labeling and has the potential to lead the public to consider all types of materials recycling as greenwashing.

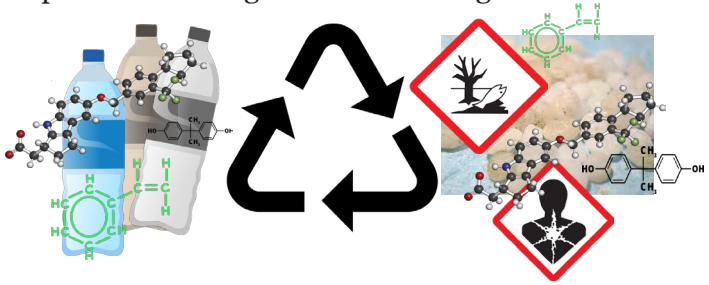
In 2024, the US EPA rejected the industry's mass balance approach, instead requiring their "Safer Choice" labeled products to use a weight-based approach for measuring recycled content (Song 2024). The EU is debating a much weaker position that excludes fuels but allows credits for pyrolysis outputs that will never become recycled plastic. Notably, the free allocation mass balance scheme was opposed by mechanical recyclers and some chemical recyclers (solvolysis) on the basis that it creates a large advantage for pyrolysis over other recyclers and could lead to technological lock-in of pyrolysis for decades.

NUMBER OF CHEMICALS

Aside from not knowing how much plastic is recycled, what the recycled content is, where the plastic credits go, or how much plastic waste is traded, the composition of the recycled plastics is also mostly unknown. Plastic recycling is often presented like this:



The reality, however, is quite different since the composition is unknown, meaning that the number and hazard profile of chemicals in recycled plastics are not known. This is because plastic recycling is based on combining one pile of plastic materials with unknown composition with another pile of plastic materials with unknown composition. A more realistic representation might look something like this:



Studies where recycled plastics are analyzed have repeatedly confirmed that chemicals in plastics are spread to the recycled plastic material. One study that looked at 28 samples of recycled plastic pellets found 491 different chemicals, including pesticides, pharmaceuticals, industrial chemicals, and plastic additives (Carmona 2023). Another study that looked at recycled pellets from 23 countries found that all samples contained toxic chemicals and half contained brominated flame retardants, including DecaBDE—a chemical so toxic that it has been banned globally (Brosché et al. 2023). Another study found that toys made of recycled plastic contained brominated dioxins and furans, likely formed from brominated flame retardants in the original materials reacting during recycling processes (Petrlik 2018; Budin et al. 2020). Other studies have also shown that plastic chemicals such as PBDEs, PAH, PCBs, and heavy metals are released during the process of plastic recycling (Hahladakis et al. 2018; Sakai et al. 2004; Qin et al. 2022).

CONCLUSIONS

The promise of plastic recycling is overstated, as most plastics are not recyclable, and the numbers are often misleading. High-income nations often export plastic waste under the guise of recycling, but much of the exported waste ends up in landfills, incinerators, or even open burned. This creates a cycle of environmental injustice, where marginalized communities are disproportionately impacted by the consequences of plastic pollution while wealthy nations avoid addressing their own waste issues and can claim a higher percentage of "recycled" materials. For the plastics that are actually recycled, the recycling process often releases harmful pollutants and recirculates toxic chemicals into new products.

Industry often points to different techniques such as "advanced" recycling/chemical recycling as the solution to some of the challenges encountered with mechanical recycling, but once you look beyond misleading mass-balance numbers, it is clear that these techniques have failed to work for decades and result in large volumes of hazardous wastes. Instead of investing in such flawed methods, which would result in costly and harmful technological lock-ins, efforts should focus on reducing plastic production and eliminating toxic plastic chemicals.

Moreover, it is important to note that to address the challenges with plastic wastes, it is important to start with upstream changes. Focusing on downstream techniques with inherent limitations may slow—rather than accelerate—the transition to a different model that takes an integrated approach to sustainability, including measures like limiting the production of certain problematic plastics, improving product design, and prohibiting the use of toxic plastic chemicals.

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