Our Plastic Planet

The United Nations: Sustainable Development Goals

DONATE WHAT YOU DON'T USE.

More than 700 million people still live in extreme poverty.

WASTE LESS FOOD AND SUPPORT LOCAL FARMERS.

A third of the world's food is wasted, yet 821 million people are undernourished.

VACCINATE YOUR FAMILY.

Vaccinations resulted in an 80% drop in measles deaths between 2000 and 2017.

HELP EDUCATE THE CHILDREN IN YOUR COMMUNITY.

617 million children and adolescents lack minimum proficiency in reading and mathematics.

EMPOWER WOMEN AND GIRLS AND ENSURE THEIR EQUAL RIGHTS.

1 in 3 women has experienced physical and/or sexual violence.

AVOID WASTING WATER.

Water scarcity affects more than 40% of the world's population.

USE ONLY ENERGY-EFFICIENT APPLIANCES AND LIGHT BULBS.

Three billion people still lack clean cooking fuels and technologies.

CREATE JOB OPPORTUNITIES FOR YOUTH.

One-fifth of young people are not in education, employment or training.

FUND PROJECTS THAT PROVIDE BASIC INFRASTRUCTURE.

Roads, water, sanitation and electricity remain scarce in many developing countries.

SUPPORT THE MARGINALIZED AND DISADVANTAGED.

The poorest 40% of the population earn less than 25% of global income.

BIKE, WALK OR USE PUBLIC TRANSPORTATION.

9 out of 10 urban residents breathe polluted air.

RECYCLE PAPER, PLASTIC, GLASS AND ALUMINIUM.

By 2050, the equivalent of almost three planets could be required to sustain current lifestyles.

ACT NOW TO STOP GLOBAL WARMING.

Global emissions of carbon dioxide (CO2) have increased by almost 50% since 1990.

AVOID PLASTIC BAGS TO KEEP THE OCEANS CLEAN.

Over three billion people depend on marine and coastal biodiversity for their livelihoods.

PLANT A TREE AND HELP PROTECT THE ENVIRONMENT.

Forests are home to more than 80% of all terrestrial species of animals, plants and insects.

STAND UP FOR HUMAN RIGHTS.

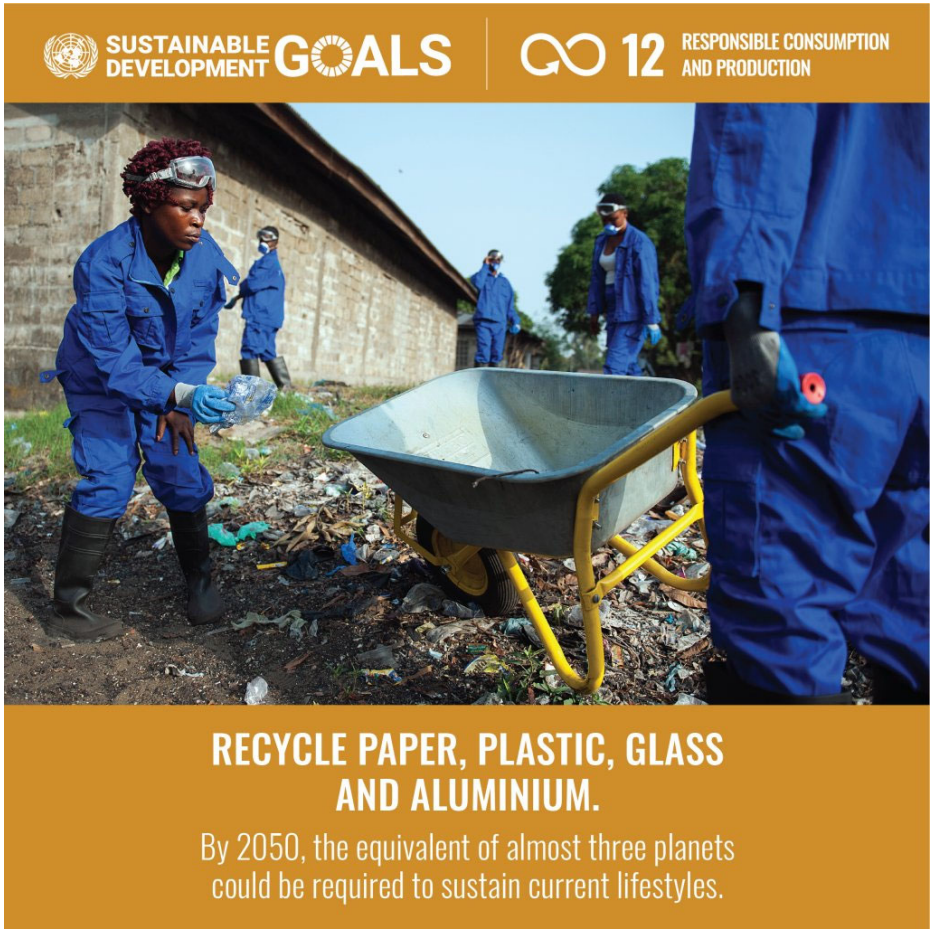
In 2018, the number of people fleeing war, persecution and conflict exceeded 70 million.

LOBBY YOUR GOVERNMENT TO BOOST DEVELOPMENT FINANCING.

Achieving the SDGs could open up US$12 trillion of market opportunities and create 380 million new jobs by 2030

The United Nations: Sustainable Development Goals

Goal 12: Responsible Consumption and Production: Responsible Production and Consumption

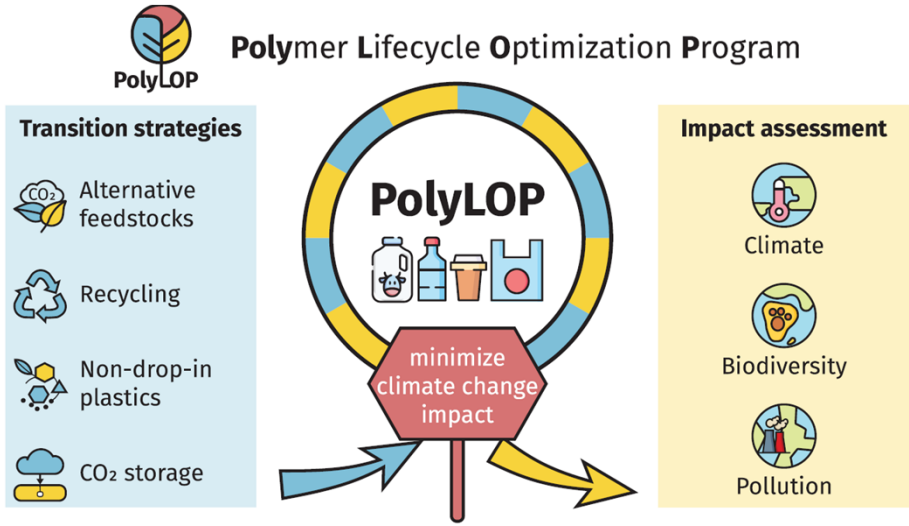


Goal 14: Life Below Water: Careful management of this essential global resource is a key feature of a sustainable future.

The Triple Planetary Crisis

The sustainable transition of the plastic industry - shifting from its fossil reliance and linear produce-use-dispose modelis imperative to minimize its contribution to **the triple planetary crisis of climate change, biodiversity loss, and pollution**. While previous studies assessed transition strategies in isolation, focused mainly on climate impacts, and neglected regional differences, our integrated model assesses transition strategies, globally and regionally, addressing the potential co-benefits and trade-offs across several key drivers of the triple planetary crisis.

We note that other important impacts, such as **microplastic leakage**, remain to be quantified. Achieving a net-zero plastic industry by 2050 (1 gigaton (Gt = $1x10^9$ tonnes) annual production) is technically feasible through lignocellulose residue-based feedstocks, recycling, and carbon capture. Meanwhile, this would require consuming all available global lignocellulose residues (2.3 Gt), early retirement of fossil infrastructure to avoid at least 0.35 Gt CO^2-eq emissions, and ensuring grid decarbonization, presenting great challenges. Without internationally coordinated relocation of plastic production facilities or trade of biomass feedstocks or the derived intermediate chemicals, global net zero becomes unattainable. The global climate benefits through the transition come with trade-offs in higher land-use-related biodiversity loss and particulate matter-related health impacts, especially in regions with vulnerable ecosystems and dense populations, necessitating tailored regional solutions. Reducing primary plastics production could ease the transition, but unsustainable material substitutes need to be avoided.



Huo 2025, Global plastic industry transition addressing key drivers of the triple planetary crisis

Reducing Plastic Pollution:

Purdue Engineering Distinguished Lecture Series Lecture

February 24, 2026

Jenna Jambeck, Ph.D.
Regents' Professor, Georgia Athletic Association Distinguished Professor of Environmental Engineering

Fighting plastic waste + marine debris

Named a 2022 MacArthur Fellow for her work investigating the scale of plastic pollution and galvanizing efforts to address plastic waste, Jenna Jambeck is the Georgia Athletic Association Distinguished Professor of Environmental Engineering in the University of Georgia College of Engineering. Jambeck is internationally recognized for her research on plastic waste in the ocean and for the Marine Debris Tracker app she co-created with fellow faculty member Kyle Johnsen. She notes that being active in research helps bring current environmental engineering issues into the classroom for students.

https://engineering.uga.edu/team_member/jenna-jambeck/
https://youtu.be/Ue-1-encERg

Why Are Plastics So Popular?

Plastics are Addictive & Forever

We are addicted to plastics, simply because they do the job so well that we cannot live without them. We don't think what will happen to the plastics that we just threw away. That plastics we just wasted will be on this planet for thousands of years. The plastics we disposed are already coming into our food system.

"Plastics are marvellous. There is no getting away from them. Through their intrinsic properties, plastic materials have found ubiquitous application in building and construction, electronics, automotive design, a myriad of health applications, packaging, paints and coatings, adhesives and energy production; the list goes on and on. It is hard to think of any area of life that hasn't been massively impacted by plastics; indeed, life without plastics seems unimaginable today. However, plastics have a dark side.

Plastics are typically designed to have a service life of 1–50 years and by far the largest sector for plastics is short-term, single-use packaging for food, beverages, tobacco products and the like. Thus, of the ~348 million metric tons produced in 2017 **(450 million metric tons in 2025)**, ~40% was for single-use products composed of (linear) low, medium and high density polyethylene (PE), polypropylene (PP) and polyethylene terephthalate (PET). Not surprisingly, these polymers are three of the four most heavily utilized plastics, accounting for roughly two-thirds of the production of non-fibre plastics. Only the key construction material polyvinylchloride (PVC) rivals these numbers (it accounts for ~12% of the market). Polystyrene, and thermosetting polyurethane are way behind, and every other polymer you can think of or name pales into insignificance.

So, coming up on half of all plastics used today are for single-use items. For those of us who are old enough to remember what life was like 20 or more years ago, an unfortunately uncommon refrain is, 'how did we get to this?' Take for example the ubiquitous 330 ml plastic bottle of water. **Somehow, not too long ago, life went along fine without them.**"

Gibb 2019, Plastics are forever, Nature Chemistry, 11: 394–395.

Plastics are Practical: The Urgent Efforts to Save Winter in the Alps

Sun-blocking plastic fabric drapes the tip of the Rhône Glacier in Switzerland. A cave dug each summer in the shifting ice has attracted tourists since 1870. For now, the year-round, 12-acre cover preserves enough ice to house the cave.

Precious snow is covered with fabric to protect it from melting over the summer at Diavolezza, a Swiss resort. Natural snow has become so unreliable in the Alps that the ski industry now depends on making it artificially and storing it in depots.

https://www.nationalgeographic.com/magazine/article/saving-winter-in-the-alps-feature?cmpid=org%3Dngp%3A%3Amc%3Dcrm-email%3A%3Asrc%3Dngp%3A%3Acmp%3Deditorial%3A%3Aadd%3DPlanet_Possible_20220222%3A%3Arid%3DFF526C1F1B0738788B420FE1D0034350&loggedin=true

Save Our Glacier: Using Polyethylene?

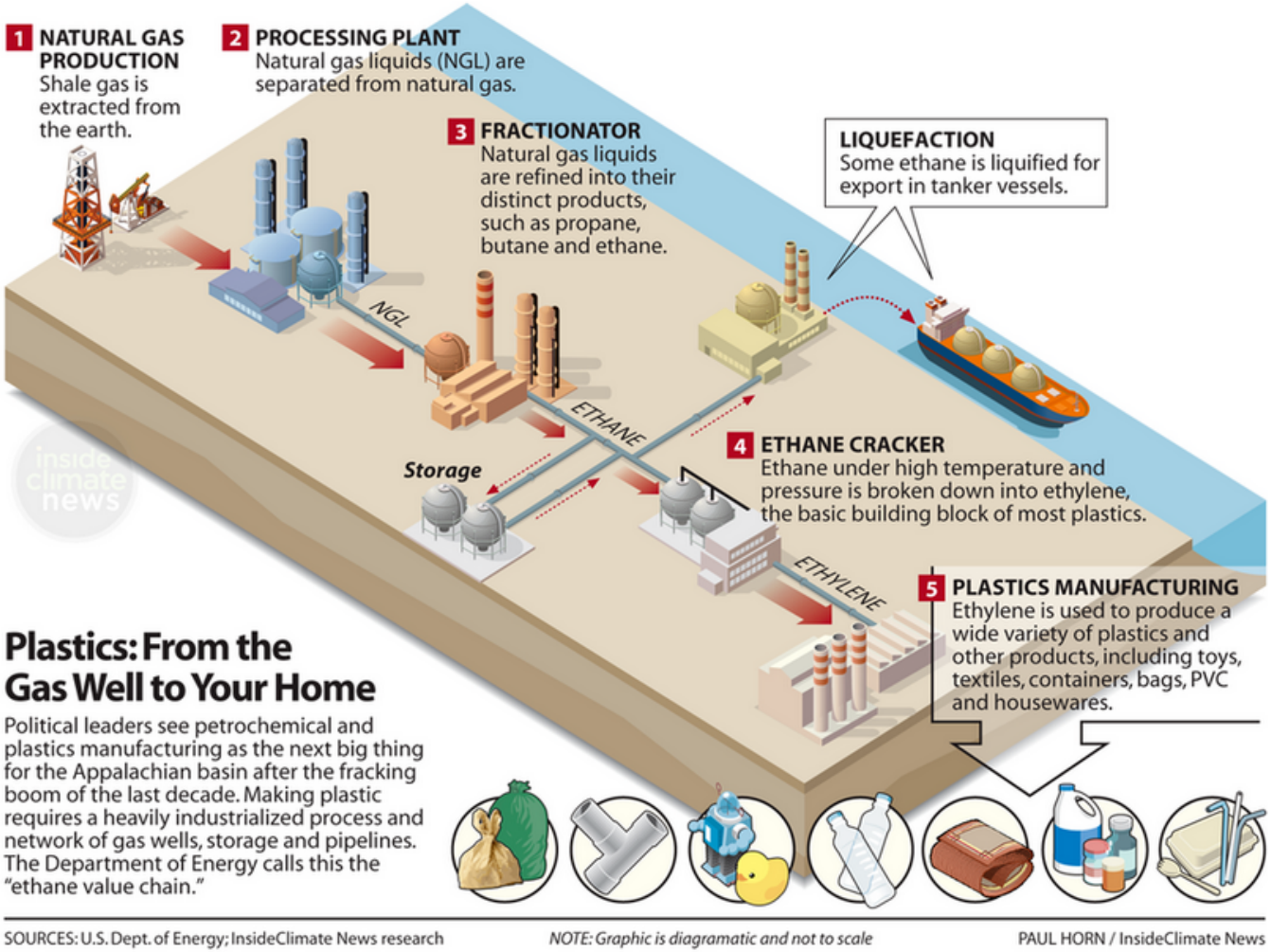
Cost: $12 million per square mile

Workers cover the ski slopes on the Pitztal Glacier in Austria with an innovative white fleece in an effort to protect the mountain from glacier melting.

https://www.scientificamerican.com/article/could-giant-blankets-and-other-extreme-actions-save-glaciers/

Plastics Business is Booming, but It Harms Environment

Business is Booming, But Public Anger Toward Plastics Grows With Environmental Harms



https://www.kqed.org/science/1956117/business-is-booming-but-public-anger-toward-plastics-grows-with-environmental-harms

The Circle of Plastics

Nurdles
Microplastics
Nanoplastics

Microplastics

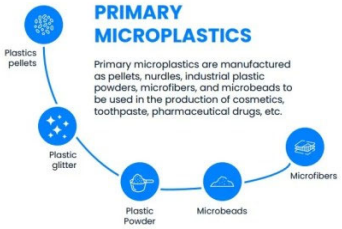
Microplastic particles

Primary microplastics: Industrial pellets that serve as precursors for manufactured plastic products.
Any plastic manufactured to be < 5 mm. Can be a finished product (e.g., microbeads, fiber)

Secondary microplastics: Fragments or fibers of plastics derived from the breakdown of larger plastic products.

Primary microplastics are specifically manufactured for commercial use and can take the form of pellets, nurdles, industrial plastic powders, microfibers, and microbeads. These materials are commonly found in cosmetics, toothpaste, pharmaceutical drugs, and other products.

Secondary microplastics, on the other hand, are the result of larger plastic items breaking down into smaller pieces over time. This breakdown occurs under various chemical, physical, and biological conditions.



Plastic pellets
Glitter made from plastic
Powdered plastic
Microbeads
Microfibers

Plastic packaging
Particles from tire wear
Synthetic textile fibers
Fishing gear (nets, lines, traps)
Tea bags

https://www.prescouter.com/2023/06/how-to-avoid-microplastics/

Nurdle (aka “mermaid tears”) is a specific type of primary microplastic, and always an intermediate "raw material."

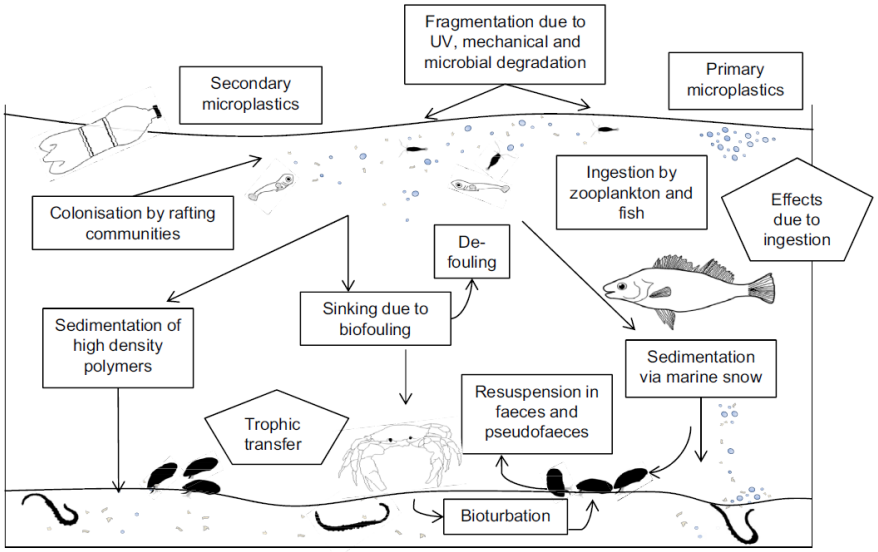


Fig. 1. Potential pathways for the transport of microplastics and its biological interactions.

Wright 2013, The physical impacts of microplastics on marine organisms: A review

Microplastics: Definition is Arbitrary

A wide variety of environmental factors (such as exposure to UV radiation, wind, waves, seawater, and bacteria) cause plastic waste to experience concurrent influences leading to cracking, surface erosion, abrasion, and breakdown to pieces of different sizes (Min 2020).

Richard Thompson, the oceanologist who first coined the term "microplastic" in 2004 to describe difficult-to-capture bits under 2 mm in length (Buranyi 2019). This definition was later revised in 2009. In the study of small plastic particles found in the environment, a team of scientists got together to define certain terms (Arthur 2009, Thompson 2019). At the workshop, microplastics were defined as plastic particles smaller than 5 mm. **Why 5 mm?** The 5 mm upper size was chosen to focus the microplastics discussion on possible ecological effects other than physical blockage of gastrointestinal tracts. Though "micro" infers the need for microscopy to view these plastic pieces, due to the early state of research the Steering Committee chose not to exclude visible components of the small plastic spectrum and thus set the upper limit at 5 mm. **Perhaps when the science advances, "small plastics" that can be seen without the aid of microscopy will be assigned to a separate category and only microscopic polymer fragments will be included as "microplastics**."

While there is no requirement for a "lower bound" in size, as a practical matter **defining microplastics as those that range between 5 mm and 333 µm** recognizes the common use of 333 µm (or 335 µm) mesh neuston nets commonly used in the field to capture plankton and floating debris (Barrows 2017). The neuston net had a rectangular opening 45 cm high x 95 cm wide, a 4 meter-long net, and a 31 cm high x 9 cm diameter, 335 µm mesh cod end (Barrows 2017).

A neuston net

K. Min, J.D. Cuiffi, & R.T. Mathers 2020, Ranking environmental degradation trends of plastic marine debris based on physical properties and molecular structure, Nature Communications, 11: Article number: 727 (2020)

Buranyi 2019, The missing 99%: why can't we find the vast majority of ocean plastic? https://www.theguardian.com/us-news/2019/dec/31/ocean-plastic-we-cant-see.

Arthur 2009, Microplastic marine debris (Arthur, C., Baker, J., Bamford, H., Eds., Proceedings of the International Research Workshop on the Occurrence, Effects and Fate of Microplastic Marine Debris. Sept 9-11, 2008. NOAA Technical Memorandum NOS-OR&R-30, 2009. p. 10.)

Thompson 2019, Microparticles in the environment, pp. 60-81, in Plastics and the Environment, R.M. Harrison & R.E. Hester, Eds.. Royal Society of Chemistry.

Barrows 2017, Grab vs. neuston tow net: a microplastic sampling performance comparison and possible advances in the field, Anal. Methods, 9: 1446-1453, 2017.

Hidalgo-Ruz 2012, Microplastics in the marine environment: A review of the methods used for identification and quantification, Environmental Science & Technology 2012, 46, 6, 3060-3075.

Eriksen 2014, Plastic pollution in the world's oceans: More than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea, PLoS ONE 9(12): e111913. December 2014. https://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0111913&type=printable

Nanoplastics: Definition is Arbitrary

Nanoplastic particles

Primary nanoplastics: Nanoplastics manufactured, such as those contained in personal care products.

Secondary nanoplastics: Fragments or degradation products of macro and microplastics.

Definition

Nobody has been able to define what nanoplastics, more generally nanoparticles, are. A variety of different definitions have been proposed over the years. Nanoplastics have been defined as plastic particles with at least 50% of particles having at least one dimension <100 nm (Mattsson 2015), <1 µm (da Costa 2019), or <333 µm (Mintenig 2018).

Mesoplastic	~5–20 mm
Large microplastic	~1–5 mm
Small microplastic	~20–999 µm
Nanoplastic	<1 µm

Nanoplastics can be released into the environment directly or can be formed when larger plastic items degrade and fragment under the impact of various environmental stressors (Mintenig 2018). The actual fragmentation processes are unknown, but it is widely assumed that the fragmentation into small microplastics and eventually into nanoplastics is one of the explanations for **the 'missing plastic'** budget, a term defined by Cozar et al., who detected lower microplastics concentrations in the open ocean surfaces than predicted by their model (Cozar 2014).

Regardless of the definition of plastic particles, one challenge posed by microplastics and nanoplastics is that their small size makes them easier to (consciously or unconsciously) ingest. Ingestion of microplastics could have detrimental impacts on wildlife health. The small size of these particles makes them difficult to track and monitor; evidence on their impacts and behaviour is therefore currently very limited. (https://ourworldindata.org/faq-on-plastics#what-are-microplastics)

Hidalgo-Ruz 2012, Microplastics in the marine environment: A review of the methods used for identification and quantification. Environ. Sci. Technol. 46: 3060.
González-Pleiter 2019, Secondary nanoplastics released from a biodegradable microplasticseverely impact freshwater environments, Environ. Sci.: Nano, 2019, 6, 1382
Mattsson 2015, Nano-plastics in the aquatic environment (K. Mattsson, L. A. Hansson and T. Cedervall, Environ. Sci.: Processes Impacts, 2015, 17, 1712–17218).
Mintenig 2018, Closing the gap between small and smaller: towards a framework to analyse nano- and microplastics in aqueous environmental samples, Environ. Sci.: Nano, 5:1640-1649, 2018.
Cozar 2014, Plastic debris in the open ocean, Proc. Natl. Acad. Sci. U. S. A., 2014, 111, 10239–10244. https://www.pnas.org/content/pnas/111/28/10239.full.pdf
da Costa 2019, Nanoplastics in the environment, pp. 82-105, in Plastics and the Environment, R.M. Harrison & R.E. Hester, Eds.. Royal Society of Chemistry.

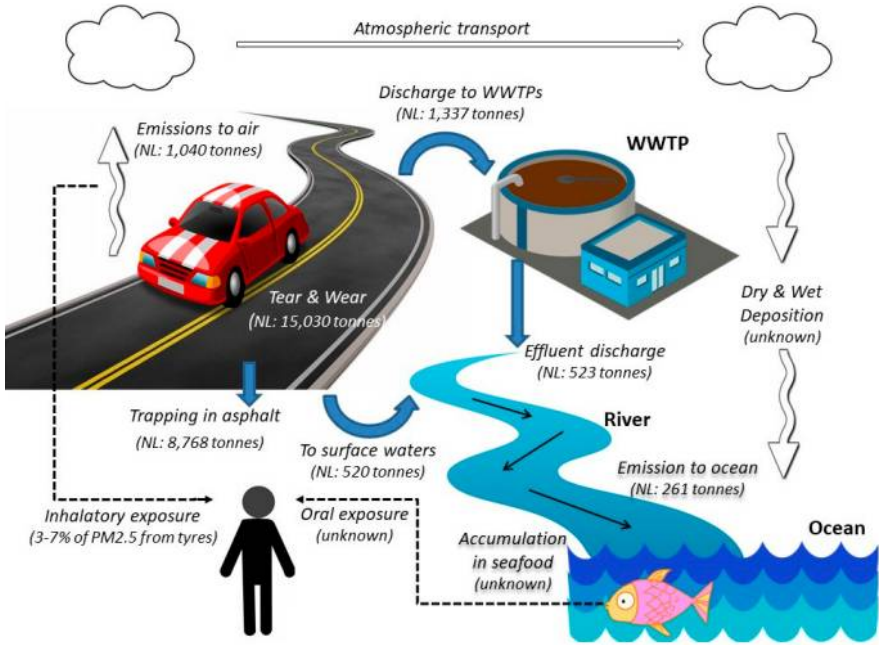
ter Halle, A. et al. Understanding the fragmentation pattern of marine plastic debris. Environ. Sci. Technol. 50, 5668–5675 (2016).

Poulain, M. et al. Small microplastics as a main contributor to plastic mass balance in the North Atlantic Subtropical Gyre. Environ. Sci. Technol. 53, 1157–1164 (2019).

Ter Halle, A. et al. Nanoplastic in the North Atlantic Subtropical Gyre. Environ. Sci. Technol. 51, 13689–13697 (2017).

Stealthy Sources of Microplastics

Wear and tear from tires significantly contributes to the flow of (micro-)plastics into the environment. The estimated per capita emission ranges from 0.23 to 4.7 kg/year, with a global average of 0.81 kg/year. Emissions and pathways depend on local factors like road type or sewage systems. The relative contribution of tire wear and tear to the total global amount of plastics ending up in our oceans is estimated to be 5-10%. In air, 3-7% of the particulate matter is estimated to consist of tire wear and tear, indicating that it may contribute to the global health burden of air pollution which has been projected by the World Health Organization (WHO) at 3 million deaths in 2012. The wear and tear also enters our food chain, but further research is needed to assess human health risks. Tire wear and tear is a stealthy source of microplastics in our environment, which can only be addressed effectively if awareness increases, knowledge gaps on quantities and effects are being closed, and creative technical solutions are being sought.



Kole 2017, Wear and tear of tyres: A stealthy source of microplastics in the environment

Microfibers from Synthetic Clothes

Thousands of plastic microfibers are shed when synthetic clothes get washed.

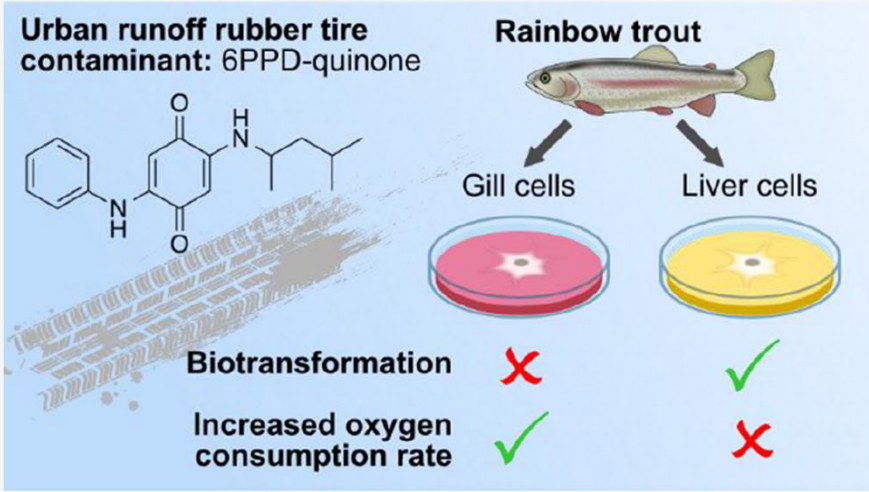
Groundbreaking study finds 13.3 quadrillion plastic fibers in California's environment. Report reveals far more microfibers than there are stars in the Milky Way – and they can easily enter oceans and waterways.

https://www.theguardian.com/us-news/2020/oct/16/plastic-waste-microfibers-california-study?CMP=oth_b-aplnews_d-1

Mitochondrial Dysfunction In Vitro by Tire Rubber-Derived Contaminants

ABSTRACT: N-(1,3-Dimethylbutyl)-N′-phenyl-p-phenylenediamine-quinone (6PPD-quinone), a rubber tire oxidation product found in road runoff, is highly and acutely toxic to selected salmonids including coho salmon, brook trout, and rainbow trout but not other fish species and invertebrates studied to date. Sensitive species displayed increased ventilation and gasping, suggesting a possible impact on respiration. Here, adherent cell lines RTL-W1 and RTgill-W1 were exposed to 5–80 μg/L 6PPD-quinone, and cytotoxicity, oxygen consumption rate (OCR), and biotransformation of 6PPD-quinone were measured to assess the ability of 6PPD-quinone to uncouple mitochondrial respiration *in vitro*. RTL-W1 cells were not sensitive to 6PPD-quinone, and exposure did not result in significant impacts on cytotoxicity or OCR. In contrast, RTgill-W1 cells demonstrated decreased cell viability at 80 μg/L and a 2-fold increase in OCR at 20 μg/L. Effects appear to be partly driven by toxicokinetic differences where incubation of RTL-W1 cells with 6PPD-quinone led to almost quantitative conversion of 6PPD-quinone into a suspected hydroxy-metabolite, which was not observed in RTgill-W1 cells. Exposure studies with primary cultures of rainbow trout gill cells indicated that 6PPD-quinone increased OCR by uncoupling the mitochondrial electron transport chain. Together, these findings suggest that 6PPD-quinone toxicity might be driven by a tissue-specific disruption of mitochondrial respiration.

KEYWORDS: *N-(1,3-dimethylbutyl)-N′-phenyl-p-phenylenediamine-quinone, Oncorhynchus mykiss, cell lines, in vitro, oxidative phosphorylation, uncoupler*



Mahoney 2022, Exposure to the tire rubber-derived contaminant 6PPD-quinone causes mitochondrial dysfunction in vitro

The Missing 99%: Why Can't We Find the Vast Majority of Ocean Plastic?

Every year, 8 million tons of plastic enter the ocean. But for at least a decade, the biggest question among scientists who study marine plastic hasn't been why plastic in the ocean is so abundant, but why it isn't. What scientists can see and measure, in the garbage patches and on beaches, accounts for only a tiny fraction of the total plastic entering the water. So where is the other 99% of ocean plastic?

Professor Anela Choy's team found that at a depth of 200 m, there were nearly 15 bits of plastic in every liter of water, similar to the amount found at the surface of the so-called garbage patches.

Nanoplastic research is still in its infancy. But laboratory tests show that unlike microplastics, **nanoplastics are small enough to accumulate within the bloodstreams and cell membranes of a range of organisms**, even passing the blood-brain barrier in a test on Japanese medaka fish, and cause various toxic effects, including neurological damage, and reproductive abnormalities.

Plastic retained in front of an extended cork line in the Pacific ocean.

Microplastics may be concentrated in the deep ocean, researchers say. Photograph: Bobby Yip

Pieces of human society': deep ocean may be riddled with microplastics
Quantity of particles hundreds of meters underwater off California is on par with Great Pacific Garbage Patch, study finds. (Choy 2019, The vertical distribution and biological transport of marine microplastics across the epipelagic and mesopelagic water column, Scientific Reports 9: 7843, 2019).

Stephen Buranyi, 2019 https://www.theguardian.com/us-news/2019/dec/31/ocean-plastic-we-cant-see
Katharine Gammon 2019, https://www.theguardian.com/environment/2019/jun/06/plastics-microplastics-ocean-study

Our fruits and veggies are sucking up microplastics through their roots

Plastic is everywhere—and now it's in our produce. (By Kristin Toussaint, 06-25-2020)
Microplastics—tiny pieces of plastic less than 5 millimeters in length—can now be found throughout the ocean and all over protected national parks. They've been found in our seafood, salt, and even beer. Now, new research has shown that **microplastics can penetrate the roots of crops, traveling up the plant into the parts we eat**.

Two peer-reviewed studies published today highlight the presence of microplastics in our food and call for more research into the relationship between plastic and our health. One from the University of Catania, in Italy, and published in Environmental Research found microplastics in produce from both supermarkets and local produce sellers in Catania. Researchers took samples of carrots, lettuce, broccoli, potatoes, apples, and pears, showing for the first time, they say, the presence of these tiny pieces of plastic in fruits and vegetables that we eat. Another study published in Nature Sustainability from researchers at Yantai Institute of Coastal Zone Research, in China, and Leiden University, in the Netherlands, found that **cracks in the roots of lettuce and wheat crops can take in microplastics from the surrounding soil and water. Those microplastics can then travel from the roots up to the edible parts of the crop**. Though researchers already knew that very, very small particles—about 50 nm in size—could penetrate plant roots, Willie Peijnenburg, an environmental toxicology professor at Leiden University, says his study found that particles about 40 times that size can get into plants as well.

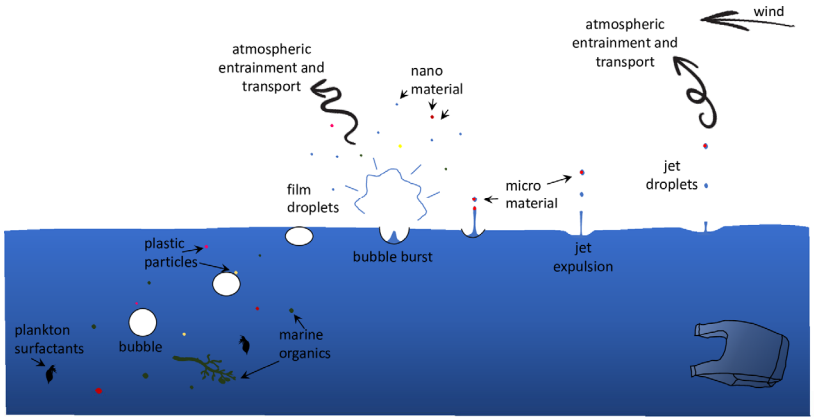
Peijnenburg's study was done in a lab and looked at two different ways of growing plants: hydroponically in wastewater, and in sandy soil to which wastewater was added. Peijnenburg says they tried to simulate how many countries use wastewater to irrigate their crops, and that those larger microplastics could get in through the roots in part because they were flexible plastics. "They are spherical particles with a size up to 2 micrometers and they are a little bit flexible, so they can themselves more or less be squeezed into the small pores' cells of the plant roots," he says. "Another mechanism is that inside newly developed roots there are small cracks present, and then the particles [go into] those cracks, so it's even possible that bigger particles than the ones we studied might also be taken up by plants." Aside from the possible health impacts, he hopes the presence of microplastics in our crops is something we simply don't want from a sustainability point of view as well.

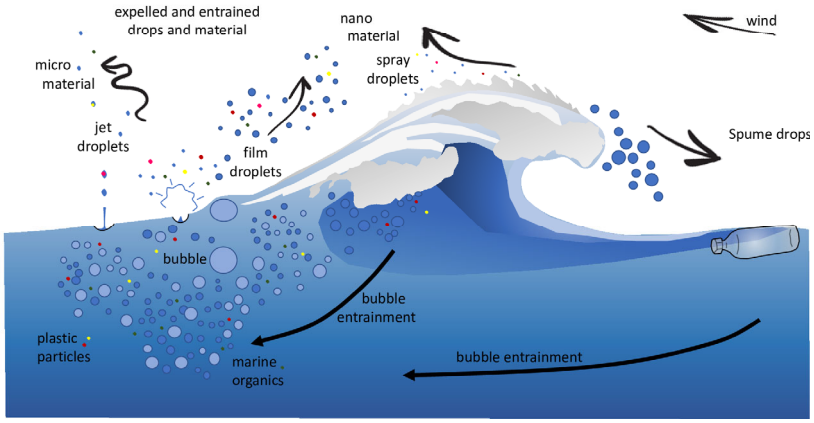
In the Italian study, the produce from local sellers was found to have higher levels of microplastics than the produce bought at supermarkets. The smallest pieces of plastic were found in carrots at about 1.5 µm, and the largest, found in lettuce, were 2.5 µm. Carrots were the most contaminated of the vegetables sampled, and for the fruits, apples were more contaminated with microplastics than pears. There were more microplastics found in the fruits than the vegetables, which researchers think has to do with how older fruit trees have a larger root system than vegetable plants. We don't yet know enough about how ingesting microplastics affects our health, but researchers of both studies say this presence of plastics in our crops is worrying, and more research on the health consequences is needed. Even if there aren't harmful side effects to ingesting super-tiny pieces of plastic (though researchers note there may be long-term impacts, since plastic can contain harmful chemical additives), Peijnenburg adds that "simply, most people don't like to be eating plastics." Both studies have been shared with the Plastic Health Coalition ahead of an April 2021 summit in Amsterdam, organized by the Plastic Soup Foundation, that will look into the relationship between plastic and health.

https://www.fastcompany.com/90521397/our-fruits-and-veggies-are-sucking-up-microplastics-through-their-roots?partner=rss&utm_campaign=rss+fastcompany&utm_content=rss&utm_medium=feed&utm_source=rss

Atmospheric Microplastics from the Ocean

The answer is blowing in the wind.





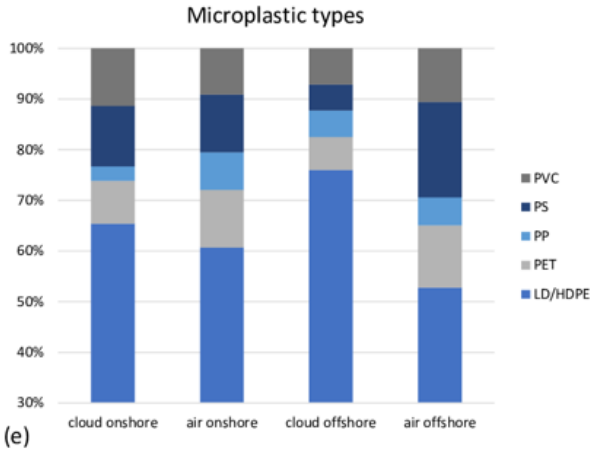
Ocean to atmosphere particle transfer processes

It appears that some plastic particles could be leaving the sea and entering the atmosphere along with sea salt, bacteria, virus' and algae. This occurs via the process of bubble burst ejection and wave action, for example from strong wind or sea state turbulence. Our results indicate a potential for MPs to be released from the marine environment into the atmosphere by sea-spray giving a globally extrapolated figure of 136,000 ton/yr blowing on shore.

Air water droplet sampler, Caltech Active Strand Cloudwater Collector (CASCC), fan forced sampling of vapour droplets >10µm.

Active pumped air sampler, positioned 1.5m above the surface facing offshore.

(h)



(e)

Allen 2020, Allen S, Allen D, Moss K, Le Roux G, Phoenix VR, Sonke JE (2020) Examination of the ocean as a source for atmospheric microplastics. PLoS ONE 15(5): e0232746. https://doi.org/10.1371/journal.pone.0232746

https://grist.org/climate/that-ocean-breeze-may-be-full-of-tiny-bits-of-plastic/

Plastics in the Earth System

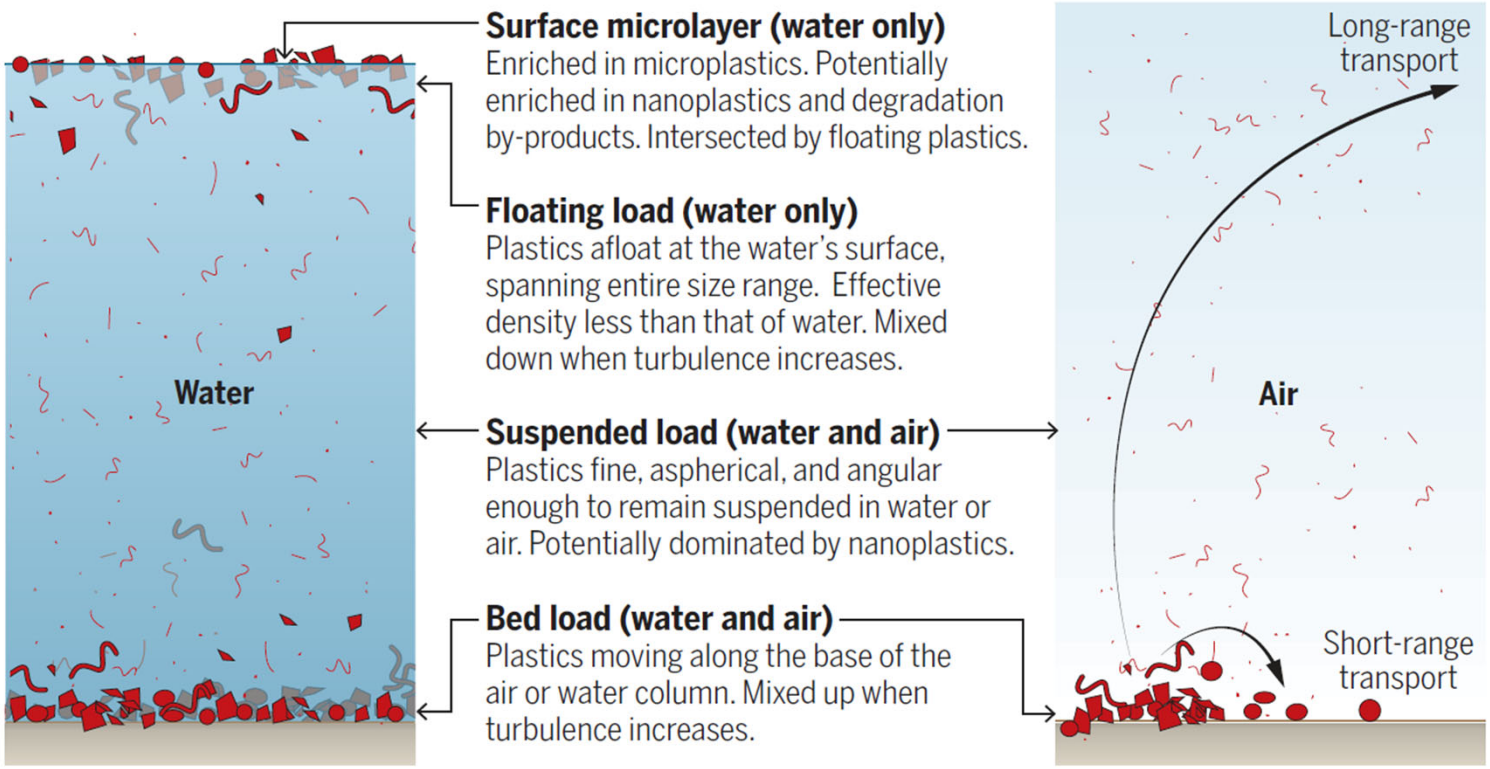
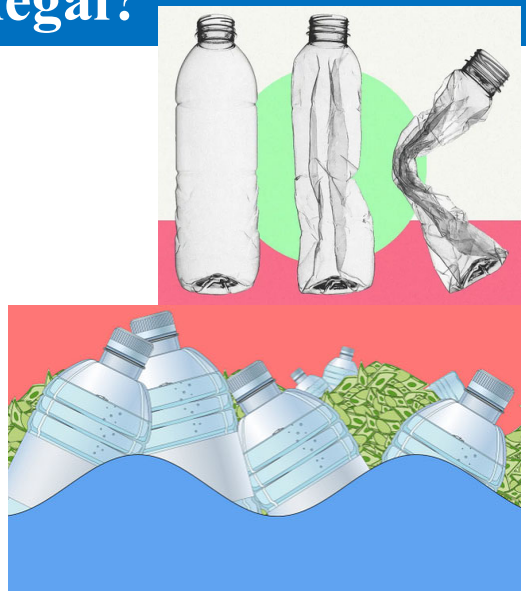


Fig. 4. Distribution of plastics in water and air. In water, four layers are considered: the surface microlayer, the floating load (the most often studied fraction in water), the suspended load (seldom studied in water), and the bed load (somewhat studied in water as deposited materials). Plastics that are less dense than water tend to float and become concentrated in the surface microlayer and floating load, whereas plastics that are denser than water tend to accumulate in the bed load. All plastics are denser than air. Thus, in air, only two layers are considered: the suspended load and the bed load.

Stubbins 2021, Plastics in the Earth system

Disposable Plastic is Bad for the Environment, But is It Illegal?



Coca-Cola and Pepsi are about to find out. By Mark Wilson, 2020

Coca-Cola. Nestlé. Pepsi. Mars. P&G. These are some of the world's most iconic brands. They are also some of **the biggest plastic polluters** on the planet. They sell goods in single-use plastic containers, which end up in our oceans and never biodegrade. Whether we buy their products or not, we're all affected by their footprint. And in turn, a landmark lawsuit by **the Plastic Pollution Coalition and Earth Island Institute** has been filed in California against all of the aforementioned corporations and several other major food, beverage, and consumer product companies. The groups are suing for damages to repair the problem of plastic waste.

The case is important to watch, because it argues that plastic isn't just a pollutant, but **an actual design defect these companies are liable for producing**. As the complaint outlines in clear detail: More than 90% of plastic packaging can't be recycled, so it's discarded as waste. The single-use packaging ends up in the oceans forever. **The societal cost of that single-use plastic waste is far greater than any benefit (just a little bit of convenience) to consumers**. In fairness, businesses are eagerly looking for alternative packaging solutions to single-use plastics. Nestlé, the largest food packaging company in the world, has committed to eliminating all single-use plastic and adopting 100% recycled and biodegradable packaging by 2025 (though the definition of recyclable is up for debate). Unilever and P&G are part of a coalition of brands pushing reusable packaging in an effort dubbed Loop.

Gass suggests that the suit, if successful, could force companies to invest even more than they **already** do in alternatives, with a greater sense of urgency. Win or lose, this case marks new ground: If you make a product packaged in single-use plastic, you just might be sued for it.

https://www.fastcompany.com/90486395/6-ways-to-learn-a-foreign-language-for-free-while-youre-sheltering-in-place-for-covid-19
https://www.fastcompany.com/90425011/coca-cola-nestle-and-pepsico-are-the-worlds-biggest-plastic-polluters-again
https://www.plasticpollutioncoalition.org/blog/2020/2/27/earth-island-institute-and-plastic-pollution-coalition-take-on-big-plastic
https://www.fastcompany.com/90296956/a-coalition-of-giant-brands-is-about-to-change-how-we-shop-forever-with-a-new-zero-waste-platform

History Repeats Itself

The Jungle (1906)

Sinclair. "I aimed at the public's heart (workers' right), and by accident I hit it in the stomach."

Upton Sinclair : The Jungle

A NAUSEATING JOB, BUT IT MUST BE DONE
(President Roosevelt takes hold of the investigating muck-rake himself in the packing-house scandal.)

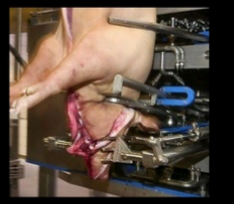
- The effects from the accusations against the meat packing industry in *The Jungle* led to investigations into the food and patent medicine industry in general.

Upton Sinclair's *The Jungle*

- Laws passed after Congress' investigation:
- ***Meat Inspection Act***
  - USDA (US Department of Agriculture)
- ***Pure Food and Drug Act***
  - FDA (Food and Drug Administration)

Criticism of Upton Sinclair's *The Jungle*

- Was Sinclair *too biased*? Was Sinclair just anti-capitalist trying to attack the meat industry? Did Sinclair *exaggerate* about what was *really* taking place in the meat-packing factories?
- *The Jungle's* fictitious characters tell of men falling into tanks in meatpacking plants and being ground up with animal parts, then made into "Durham's Pure Leaf Lard."
- Historian Stewart H. Holbrook argues this was nonsense. Sinclair's *The Jungle* was far from reality:
  - ***"The grunts, the groans, the agonized squeals of animals being butchered, the rivers of blood, the steaming masses of intestines, the various stenches . . . were displayed along with the corruption of government inspectors and, of course, the callous greed of the ruthless packers."***



https://www.slideshare.net/iRawrPanda/upton-sinclair-and-critics-of-the-jungle

Criticism of Upton Sinclair's *The Jungle*

- When the sensational accusations of *The Jungle* became worldwide news, foreign purchases of American meat dropped by *HALF!* American meat packing companies were losing a huge market share.
- The meatpackers looked for new regulations to give their markets a calming sense of security so the public (and consumers across the world) would trust and buy their meat instead of fearing what was in it.
- Congressional hearings for what became the Meat Inspection Act of 1906 were held by Congressman James Wadsworth's Agriculture Committee:
- *"Knowing that a new law would allay public fears fanned by The Jungle, bring smaller competitors under regulation, and put a newly-laundered government stamp of approval on their products, the major meat packers strongly endorsed the proposed act and only argued over who should pay for it."*

The 1906 Pure Food and Drugs Act

The Pure Food and Drug Act (1906)

Signed by President Theodore Roosevelt in 1906.

It was commonly known as the Harvey Law.

Commemorative 50th Anniversary of Pure Food and Drug Laws stamp first issued by the U.S. Postal Service on June 27, 1956

The Federal Food, Drug, and Cosmetic Act (1938)

Signed by President Roosevelt in June 1938.

New drugs have to be tested for safety before marketing, and the result has to be submitted to FDA in a new drug application (NDA).

Point:
Drink a milk from a grocery → Safe

The Kefauver-Harris Amendments (1962)

Drug manufacturers must prove that their products were both safe and effective for approval.

Safety and effectiveness should consist of "adequate and well-controlled" scientific experiments carried out by "experts qualified by scientific training."

Thalidomide devastation

http://www.fda.gov/ForConsumers/ConsumerUpdates/ucm322856.htm

White Pollution

The term "**white pollution**" used to mean that discarding too many white plastic bags or single-use plastic tableware into our environment.

https://polyfill.com.vn/white-pollution-and-how-manufacturers-deal-with-it/

white pollution and how manufacturers deal with it

White Pollution: The plastic things viz., plastic bottles, plastic bags, plastic silverware and so on kills the animals and degrades the quality of the environment on the earth.

Plastic derived from the petrochemical industry with a high molecular weight constitutes about 9-13% of total solid waste. Since the industrial revolution, the use of plastic has increased manifold without improving its adequate management as a waste. Most of the plastic waste produced in the world is mainly from packaging industry followed by building and construction. **Plastic is a non-degradable deadly pollutant to degrade environmental quality** and are known to remain in water and soil for years without making any change in their structure. Due to enormous generation, open burning of plastic is also preferred due to the lack of resource in the developing countries thus releasing toxic gases thereby causing air pollution. Plastic disturbs the balance of the environment by acting as physical barrier leading to the drainage of the drains, degrading soil properties, and are often ingested by the organisms ultimately leading to their death. Thus, it becomes more important to manage the plastic pollution keeping in view its detrimental impacts on the environment.

Hameed, M., Bhat, R., Dsingh, D.V., and Mehmood, M.A.: White pollution: A hazard to environment and sustainable approach to its management collapse, in *Innovative Waste Management Technologies for Sustainable Development,* 2020. IGI Global, Ch. 4 (pp.73-103).

https://www.semanticscholar.org/paper/White-Pollution-Hameed-Bhat/71b68a69ba4be5c07a0ff0734e48d265f441b387

https://www.dailymail.co.uk/femail/article-8628437/Infuriating-brainteaser-challenges-jellyfish-sea-plastic-bags.html?ITO=applenews

Planet Plastic

How Big Oil and Big Soda kept a global environmental calamity a secret for decades. Tim Dickinson, 2020

Every human on Earth is ingesting nearly 2,000 particles of plastic a week. These tiny pieces enter our unwitting bodies from tap water, food, and even the air, according to an alarming academic study sponsored by the World Wildlife Fund for Nature, dosing us with five grams of plastics, many cut with chemicals linked to cancers, hormone disruption, and developmental delays. Since the paper's publication last year, Sen. Tom Udall, a plain-spoken New Mexico Democrat with a fondness for white cowboy hats and turquoise bolo ties, has been trumpeting the risk: "**We are consuming a credit card's worth of plastic each week**," Udall says.

We've been slow to recognize that we're actually **in the midst of a plastic pandemic**. Over the past 70 years, we've gotten hooked on disposable goods and packaging — as plastics became the lifeblood of an American culture of speed, convenience, and disposability that's conquered the globe. Plastic contains our hot coffee and frozen dinners. It is the material of childhood, from Pampers to Playmobil to PlayStation 4. It cloaks our e-commerce purchases and is woven into our sneakers, fast fashion, and business fleece. Humans are now using a million plastic bottles a minute, and 500 billion plastic bags a year — including those we use to bag up our plastic-laden trash.

But the world's plastic waste is not so easily contained. **Massive quantities of this forever material are spilling into the oceans — the equivalent of a dump-truck load every minute**. Plastic is also fouling our mountains, our farmland, and spiraling into an unmitigatable environmental disaster. John Hocevar is a marine biologist who leads the Oceans Campaign for Greenpeace, and spearheaded the group's response to the BP oil spill in the Gulf. Increasingly, his work has centered on plastics. "This is a much bigger problem than 'just' an ocean issue, or even a pollution issue," he says. "We've found plastic everywhere we've ever looked. It's in the Arctic and the Antarctic and in the middle of the Pacific. It's in the Pyrenees and in the Rockies. It's settling out of the air. It's raining down on us."

https://www.rollingstone.com/culture/culture-features/plastic-problem-recycling-myth-big-oil-950957/
https://www.sfgate.com/entertainment/article/Planet-Plastic-15100964.php

Nano- & Microplastics in Our Body

Nanoplastics: We Are Eating Them

Mechanical weathering, biological action, and sunlight degrade primary plastics into smaller pieces, known as microplastics, typically up to 1–5 mm in size. Further breakdown may produce nanoplastics, which can be consumed by algae and bacteria and subsequently find their way up the food chain; nanoplastics, such as plastic beads found in personal care products, are also released directly into the environment. High-density plastics and biofouled materials undergo sedimentation, sinking to the ocean floor where they may persist for long periods. The absence of ultraviolet solar radiation at depth results in slower degradation times for these benthic plastics and longer persistence in the environment.

Microplastics have direct negative impacts on organisms in aquatic systems at both the physical and molecular levels: entanglement, smothering, and ingestion of plastic can occur, while plastics may also release toxic leachates that interfere with development and survival. Moreover, plastic pollution may cause indirect harm by acting as vectors for toxic chemicals that adsorb to the plastic surface, as well as potentially transporting invasive species long distances. Microplastic consumed by plankton, invertebrates, and fish can move through the food web and end up in species that are important to commercial fisheries. Plastic debris and fibers have already been identified in fish and shellfish sold for human consumption, as well as in some supermarket sea salts.

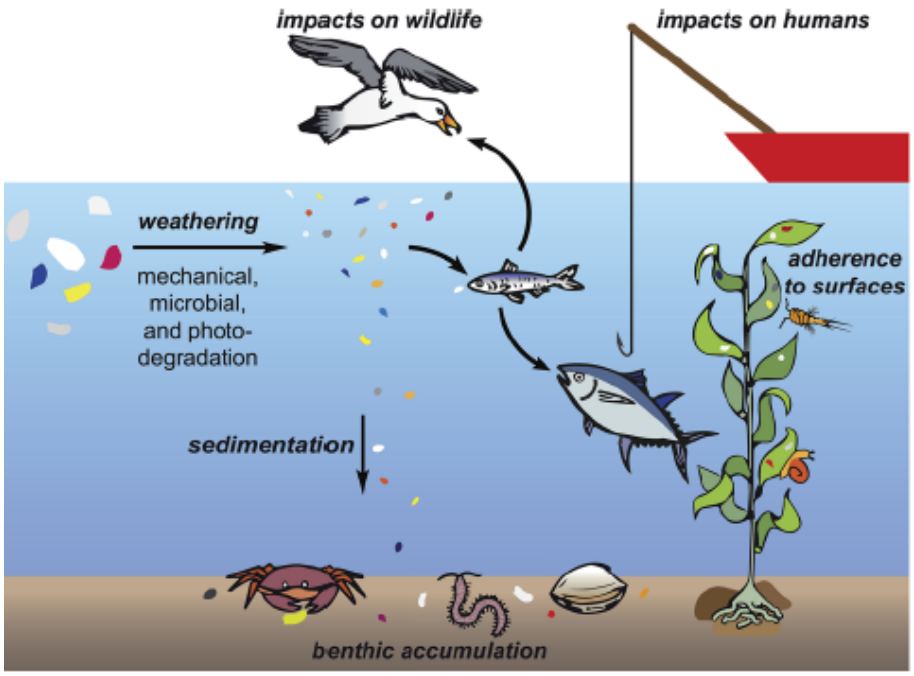


Fig. 1 Microplastic pollution in marine systems. Plastic debris undergoes weathering and is broken down into smaller particles, which may be ingested by invertebrates and fish. Predation of these organisms can result in microplastics infiltrating the entire food web, potentially affecting birds, marine mammals, and also humans

Lin 2016, Impacts of microplastics on plankton (Research highlights: impacts of microplastics on plankton, Environ. Sci.: Processes Impacts, 18, 160-163.

Americans Eat and Inhale Over 70,000 Plastic Particles Each Year

Plastics have for years been used to make nearly everything that surrounds us. But along the way, they escaped the confines of packaging and objects and settled in the environment, the food we eat and the air we breathe.

Americans are consuming and breathing in a lot of plastic, finds a new analysis published in the journal Environmental Science & Technology. Based on available data, Americans ingest an estimated 74,000 to 121,000 microplastic particles every year, the researchers found. However, the true number is probably much higher, because for some likely sources of microplastics, there were no strong data available.

If you live somewhere with clean, safe tap water, relying less on bottled water is a great place to start reducing your plastics exposure, Cox says. Bottled water was such a big contributor of microplastics that the researchers did a separate analysis; when people drink their water only from bottled sources, they ingest about 90,000 microplastic particles every year from that water, but people who drink only tap water get 4,000 of such particles a year.

"It's a 22-fold increase in plastic consumption from a single lifestyle choice," Cox says. "With these kinds of issues, small choices can make a big impact for you personally and for plastic pollution."

Mandy Oaklander, 2019. https://time.com/5601359/microplastics-in-food-air/

Nanoplastics through Food Webs

Sub-micron plastics (SMPs, size < 1 µm) are potentially taken up by plants. Serious concerns arise that how far SMPs can transfer from plants into food webs. Here, we show that lettuce takes up 250 nm gadolinium labelled polystyrene (PS) and polyvinyl chloride (PVC) SMPs from the soil. The polymer type influences the biodistribution of the particles in lettuce (roots and leaves) and the number of particles transferred from the plants to insects feeding on the treated lettuce. The SMPs were further transferred from insects to insect-feeding fish to accumulate mostly in the fish liver. No Gd was released from the particles upon biotransformation (formation of protein corona on the particles) in the plants or insects. However, Gd ion was detected in fish fed with PS-SMP treated insects, indicating the possible degradation of the particles. No biomagnification in fish was detected for either type of SMPs. We conclude that plastic particles can potentially transfer from soil into food webs and the chemical composition of plastics influences their biodistribution and trophic transfer in organisms.

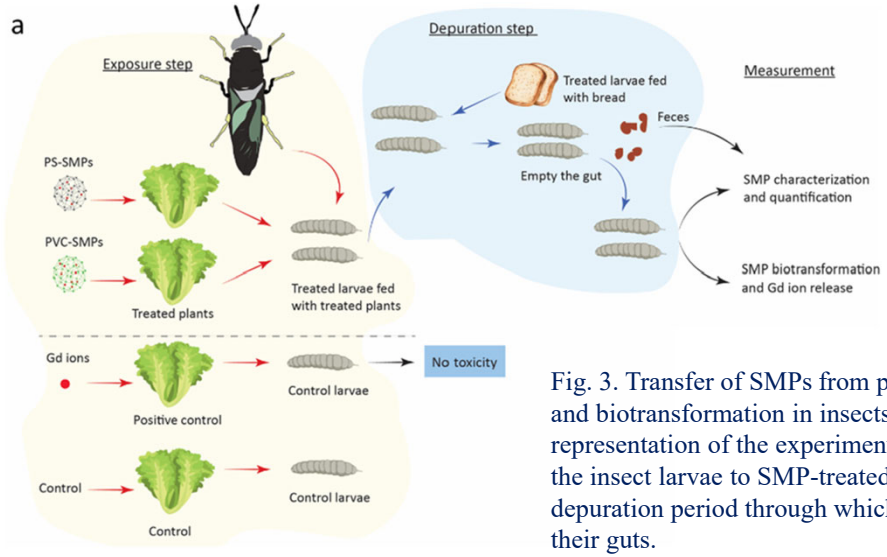
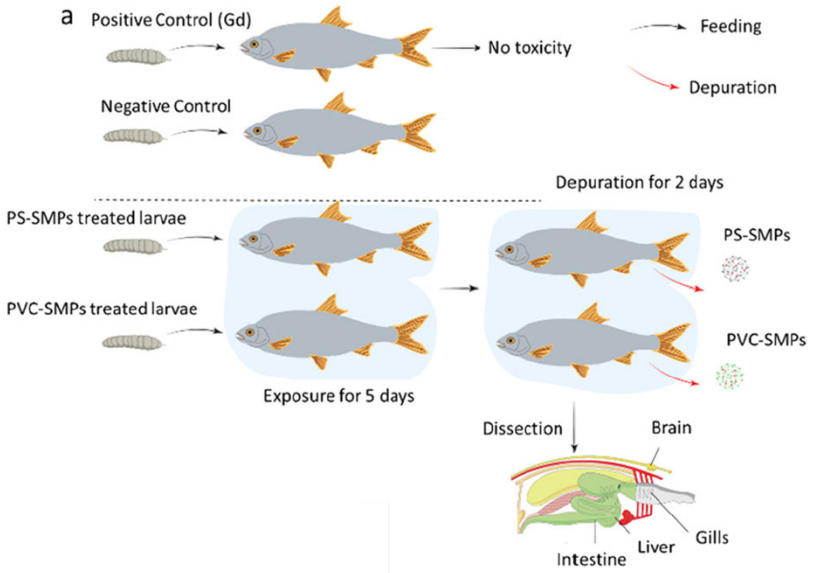


Fig. 3. Transfer of SMPs from plants to insect larvae and biotransformation in insects. a) Schematic representation of the experimental design of exposing the insect larvae to SMP-treated lettuces and the depuration period through which the insects emptied their guts.

Fig. 4. Transfer of SMPs from insect larvae to fish and consecutive biotransformation of SMPs in different physiological media. a) Schematic illustration showing the feeding of fish with insect larvae (fed with SMPs-treated lettuces and control lettuces). The illustration also shows the dissection of the fish tissues (gills, liver, intestine and brain).



Monikh 2022, Quantifying the trophic transfer of sub-micron plastics in an assembled food chain

Microplastics as Everywhere: A Commercial Opportunity

These 10 Non-Toxic Tools Helped Me Reduce Them in My Food. Starting at $6.

By An Uong. Published on May 25, 2025

After reading recent reports of the health risks associated with using plastic cutting boards and Teflon-coated cookware, I decided to replace all of my toxic kitchen tools with non-toxic alternatives, like wooden cutting boards and cast iron skillets. If you're currently taking stock of the questionable tools in your kitchen, it may feel daunting. Here are the 10 favorites I rely on to keep microplastics and chemicals out of my cooking, including a versatile wooden spatula, Pyrex glass food storage containers, a Lodge cast iron skillet, and more.

Writer-Loved Non-Toxic Kitchen Essentials

- Lodge 12-Inch Cast Iron Skillet, $26, originally $30
- Tramontina Seattle Tri-Ply Clad Stainless Steel 12-Inch Frying Pan, $35, originally $70
- Earlywood 10-Inch Multi-Purpose Wood Scraper and Spatula, $20
- WoodenHouse 8-Piece Wooden Utensil Set With Holder and Spoon Rest, $35, originally $40
- Freshware Bamboo Cutting Boards, Set of 3, $14
- Epicurean Kitchen Series Cutting Board, $30, originally $34
- Pyrex Simply Store Glass Food Storage Containers Set, 7-Pack, $30, originally $33
- ChefAide Silicone Spatula Set, Set of 5, $9, originally $10
- Nkove Stainless Steel Universal Tea Infuser, $6, originally $7
- OXO Good Grips 9-Inch Tongs With Silicone Heads, $17

- Key Points
- I replaced all of my black plastic utensils with non-toxic wooden ones like this WoodenHouse set and Earlywood scraper.
- To avoid forever chemicals found in nonstick cookware, I started using a Lodge cast iron skillet and stainless steel pans for everyday cooking.
- Instead of microwaving my food in plastic, I use Pyrex glass food storage containers.

https://www.foodandwine.com/writer-loved-kitchen-essentials-to-avoid-microplastics-amazon-11740854

A Plateful of Plastic: Visualizing the Amount of Microplastic We Eat

Microscopic pieces of plastic have been discovered in the most remote locations, from the depths of the ocean to Arctic ice. Another place that plastic is appearing is inside our bodies. We're breathing microplastic, eating it and drinking plastic-infused water every day. Plastic does not biodegrade. Instead, it breaks down into smaller pieces, and ultimately ends up everywhere, including in the food chain.

Sesame seeds Microplastic

Every week: 5 grams of plastic

Every month: 21 grams of plastic

Every 6 months: 125 grams of plastic

Every year: 250 grams of plastic

Every 10 years: 2.5kg of plastic

In our lifetime: 20kg of plastic

"We have been using plastic for decades but we still don't really understand the impact of micro- and nano-sized plastic particles on our health," said Thava Palanisami of Australia's University of Newcastle, who worked on the WWF study. "All we know is that we are ingesting it and that it has the potential to cause toxicity. That is definitely a cause for concern."

Simon Scarr https://graphics.reuters.com/ENVIRONMENT-PLASTIC/0100B4TF2MQ/index.html

Individual Exposure to Microplastics through the Inhalation Route

ABSTRACT: Human exposure to microplastics (MPs), especially from indoor air, has aroused growing public concern, but very little is known about the assessment of individual MPs inhalation exposure. In this study, a total of 30 volunteers were recruited from Shanghai, China. Both human inhaled indoor aerosol (HIA) and human exhaled breath (HEB) samples were pairwise collected for each participant and analyzed through micro-Raman imaging spectroscopy. MPs were detected in all samples, averaging 43 ± 16 (range of 11–92) items/m^3 for HIA and 12 ± 5 (range of 3–28) items/m^3 for HEB. Moreover, the dominant components in all samples were small fragment- and fiber-shaped MPs. It is estimated that the daily intake of HIA was roughly 704 ± 254 MPs items, most of which would deposited in the airway with 526 ± 203 MPs items, whereas 178 ± 75 MPs items could be daily discharged via HEB. The actual daily inhalation exposure of MPs could be overestimated by 1.33 times with the HIA-based approach and by 1.40 times for smaller MPs (<10 μm). These results suggest that integration of HIA and HEB should be considered when evaluating individual MPs exposure via respiration.

KEYWORDS: *microplastics, inhalation exposure, respiratory route, indoor aerosol, human exhaled breath, individual exposure*

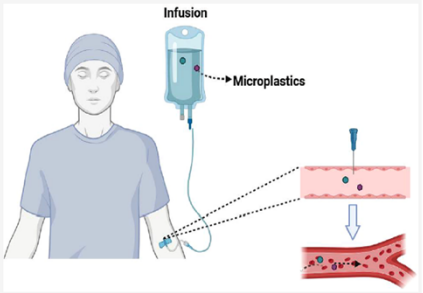
Geng 2023, Individual exposure to microplastics through the inhalation route: Comparison of microplastics in inhaled indoor aerosol and exhaled breath air

Microplastics Entry into the Blood by Infusion Therapy

Microplastics Entry into the Blood by Infusion Therapy: Few but a Direct Pathway

Long Zhu,[#] Mindong Ma,[#] Xizhuang Sun, Zhixin Wu, Yanyan Yu, Yulin Kang, Zheng Liu, Qiujin Xu,[*] and Lihui An[*]

ABSTRACT: Microplastic pollution is now ubiquitous in the environment, making human exposure to microplastics unavoidable. This results in the detection of microplastics in human bodies, including blood. However, the pathways through which microplastics enter the bloodstream still need to be clarified, despite the studies of several direct and indirect routes. Herein, the potential occurrence of microplastics in infusion therapy sets, including glass infusion bottles, plastic infusion bottles, plastic infusion bags, and plastic infusion tubes, was investigated. The results showed that a total of eight microplastics, ranging from 4 to 148 μm in size, were identified from three PP-bottled infusion, three PE-bagged infusion, and one glass-bottled infusion, consisting of PE, PA, PS, and PC, while no particles were detected in infusion tubes. The samples containing microplastics accounted for 11.66% of the total samples with 1−2 particles/unit. Although microplastics were detected in infusion solutions, microplastic exposure to the bloodstream via infusion therapy is minimal, owing to their low abundance. Nevertheless, these findings suggested that infusion therapy might be a direct pathway of microplastics entering the bloodstream, partially or fully explaining the presence of microplastics in human blood and tissues.



KEYWORDS: *Plastic particles, Exposure pathway, Infusion therapy, Blood, Health risk*

Potential Source of Microplastics in Infusion Solutions.

One plastic particle was detected in a glass-bottled infusion, indicating that microplastics detected in infusion solutions are not necessarily derived from the corresponding bottles.

This study first reported the presence of microplastics in infusion solutions. Importantly, it implied that microplastics in human blood, at least partially, are injected directly into the blood from IV therapy. The possibility of microplastics crossing cell walls cannot be completely ruled out, owing to the current availability of limited data. Further robust evidence is required to identify all sources of microplastics in the human circulatory system and tissues. Simultaneously, it is urgent to determine the adverse impacts of the appearance of microplastics in the bloodstream and tissues and to differentiate whether they are a potential cause or consequence of diseases resulting from human exposure to microplastics.

Zhu 2024, Microplastics entry into the blood by infusion therapy- Few but a direct pathway

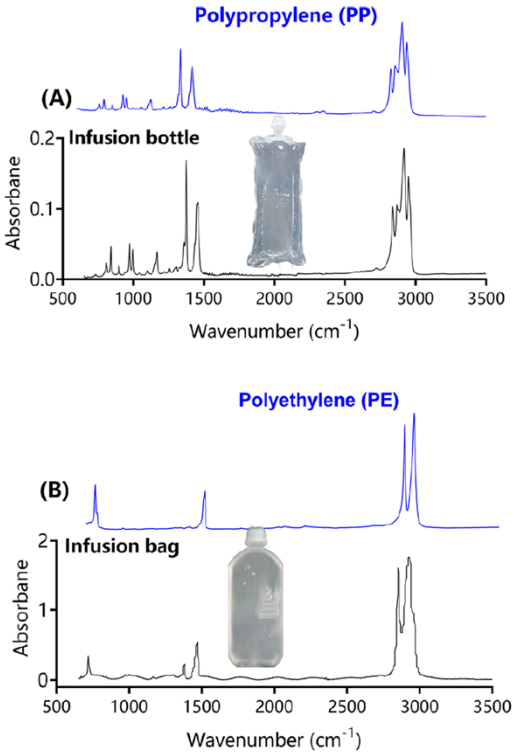


Figure 1. Polyethylene infusion bags (A) and polypropylene infusion bottles (B) identified by the FT-IR spectrum.

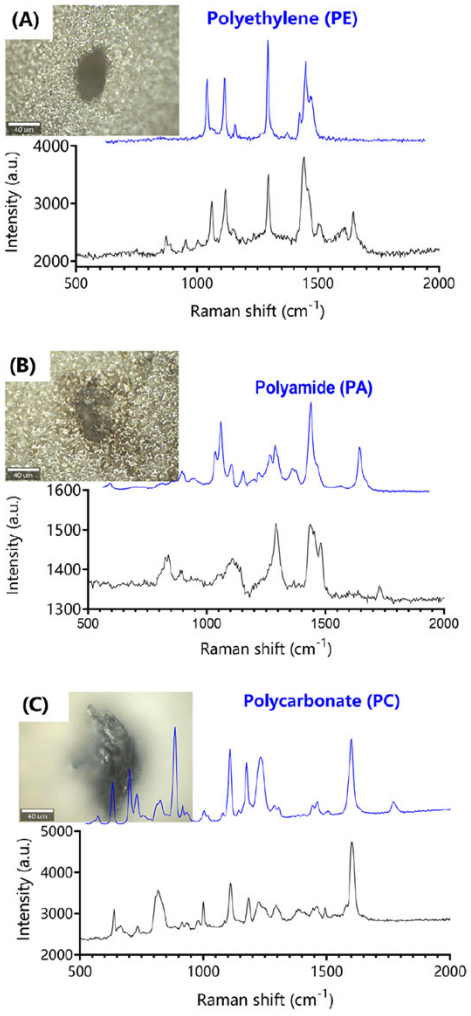


Figure 2. Microplastics in infusion detected by Raman spectrum: (A) polyethylene (PE), (B) polyamide (PA), and (C) polycarbonate (PC).

Weekly Consumption of Microplastics

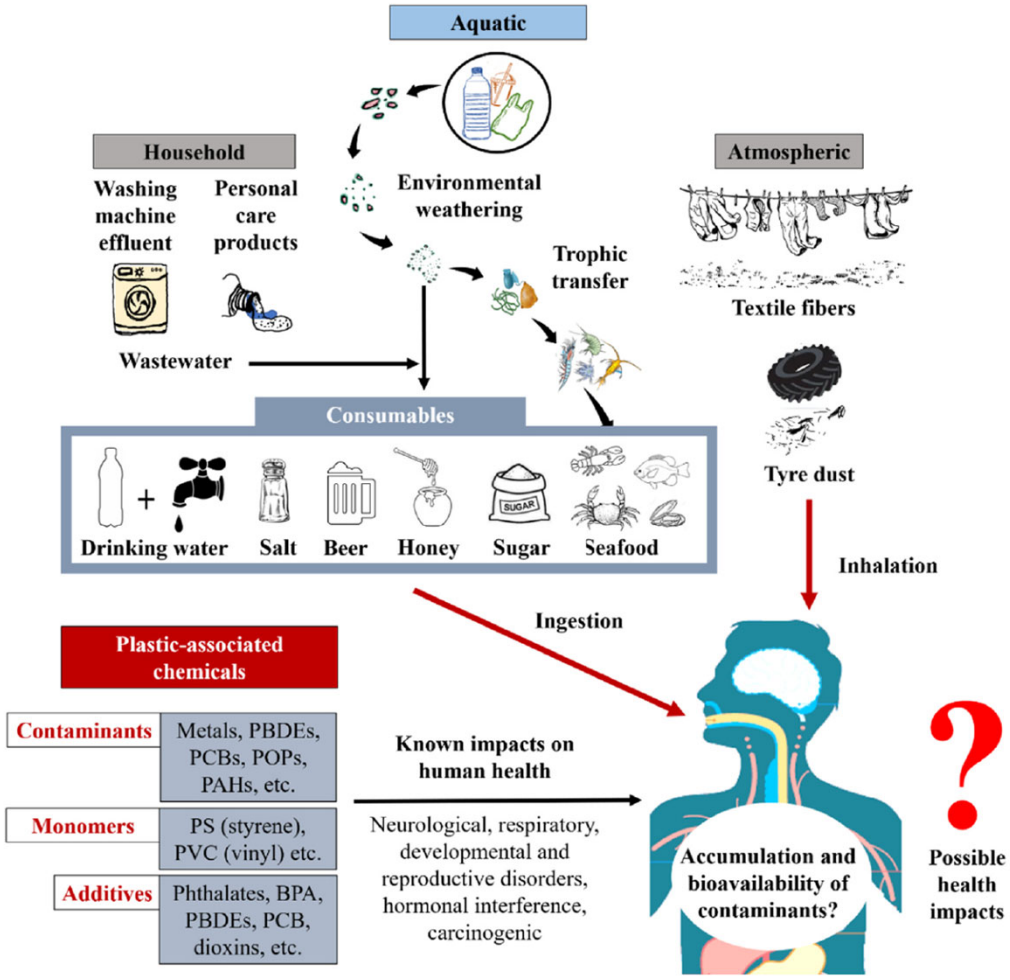


Table 9
Estimates of the global average rate of Microplastics ingested using a combination of approaches and the rationale behind the choice of average mass of individual microplastic.

Consumable Category	AMIMP to consider	Rationale for choice of AMIMP	GARMI (g/yr)
Shellfish	$AMIMP_{aquatic}$	Microplastics found in aquatic organisms mirror the microplastics in the aquatic environment (Kim et al., 2018; Catarino et al., 2018; Qu et al., 2018b)	26.4
Salt (aquatic and terrestrial: sea salt, rock salt, lake salt)	$AMIMP_{consumable\ (sphere)}$	Studies suggest that salt are heavily concentrated with microplastics. The refining process of salt can remove particles, however, conversely, add particles if cleaning agents with microbeads are used in the processing plants (Kim et al., 2018).	7.4
Water	$AMIMP_{consumable\ (cube)}$	Easy to underestimate fine particles (Toussaint et al., 2019b; Oßmann et al., 2018b) in liquids from small volume of samples (Mintenig et al., 2019), use of cube to compensate	0.08
Beer	$AMIMP_{consumable\ (cube)}$	Easy to underestimate fine particles in liquids from small volume of samples and PSD, cube to compensate	0.5
TOTAL INGESTING ALL CONSUMABLES			34.4 (0.7 g/wk)

Senathirajah 2021, Estimation of the mass of microplastics ingested- A pivotal first step towards human health risk assessment
Cox 2019, Human consumption of microplastics

Which Proteins Contain the Most Microplastics?

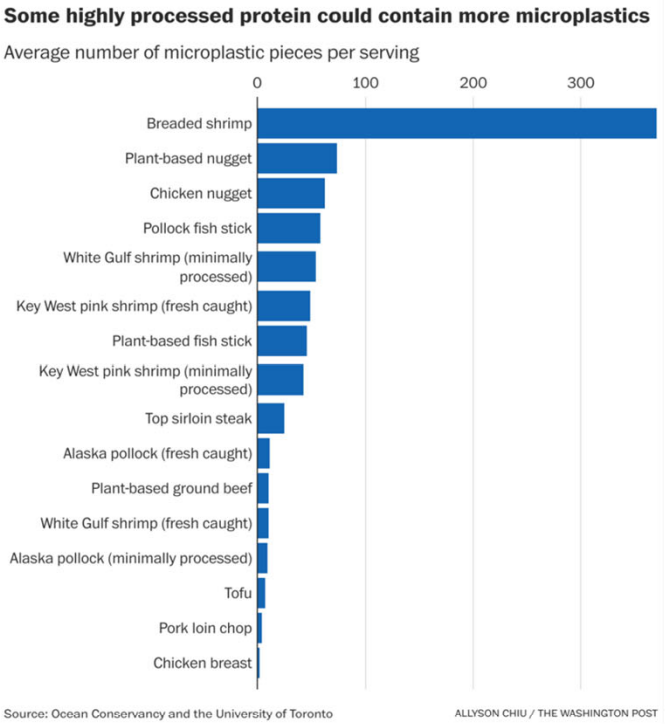
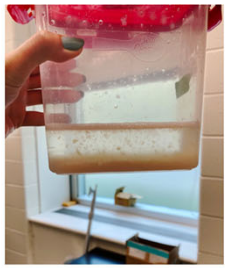


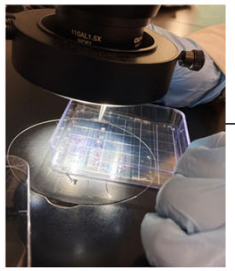
Table 1
U.S. adult exposure to microplastics across different protein product types. Mean serving size and mean number of annual servings were calculated using U.S. adult protein consumption data from a 2021 nationwide social survey conducted by our research team (Baechler et al., 2024). For each sample type, exposure was calculated using survey data for the mean number of annual servings ("Avg MPs/year ± SD" column), low number of annual servings (one serving monthly scaled to 12 servings annually), and high number of annual servings (10 servings monthly scaled to 120 servings annually) ("Range of MPs/year" column). For calculation of mean number of servings only nonzero answers were used (i.e., survey respondents that never consumed that certain type of protein were excluded from the analysis). Raw data can be obtained from the supplementary file titled "Sample Sheets Raw." MP = microplastic; SD = standard deviation; # = number; g = gram.

Protein type	MP concentrations and reported protein consumption					Annual U.S. adult exposure	
	Sample type	Avg # MPs/g	Mean serving size (g)	Avg # MPs/ serving ± SD	Mean # servings/yr	Avg # MPs/yr ± SD	Range of MPs/yr ± SD
Seafood	**Breaded shrimp**	**1.2**	**320**	**370 ± 580**	**35**	**13,000 ± 21,000**	**4400 ± 6800 -44,000 ± 68,000**
	Pollock fish stick	**0.26**	**220**	**58 ± 57**	**37**	**2100 ± 2100**	**680 ± 670 -6800 ± 6700**
	White Gulf shrimp (minimally processed)	**0.22**	**240**	**54 ± 87**	**40**	**2100 ± 3700**	**640 ± 1000–6400 ± 10,000**
	Key West pink shrimp (fresh caught)	**0.20**	**240**	**49 ± 36**	**40**	**1900 ± 1500**	**600 ± 420 -6000 ± 4200**
	Key West pink shrimp (minimally processed)	**0.17**	**240**	**42 ± 39**	**40**	**1700 ± 1600**	**500 ± 460 -5000 ± 4500**
	Alaska pollock (fresh caught)	**0.06**	**180**	**11 ± 16**	**36**	**390 ± 590**	**130 ± 190 -1300 ± 1800**
	Alaska pollock (minimally processed)	**0.05**	**180**	**9 ± 7**	**36**	**330 ± 240**	**120 ± 76 -1200 ± 760**
	White Gulf shrimp (fresh caught)	**0.04**	**240**	**10 ± 11**	**40**	**390 ± 460**	**130 ± 130 -1300 ± 1300**
Terrestrial Meat	**Chicken nugget**	**0.31**	**200**	**62 ± 78**	**45**	**2800 ± 3800**	**750 ± 920 -7500 ± 9200**
	Top sirloin steak	**0.12**	**200**	**25 ± 38**	**73**	**1800 ± 3100**	**300 ± 440 -3000 ± 4400**
	Pork loin chop	**0.02**	**190**	**4 ± 2**	**50**	**188 ± 99**	**38 ± 22–380 ± 220**
	Chicken breast	**0.01**	**190**	**2 ± 2**	**75**	**140 ± 130**	**29 ± 18–290 ± 180**
Plant-based protein	**Plant-based nugget**	**0.32**	**230**	**73 ± 90**	**46**	**3300 ± 4400**	**874 ± 1000–8700 ± 11,000**
	Plant-based fish stick	**0.23**	**200**	**46 ± 59**	**47**	**2100 ± 2600**	**560 ± 690 -5600 ± 6900**
	Plant-based ground beef	**0.06**	**170**	**10 ± 10**	**44**	**440 ± 430**	**120 ± 110 -1200 ± 1100**
	Tofu	**0.03**	**230**	**7 ± 3**	**42**	**290 ± 120**	**78 ± 30–780 ± 300**

A study of more than a dozen kinds of protein, including beef, tofu and breaded shrimp, found microplastics in nearly 90 percent of the tested samples



A container holding a food sample following chemical digestions. At this stage, most of the food material has been broken down but the microplastic content has been preserved, facilitating their identification. (Courtesy of Ocean Conservancy)



A close-up of a petri dish lined with double-sided tape for storing the microplastic particles obtained from samples. Particles are stored in this way to later be measured and chemically identified to determine their composition. (Courtesy of Ocean Conservancy)

Milne 2024, Exposure of U.S. adults to microplastics from commonly-consumed proteins https://www.washingtonpost.com/climate-solutions/2024/01/12/microplastics-fish-chicken-tofu-protein/ (Allyson Chiu. (January 12, 2024))

Microplastic Contamination in Milk and Dairy Products

The presence of microplastics in food has raised growing concern due to potential health risks. While many studies have investigated microplastics in water and seafood, limited data are available for dairy products. This study qualitatively and quantitatively characterizes microplastics in milk, fresh cheese, and ripened cheese, assessing concentration levels and polymer composition through the analysis of 28 dairy samples using Fourier-transformed infrared micro-spectroscopy in attenuated total reflectance mode. Poly(ethylene terephthalate) was the most frequent, followed by polyethylene and polypropylene. Most microplastics were smaller than 150 µm, with 51-100 µm being the most common (33.8%). Irregular fragments (77.4%) and grey particles (68.4%) were predominant. Ripened cheese exhibited the highest microplastic concentration (1857MP/kg), followed by fresh cheese (1,280 MP/kg) and milk (350.0 MP/kg). Results confirm widespread microplastic contamination in dairy products and highlight the importance of further research into contamination pathways and strategies to reduce microplastic exposure in the dairy chain.

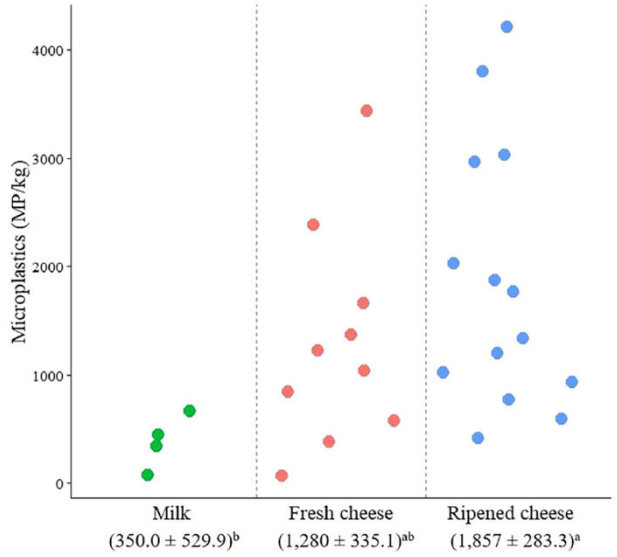


Table 3 | Descriptive statistics of MP concentration (MP/kg) in dairy products

MP	*n* of contaminated samples	Mean	SD	CV, %	Minimum	Maximum
Chlorinated polyethylene	3/28	333.3	230.9	69.3	200.0	600.0
Copolymers[a]	12/28	283.3	232.9	82.2	200.0	1000
Ethylene vinyl acetate	2/28	200.0	–	–	–	–
Nylon	5/28	200.0	–	–	–	–
Polyacrylate	6/28	233.3	81.7	35.0	200.0	400.0
Polybutadiene	1/28	200.0	–	–	–	–
Polyester	3/28	266.7	115.5	43.3	200.0	400.0
Polyethylene	15/28	640.0	442.1	69.1	200.0	2,000
Poly(ethylene terephthalate)	19/28	357.9	171.0	47.8	200.0	800.0
Polyisoprene	3/28	333.3	230.9	69.3	200.0	600.0
Polyoxymethylene	1/28	200.0	–	–	–	–
Polyphenylene sulfide	1/28	200.0	–	–	–	–
Polypropylene	12/28	516.7	199.2	38.6	200.0	800.0
Polystyrene	9/28	311.1	202.8	65.2	200.0	800.0
Polytetrafluoroethylene	5/28	200.0	–	–	–	–
Polyurethane	2/28	200.0	–	–	–	–
Polyvinyl chloride	5/28	240.0	89.4	38.3	200.0	400.0
Polyvinylidene fluoride	1/28	200.0	–	–	–	–
Resin	1/28	200.0	–	–	–	–
Silicone	4/28	550.0	700.0	127.3	200.0	1,600

[a]Copolymers class comprises: acrylonitrile–butadiene–styrene, chlorinated polyethylene–polystyrene copolymer, polyacrylonitrile–butadiene–styrene copolymer, polyethylene–nylon copolymer, polyethylacrylate–polystyrene–polyacrylamide copolymer, polystyrene–polyacrylate copolymer, polystyrene–polybutadiene copolymer, silicone–polyisoprene copolymer, and styrene–ethylene–butylene–styrene.
SD standard deviation, *CV* coefficient of variation.

Visentin 2025, Assessing microplastic contamination in milk and dairy products

The Plastic Pollution in Human Body

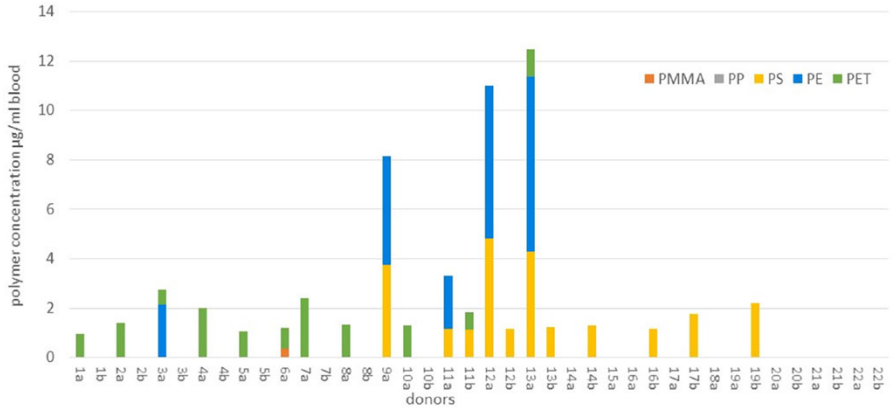
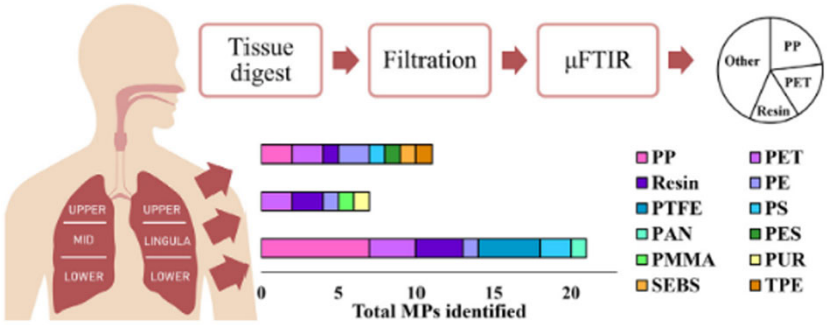


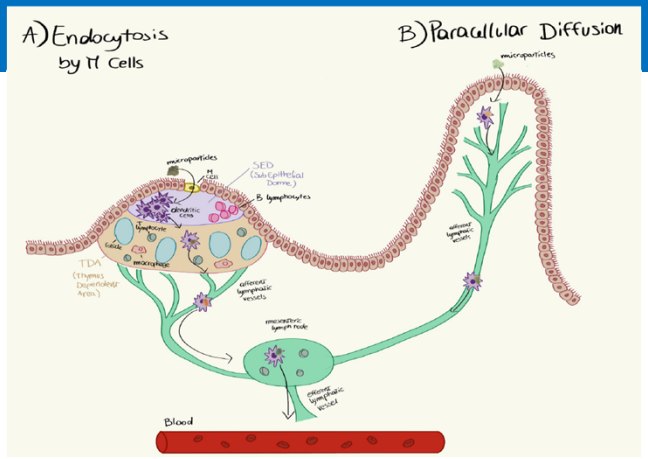
Fig. 1. Concentrations of plastic particles by polymer type in whole blood samples of 22 donors (duplicates a and b, except for No. 6, 9, 15 and 18). All values >LOQ.

Leslie 2022, Discovery and quantification of plastic particle pollution in human blood



LOD, limit of detection; LOQ, limit of quantitation;
µFTIR, micro Fourier Transform Infrared;
MCT, mercury cadmium telluride;
MP, microplastics between 1µm and 5mm;
NP, nanoplastics;
PAN, polyacrylonitrile; PE, polyethylene;
PES, polyester; PET, polyethylene terephthalate;
PMMA, polymethylmethacrylate; PP, polypropylene;
PS, polystyrene; PTFE, polytetrafluoroethylene;
PUR, polyurethane; PVA, polyvinyl alcohol;
ROS, reactive oxygen species;
SEBS, styrene-ethylene-butylene co-polymer;
TPE, thermoplastic elastomer.

Jenner 2022, Detection of microplastics in human lung tissue using µFTIR spectroscopy



Ragusa 2021, Plasticenta-First evidence of microplastics in human placenta

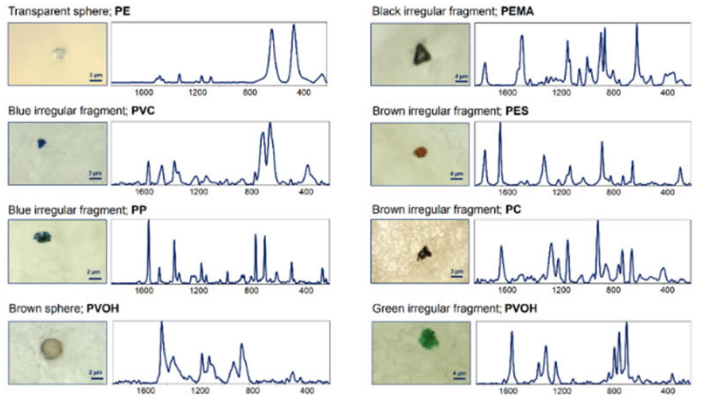


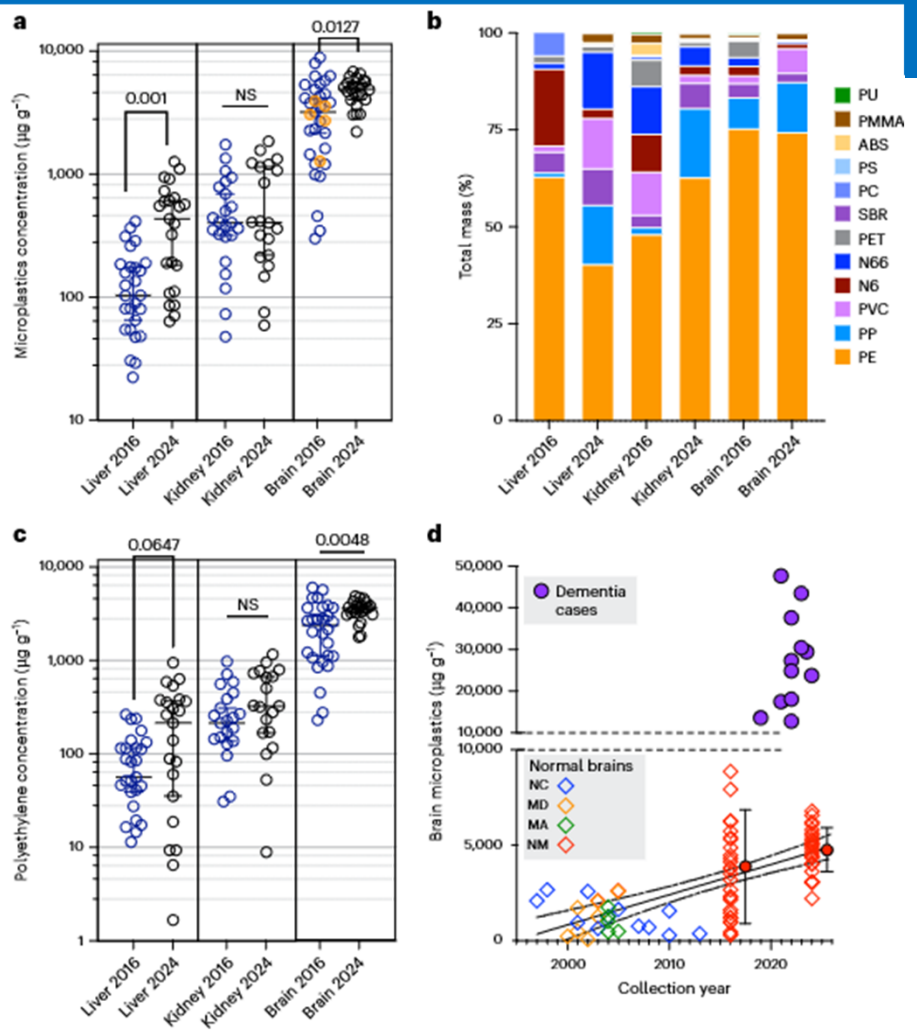
Figure 1. Microphotographs and Raman spectra (wavenumbers, cm^{-1}) of some selected MPs found in the analysed breastmilk samples. PE: polyethylene; PVC: polyvinyl chloride; PP: polypropylene; PVOH: polyvinyl alcohol; PEVA: poly(ethylene-co-vinyl acetate); PEMA: poly(ethyl methacrylate); PES: polyester, and PC: polycarbonate.

Ragusa 2022, Raman microspectroscopy detection and characterisation of microplastics in human breastmilk

Microplastic in Human Brains

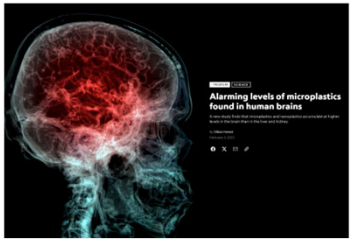
Rising global concentrations of environmental **microplastics and nanoplastics (MNPs)** drive concerns for human exposure and health outcomes. Complementary methods for the robust detection of tissue MNPs, including pyrolysis gas chromatography–mass spectrometry, attenuated total reflectance–Fourier transform infrared spectroscopy and electron microscopy with energy-dispersive spectroscopy, confirm the presence of MNPs in human kidney, liver and brain. MNPs in these organs primarily consist of polyethylene, with lesser but significant concentrations of other polymers. Brain tissues harbor higher proportions of polyethylene compared to the composition of the plastics in liver or kidney, and electron microscopy verified the nature of the isolated brain MNPs, which present largely as nanoscale shard-like fragments. Plastic concentrations in these decedent tissues were not influenced by age, sex, race/ethnicity or cause of death; the time of death (2016 versus 2024) was a significant factor, with increasing MNP concentrations over time in both liver and brain samples ($P = 0.01$). Finally, even greater accumulation of MNPs was observed in a cohort of decedent brains with documented dementia diagnosis, with notable deposition in cerebrovascular walls and immune cells. These results highlight a critical need to better understand the routes of exposure, uptake and clearance pathways and potential health consequences of plastics in human tissues, particularly in the brain.

Nihart 2025, Bioaccumulation of microplastics in decedent human brains



https://www.nationalgeographic.com/science/article/microplastic-human-brain-health?rid=FF526C1F1B0738788B420FE1D0034350

https://pubmed.ncbi.nlm.nih.gov/39283733/
JAMA Netw Open 2024 Sep 3;7(9):e2440018.
doi: 10.1001/jamanetworkopen.2024.40018.
Microplastics in the Olfactory Bulb of the Human Brain
This case series provides evidence of MPs found in the human olfactory bulb, suggesting a potential pathway for the translocation of MPs to the brain. The findings underscore the need for further research on the health implications of MP exposure, particularly concerning neurotoxicity and the potential for MPs to bypass the blood-brain barrier.



Microplastics and Nanoplastics in Atheromas and Cardiovascular Events

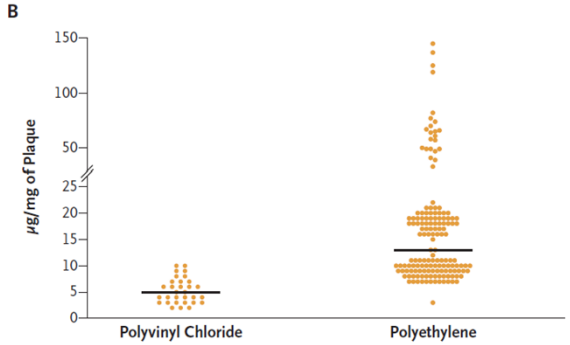


Figure 1. MNPs in Carotid Artery Plaque. Median and individual levels of polyethylene and polyvinyl chloride in excised carotid artery plaque that contained evidence of these compounds are shown in micrograms per milligram of atherosclerotic plaque (Panel B).

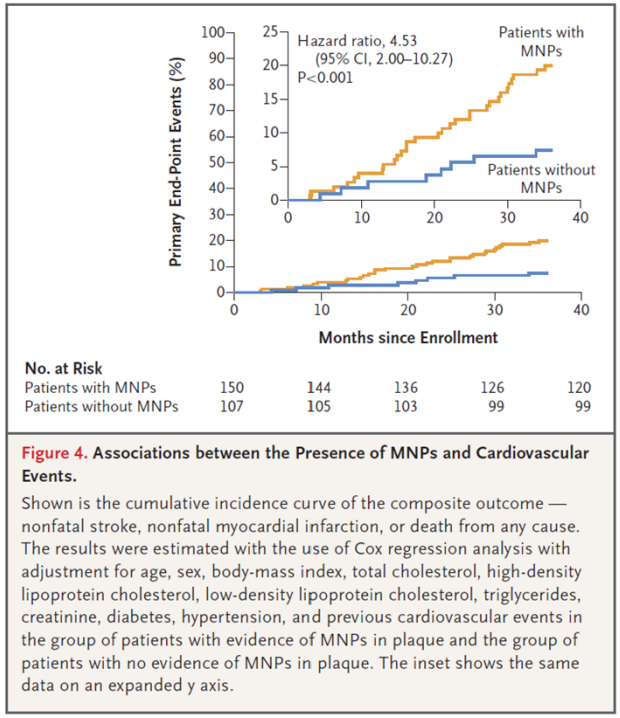


Figure 4. Associations between the Presence of MNPs and Cardiovascular Events.

Shown is the cumulative incidence curve of the composite outcome — nonfatal stroke, nonfatal myocardial infarction, or death from any cause. The results were estimated with the use of Cox regression analysis with adjustment for age, sex, body-mass index, total cholesterol, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, triglycerides, creatinine, diabetes, hypertension, and previous cardiovascular events in the group of patients with evidence of MNPs in plaque and the group of patients with no evidence of MNPs in plaque. The inset shows the same data on an expanded y axis.

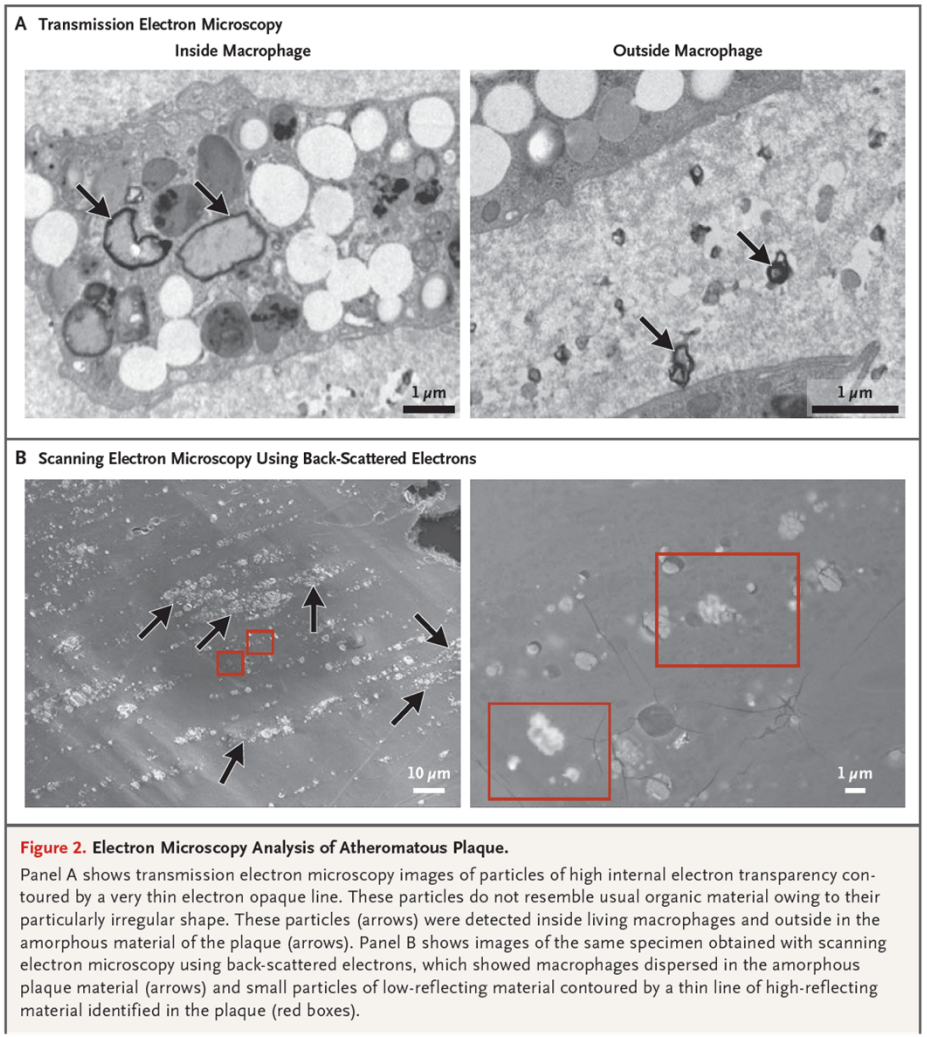


Figure 2. Electron Microscopy Analysis of Atheromatous Plaque.

Panel A shows transmission electron microscopy images of particles of high internal electron transparency contoured by a very thin electron opaque line. These particles do not resemble usual organic material owing to their particularly irregular shape. These particles (arrows) were detected inside living macrophages and outside in the amorphous material of the plaque (arrows). Panel B shows images of the same specimen obtained with scanning electron microscopy using back-scattered electrons, which showed macrophages dispersed in the amorphous plaque material (arrows) and small particles of low-reflecting material contoured by a thin line of high-reflecting material identified in the plaque (red boxes).

Marfella 2024, Microplastics and nanoplastics in atheromas and cardiovascular events

Effects of Microplastic Exposure on Human Health

Effects of Microplastic Exposure on Human Digestive, Reproductive, and Respiratory Health: A Rapid Systematic Review

Nicholas Chartres,* Courtney B. Cooper, Garret Bland, Katherine E. Pelch, Sheiphali A. Gandhi, Abena BakenRa, and Tracey J. Woodruff*

Cite This: *Environ. Sci. Technol.* 2024, 58, 22843−22864

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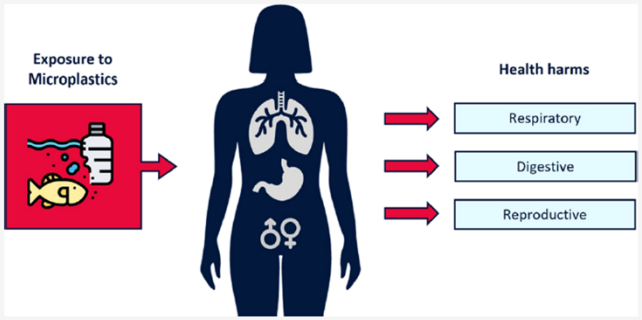
ABSTRACT: Microplastics are ubiquitous environmental contaminants for which there are documented human exposures, but there is a paucity of research evaluating their impacts on human health. We conducted a rapid systematic review using the "Navigation Guide" systematic review method. We searched four databases in July 2022 and April 2024 with no restriction on the date. We included studies using predefined eligibility criteria that quantitatively examined the association of microplastic exposure with any health outcomes. We amended the eligibility criteria after screening studies and prioritized digestive, reproductive, and respiratory outcomes for further evaluation. We included three human observational studies examining reproductive (n = 2) and respiratory (n = 1) outcomes and 28 animal studies examining reproductive (n = 11), respiratory (n = 7), and digestive (n = 10) outcomes. For reproductive outcomes (sperm quality) and digestive outcomes (immunosuppresion) we rated overall body evidence as "high" quality and concluded microplastic exposure is "suspected" to adversely impact them. For reproductive outcomes (female follicles and reproductive hormones), digestive outcomes (gross or microanatomic colon/small intestine effects, alters cell proliferation and cell death, and chronic inflammation), and respiratory outcomes (pulmonary function, lung injury, chronic inflammation, and oxidative stress) we rated the overall body of evidence as "moderate" quality and concluded microplastic exposure is "suspected" to adversely impact them. We concluded that exposure to microplastics is "unclassifiable" for birth outcomes and gestational age in humans on the basis of the "low" and "very low" quality of the evidence. We concluded that microplastics are "suspected" to harm human reproductive, digestive, and respiratory health, with a suggested link to colon and lung cancer. Future research on microplastics should investigate additional health outcomes impacted by microplastic exposure and identify strategies to reduce exposure.



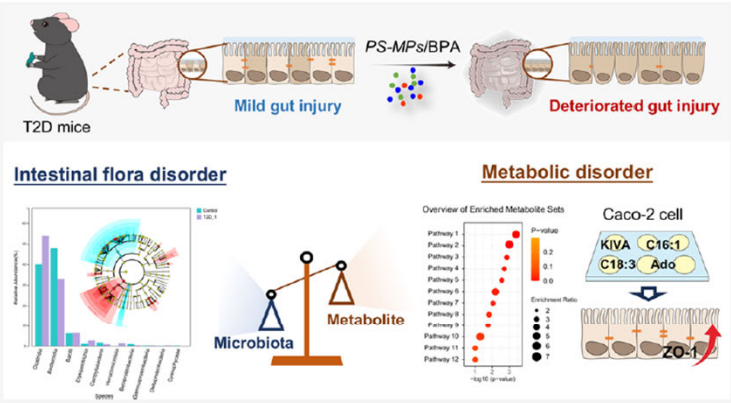
Chartres 2024, Effects of microplastic exposure on human digestive, reproductive, and respiratory health

The Plastic Pollution in Human Body

The ubiquitous existence of microplastics and nanoplastics raises concerns about their potential impact on the human reproductive system. Limited data exists on microplastics within the human reproductive system and their potential consequences on sperm quality. Our objectives were to quantify and characterize the prevalence and composition of microplastics within both canine and human testes and investigate potential associations with the sperm count, and weights of testis and epididymis. Using advanced sensitive Pyrolysis-Gas Chromatography/Mass Spectrometry (Py-GC/MS), we quantified 12 types of microplastics within 47 canine and 23 human testes. Data on reproductive organ weights and sperm count in dogs were collected. Statistical analyses, including descriptive analysis, correlational analysis, and multivariate linear regression analyses, were applied to investigate the association of microplastics with reproductive functions. Our study revealed the presence of microplastics in all canine and human testes, with significant inter-individual variability. Mean total microplastic levels were 122.63 µg/g in dogs and **328.44 µg/g in humans**. Both humans and canines exhibit relatively similar proportions of the major polymer types, with PE being dominant. Furthermore, a negative correlation between specific polymers, such as PVC and PET, and the normalized weight of the testis was observed. These findings highlight the pervasive presence of microplastics in the male reproductive system in both canine and human testes, with potential consequences on male fertility.

Hu 2024, Microplastic presence in dog and human testis and its potential association with sperm count and weights of testis and epididymis

ABSTRACT: Environmental pollutants can induce multiorgan damage, with the digestive tract particularly susceptible. Diabetic enteropathy is a significant complication of type 2 diabetes mellitus (T2D). However, the relationship between environmental pollutant exposure and T2D-associated intestinal injury has not been previously explored. In this study, T2D mice were subjected to polystyrene microplastics (*PS-MPs*, 100 μg/day, 3 weeks) and bisphenol A (BPA, 100 μg/kg/day, 2 weeks). Metabolomics and 16S rRNA sequencing were used to detect changes in colonic metabolites and gut microbial composition. Caco-2 cells were utilized to investigate the functions of the altered metabolites. Compared to the T2D group, mice exposed to *PS-MPs* and BPA exhibited shorter colon length and reduced levels of gut barrier proteins ZO-1 and Occludin. Metabolomics analysis revealed that *PS-MPs* primarily affected colonic long-chain fatty acids (LCFAs) and adenosine metabolism, while BPA disrupted α-ketoisovaleric acid (KIVA) and pyruvic acid (PyrA) homeostasis. Moreover, *PS-MPs* exposure altered the abundance of *Duncaniella* and *Olsenella*, while BPA primarily affected *Phocaeicola, Olsenella,* and *Variovorax*. In vitro experiments showed that palmitoleic acid (C16:1), γ-linolenic acid (C18:3), adenosine (Ado), and KIVA promoted the expression of ZO-1 in Caco-2 cells. Our findings provide valuable insights into the impact of environmental pollutants on intestinal injury in T2D, underscoring the importance of environmental contaminant management, particularly in susceptible populations.



Zhang 2025, Polystyrene microplastics and bisphenol A exposure worsen intestinal injury in diabetic mice

Disease Burden and Costs in the U.S. by Chemicals Used in Plastic Materials

What's the Disease Burden From Plastic Exposure?

Exposure to endocrine-disrupting chemicals (EDCs) via daily use of plastics is a major contributor to the overall disease burden in the United States and the associated costs to society amount to more than 1% of the gross domestic product, revealed a large-scale analysis.

The research, published in the *Journal of the Endocrine Society* on January 11, indicated that taken together, the disease burden attributable to EDCs used in the manufacture of plastics added up to almost $250 billion in 2018 alone. **"The diseases due to plastics run the entire life course from preterm birth to obesity, heart disease, and cancers,"** commented lead author Leonardo Trasande, MD, MPP, Jim G. Hendrick, MD Professor of Pediatrics, Department of Pediatrics, NYU Langone Medical Center, New York, in a release.

Liam Davenport, January 11, 2024
https://www.medscape.com/viewarticle/whats-disease-burden-plastic-exposure-2024a10000q4?form=fpf

Table 8. Estimates of plastic-attributable disease burden and costs

Exposure	Life stage of exposure	Outcome	Cost of illness across exposure routes (source [6] unless otherwise indicated)	PRF applied in base case (sensitivity analysis)	Plastic-related cases (sensitivity analysis)	Plastic-related cost of illness (sensitivity analysis)
PBDE-47	Prenatal	IQ points loss and intellectual disability	$162 billion	98% (97%-99%)	713 000 IQ points lost 23 900 cases of intellectual disability (23 700-24 100)	$158 billion ($157-160 billion)
	Prenatal	Cryptorchidism	$35.7 million		4200 cases (4200-4300)	$35.0 million ($34.6-35.3 million)
	Prenatal	Testicular cancer	$81 million		3500 cases (3500-3600)	$79.4 million ($78.6-80.2 million)
	All	All	$162 billion		N/A	$159 billion ($157-161 billion)
DEHP	Women	Obesity	$1.95 billion	98% (96%-99%)	5350 cases (5250-5410)	$1.92 billion ($1.88-1.94 billion)
		Type 2 diabetes	$259 million		2870 cases (2810-2900)	$253 million ($249-256 million)
	Women	Endometriosis	$39.7 billion		59 100 cases (57 900-59 700)	$38.9 billion ($38.1-39.3 billion)
	Adults	Cardiovascular Mortality	$23.8 billion [7]		50 200 cases (49 200-50 700)	$23.4 billion ($22.9-23.6 billion)
BBP and DBP	Men	Male infertility	$3.14 billion	100% (71%-100%)	121 000 cases (85 900-121 000)	$3.14 billion ($1.59-2.24 billion)
Total phthalates	All	All	$68.9 billion	N/A	N/A	$66.7 billion ($64.7-67.3 billion)
BPA	Prenatal	Childhood obesity	$1.04 billion	98% (96%-99%)	7130 (6850-7060)	$1.02 billion ($1.00-1.03 billion)
PFAS (PFOA in main estimates, PFOS in sensitivity analysis)	Prenatal	Low birth weight	$1.42 billion [8]	93% (16%-96%)	9350 cases (1610-93 000)	$1.32 billion ($227 million-13.2 billion)
	Prenatal	Childhood obesity	$2.65 billion [8]		118 000 cases (20 400-444 000)	$2.46 billion ($424 million-$9.22 billion)
	Children	Pneumonia	$1.49 million [8]		415 cases (72-6490)	$1.39 million ($238 000-$21.6 million)
	Pregnant people	Gestational diabetes	$414 million [8]		5640 cases (970-12 000)	$385 million ($66.2-$818 million)
	Adult	Obesity	$17.0 billon [8]		3 990 000 cases (687 000-4 120 000)	$15.8 billion ($2.72-$16.3 billion)
	Adult	Kidney cancer	$180 million [8]		132 cases (23-136)	$171 million ($29.4-$177 million)
	Adults	Couple infertility	$37.6 million [8]		551 cases (95-25 100)	$35.0 million ($6.06 million-$1.59 billion)
	Women	Hypothyroidism	$1.26 billion [8]		13 600 cases (2300-57 400)	$1.17 billion ($201 million-4.98 billion)
	Women	Type 2 diabetes	$140 million [8]		1600 cases (276-1660)	$130 million ($22.4-$134 million)
	Women	Endometriosis	$397 million [8]		647 cases (111-17 300)	$369 million ($63.5 million-$9.79 billion)
	Women	Polycystic ovary syndrome	$10.5 million [8]		6700 cases (1150-7200)	$9.77 million ($1.68-$10.5 million)
	Women	Breast cancer	$555 million [8]		392 cases (101-2971)	$516 million ($133 million-$3.92 billion)
	Men	Testicular cancer	$6.85 million [8]		5 cases (1-5)	$6.37 million ($1.10-$6.58 million)
	All	All	$24.1 billion [8]		N/A	$22.4 billion ($3.85-60.1 billion)
All	All	All		N/A	N/A	$249 billion ($226-$289 billion)

Abbreviation: BBP, butyl benzyl phthalate; BPA, bisphenol A; DBP, dibutyl phthalate; DEHP, bis(2-ethylhexyl)phthalate; N/A, not available; PBDE, polybrominated diphenyl ether; PFAS, perfluoroalkyl and polyfluoroalkyl substances; PFOA, perfluorooctanoic acid; PFOS, perfluorooctane sulfonate; PRF, plastic-related fraction.

Trasande 2024, Chemicals used in plastic materials- An estimate of the attributable disease burden and costs in the United States
Trasande 2024, Davenport 2024, What's the disease burden from plastic exposure?

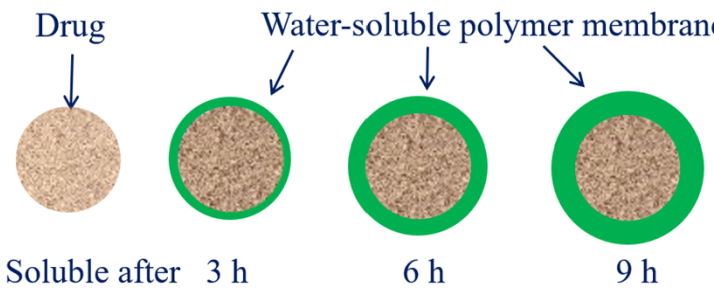
Mechanisms of Controlled Drug Release

1. Dissolution

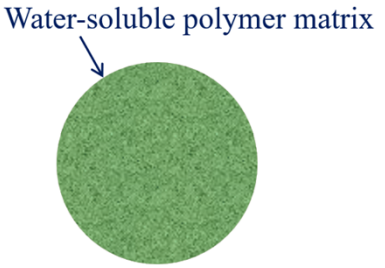
   Reservoir System

   Matrix System

Reservoir System (= Encapsulated Dissolution System)



Matrix Dissolution System



2. Diffusion

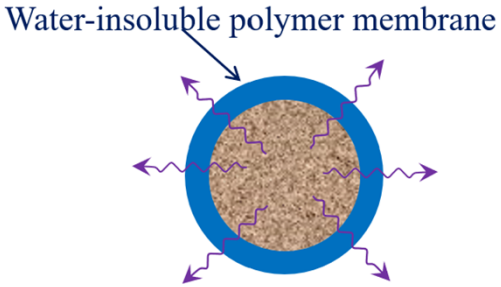
   Reservoir System

   Monolithic System

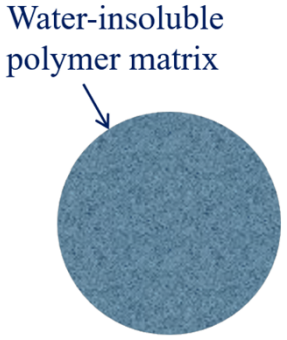
      Monolithic Solution System

      Monolithic Dispersion System

Reservoir System (= Encapsulated Diffusion System)



Monolithic Diffusion System



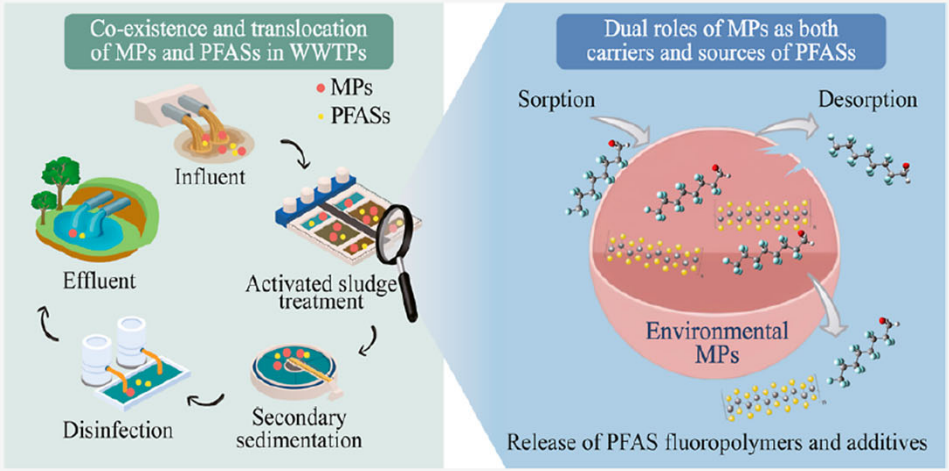
3. Osmosis

4. Ion-Exchange

Microplastics as a Carrier of PFASs and Beyond

ABSTRACT: Microplastics (MPs) and per- and polyfluoroalkyl substances (PFASs) are ubiquitous contaminants in environments, yet their co-occurrence and interactions remain insufficiently understood. In this study, we confirmed the concurrent presence of MPs and PFASs and their distinct distribution patterns in a wastewater treatment plant (WWTP) through a comprehensive sampling and analysis effort. Significant correlations ($p < 0.05$) were observed between specific types of MPs and PFASs, suggesting their shared sources. Moreover, MPs were identified as carriers of PFASs, with PFAS concentration ranging between 122 and 166 ng/g, predominantly consisting of perfluorooctanoic acid (PFOA) and perfluorobutanoic acid (PFBA). The laboratory verification experiment revealed that PFASs could be leached from MPs in aqueous environments, in which commercial MPs exhibited higher leaching potential, with the highest combined concentration of perfluorooctanesulfonate (PFOS), PFOA, and PFBA reaching 10.4 ng/mL. PFOS demonstrated a desorption efficiency exceeding 120% in sorption/desorption experiments, confirming its release from the MPs themselves. These results highlighted the dual roles of MPs as both carriers and sources of PFASs. The identified contaminant profiles and correlations between MPs and PFASs across different matrices in WWTP provide valuable insights and form a basis for further research into proactive measures to effectively mitigate their environmental contamination.

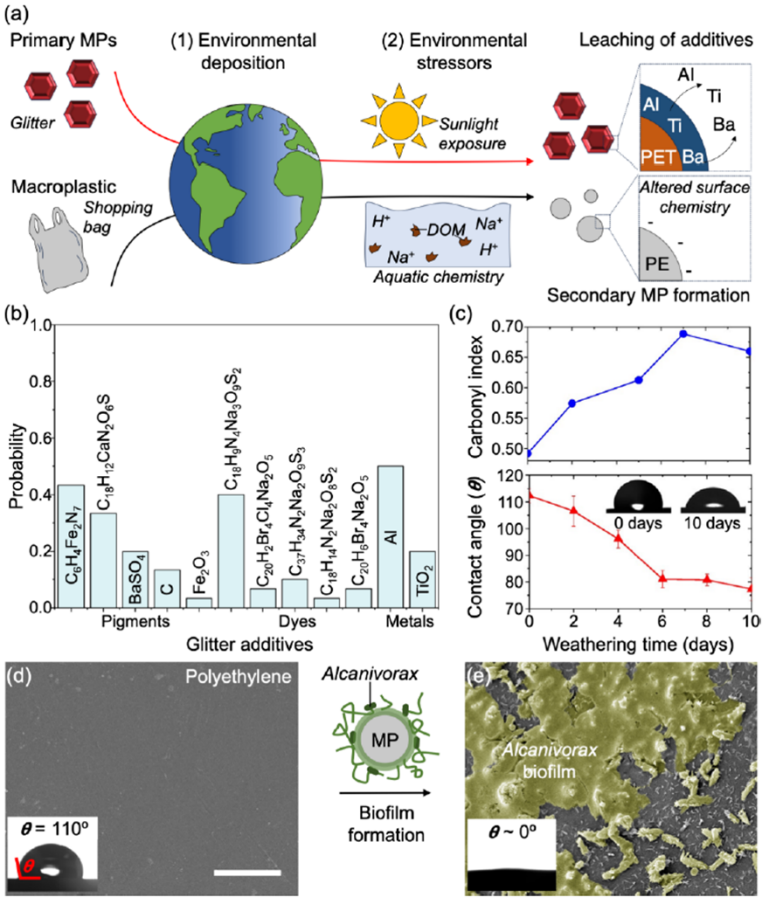
KEYWORDS: *contaminant carrier, contaminant source, co-occurrence, emerging contaminants, microplastics, PFASs*



Ma 2025, Unveiling the truth of interactions between microplastics and per- and polyfluoroalkyl substances (PFASs) in wastewater treatment plants: Microplastics as a carrier of PFASs and beyond

Colloid and Interface Science for Understanding Microplastics

The environmental behavior of microplastics (MPs) is governed by their interfacial properties, which dominate due to their small size. Wastewater treatment plants (WWTPs) are critical hotspots for MP accumulation, where the MPs are inadvertently transferred to sewage sludge and reintroduced into the environment.



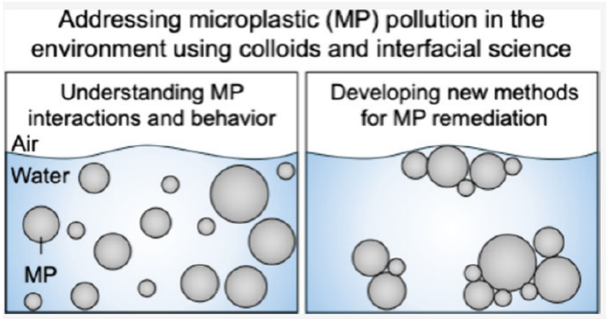


Figure 1. Effective interfacial chemistry of MPs. (a) Schematic describing the introduction of primary MPs and formation of secondary MPs in the environment, with associated dynamic changes in the surface chemistries as a result of weathering, and the adsorption of ions and dissolved organic matter (DOM). (b) Bar plot showing the probability of identifying specific chemical additives in commercial glitter from a survey of 36 different varieties examined via combined scanning electron microscopy and energy-dispersive X-ray spectroscopy (SEM-EDS). Results are grouped by additive type from values obtained by Najjar et al.[56] (c) Carbonyl index and water contact angle of PE MPs as a function of weathering time, taken from ref 9. The carbonyl index is calculated from the Fourier transform infrared (FTIR) spectra as the ratio of the areas under the specified carbonyl and methylene bands, providing insight into the degree of photo-oxidation occurring to the PE MPs. Inset images are sessile water droplets on an unweathered (0 days) and weathered (10 days) PE substrate. (d and e) Scanning electron microscopy (SEM) images of a PE sheet before and after biofilm formation, respectively, by the marine bacterium *Alcanivorax borkumensis*. The biofilm in panel e is false colored in green for improved visualization. The scale bar in panel d is 5 μm. The insets of both panels d and e are the images of the water contact angle on the respective surface. Panel c is reproduced from ref 9. Available under a CC BY 4.0 license. Copyright 2022 Bhuvnesh Bharti.

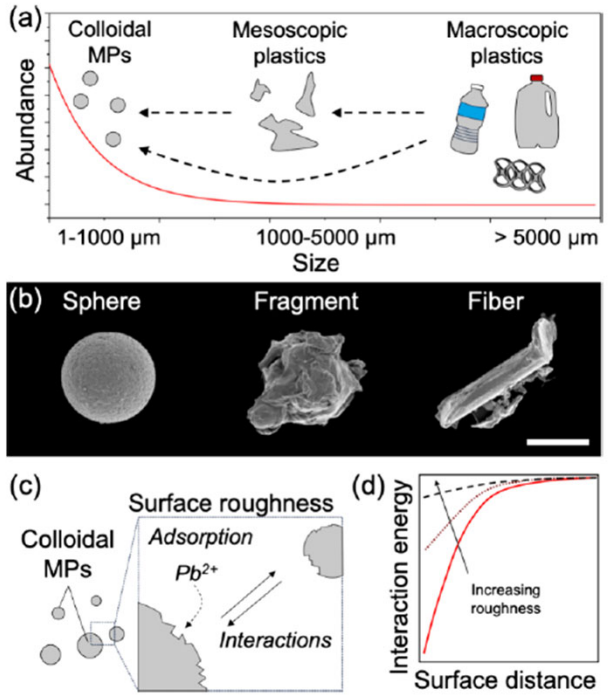


Figure 2. Key physical attributes of MPs. (a) Representation of a power-law distribution of the sizes of MPs as typically reported in field studies. The breakdown of plastics promotes the formation of increasingly smaller pollutants, from large millimeter-sized plastic debris to mesoscopic fragments to micro- and nanoplastics. (b) SEM micrographs of MPs with representative morphologies, i.e., spherical, fragment, and fiber. The scale bar is 50 μm. (c) Schematic representation of the nanoscale surface roughness of colloidal MPs, highlighting the role of surface roughness in adsorption and aggregation. (d) Representative extended DLVO interaction energy profiles between surfaces, displaying a decrease in attractive potential with an increase in surface roughness.

Harraq 2025, Colloid and interface science for understanding microplastics and developing remediation strategies

Microplastic-Derived Dissolved Organic Matter

Size and Structure-Dependent Molecular Fingerprint Transformation of Microplastic-Derived Dissolved Organic Matter in Sunlit Seawater: Implication for Marine Carbon Cycles

Yan-Jun Liu, Zhao Liang Chen,* Zekun Zhang, Yuanbi Yi, Ruanhong Cai, Ming Ye, Mengyang Liu, Meng Yan, Kenneth Mei Yee Leung, Tanveer M. Adyel, and Ding He*

Cite This: *Environ. Sci. Technol.* 2025, 59, 18846−18856

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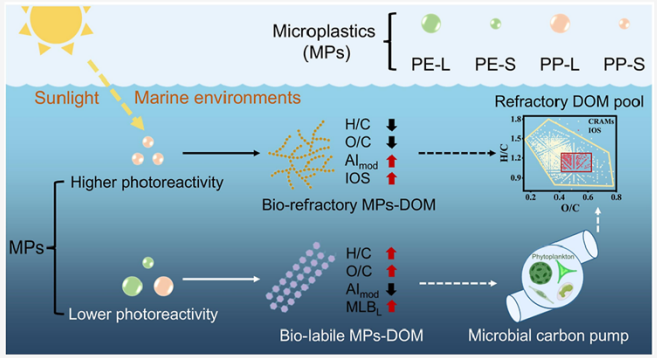
ABSTRACT: Microplastics (MPs) widely pollute marine environments, where the release of MPs-derived dissolved organic matter (MPs-DOM) induced by UV irradiation has been widely documented. However, the effect of MPs' inherent properties on photochemical transformation of MPs-DOM and its implication for oceanic carbon cycles remain poorly understood. Herein, we conducted 180 day artificial weathering experiments under sunlit seawater using polyethylene (PE) and polypropylene (PP) with different sizes as models, investigating the temporally dynamic features of MPs-DOM. Results showed that PP can release more MPs-DOM than PE, and concentrations of MPs-DOM derived from small-sized MPs (~250 μm) were 2−6 times higher than those of large-sized MPs (~5 mm). Spectroscopy and ultrahigh-resolution mass spectrum further revealed that protein-like substances can be persistently produced from MPs with lower photochemical activity (i.e., PE and large-size PP), while DOM derived from MPs with higher photochemical activity (i.e., small-size PP) could be gradually transformed from biolabile components to biorecalcitrant molecules. Furthermore, the persistently accumulated molecules were matched and projected onto an aquatic DOM database, and their relative intensity exhibited a gradually increasing trend across the river-to-ocean continuum at the molecular level. This work reveals the structure−reactivity relationships for MPs-DOM transformation and highlights MPs' potential impact in marine organic carbon cycles.

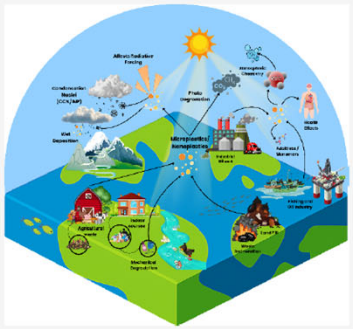


Biorecalcitrant materials are organic pollutants that are not easily biodegraded. They resist conventional biological treatment because microorganisms cannot readily degrade them. They require advanced oxidation processes (AOPs), like photo-Fenton or ozone treatment, to achieve mineralization or improve biodegradability.

Liu 2025, Size and structure-dependent molecular fingerprint transformation of microplastic-derived dissolved organic matter

Global Danger of Microplastics and Nanoplastics

ABSTRACT: Microplastics (MPs) and nanoplastics (NPs) are widespread pollutants present across all environmental matrices, including the atmosphere. They originate anthropogenically from primary sources, like microbeads, glitters, industrial abrasives, etc., and from secondary sources through degradation of larger plastic products, textile fibers, tire wear, waste incineration, etc. Degradation processes, such as mechanical, photochemical, chemical, and microbial degradation, break down plastics into smaller particles and gaseous byproducts. Atmospheric degradation processes of MPs/NPs enhance their area/volume ratio and introduce oxygenated functional groups at the surface, which increases their hydrophilicity and interactions with other pollutants in the surroundings. Thus, MPs/NPs also act as great vectors for toxic substances, including heavy metals, polycyclic aromatic hydrocarbons, and persistent organic pollutants, amplifying their environmental and health risks. MPs/NPs have been detected in various human tissues and fluids. Being bio-inert, they cannot be metabolized and leave the body only through excretory routes. They not only interact with the human organs directly but also indirectly via releasing additives and adsorbed/absorbed pollutants and, thus, can exhibit higher toxicity compared to other atmospheric aerosols. Furthermore, atmospheric MPs/NPs influence radiative forcing and cloud formation, and their photodegradation also releases greenhouse gases, like CO_2, CH_4, and volatile organic compounds (precursors of ozone), linking plastic pollution to climate change. Despite their growing recognition, the study of atmospheric MPs and NPs remains in its infancy, with numerous uncertainties surrounding their behavior, fate, and effects. This review aims to highlight underexplored degradation pathways of atmospheric MPs/NPs that may be enhancing their environmental, health, and climatic implications. It also proposes the future directions for atmospheric MP/NP research.



Dhandapani 2025, Degradation of microplastics and nanoplastics- An underexplored pathway contributing to atmospheric pollutants

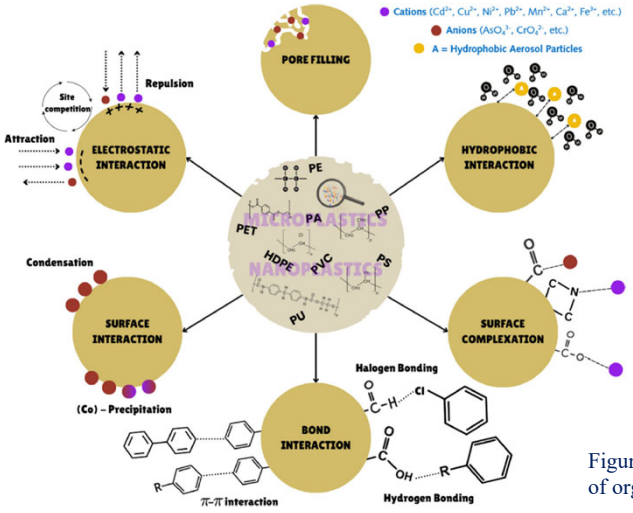


Figure 3. Adsorption and absorption mechanisms and interaction of organic and inorganic pollutants at the surface of MPs/NPs.

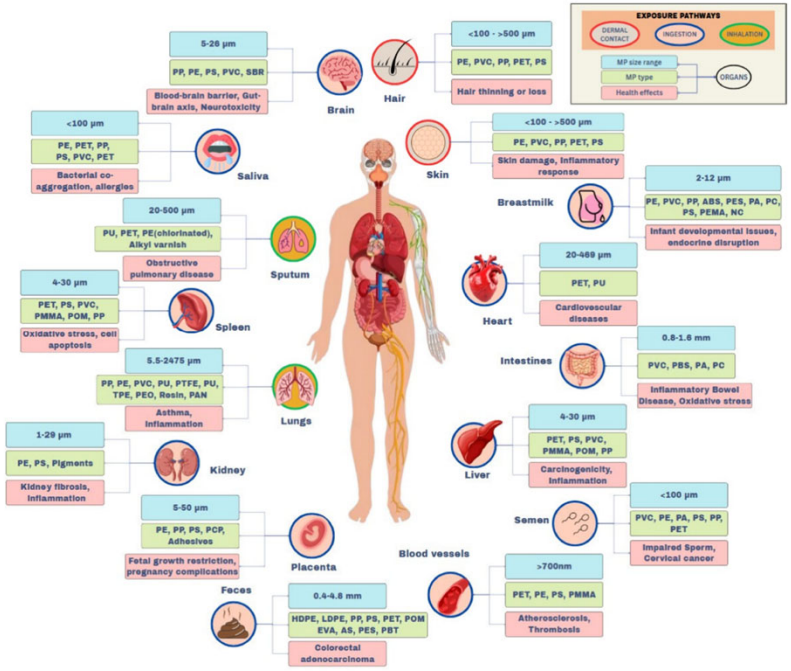


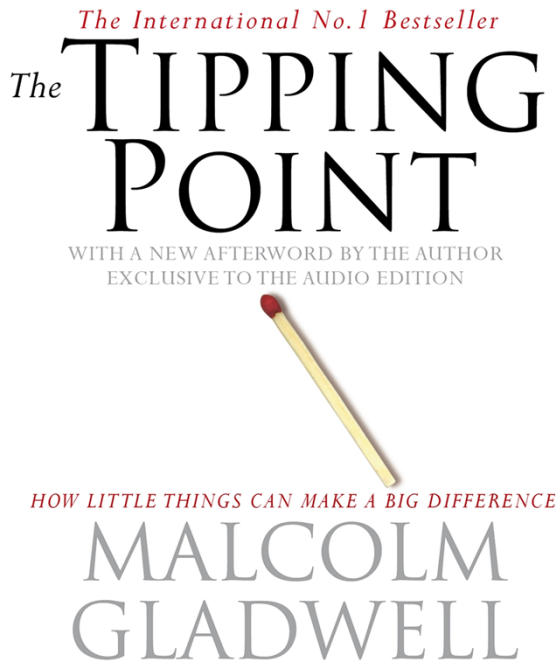
Figure 4. Compilation of reported MPs found in multiple organs in the human body, along with polymer types, size, and proposed health effects (POM, polyoxymethylene; PU, polyurethane; PC, polycarbonate; PBT, polybutylene terephthalate; and NC, nitrocellulose).

Plastic Planet

Werner Boote presents an up-close and personal view of the controversial and fascinating material that has found its way into every facet of our daily lives: plastic. He takes us on a journey around the globe, showing that plastics have become a threat for both environment and human health. 2009.

https://www.imdb.com/title/tt1292648/

Plastic Pollution: A Pandemic



Plastic Pollution: This is Much More than Pollution. It is a Pandemic.

Malaysia stops taking plastic waste from rich nations

https://environews.ph/health/chinas-ban-on-waste-imports-worsens-southeast-asias-plastic-waste-crisis/

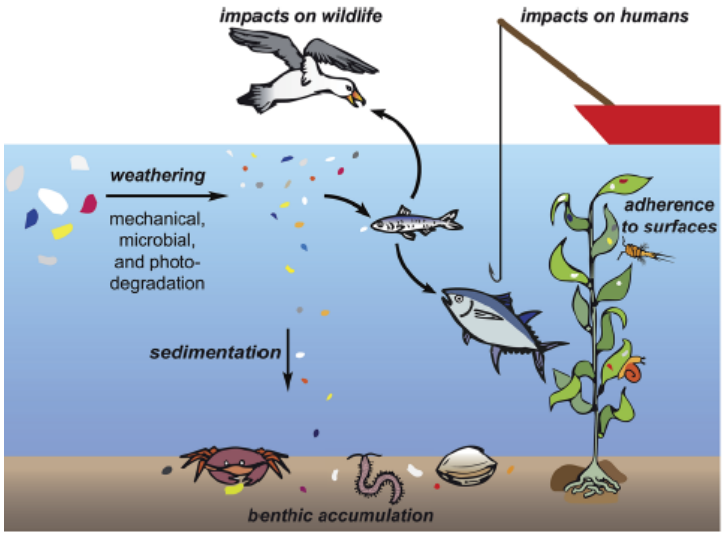
Polluted by single-use plastics.
How long can this last?

Wake-up call: Indian cities generate 15,000 tons of plastic waste daily. A file photo of a drain in New Delhi.

https://www.thehindu.com/sci-tech/energy-and-environment/un-meet-dilutes-indian-plan-to-phase-out-single-use-plastic/article26556292.ece

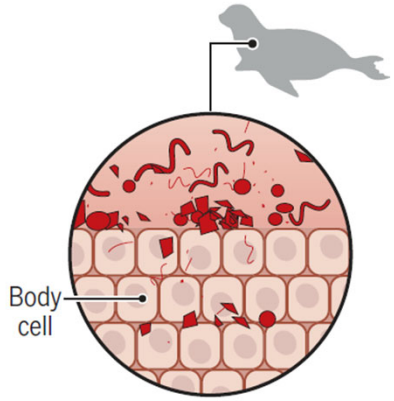
The Green Planet or The Plastic Planet?

June 2018



Plastic debris is broken down into smaller particles, which may be ingested by fish and invertebrates.

E The body
Ingested or inhaled particles can accumulate in body cavities, release fragments and chemicals, and potentially penetrate epithelial layers and tissues.



https://www.mensjournal.com/features/national-geographic-launches-planet-or-plastic-campaign/
https://www.bbc.com/news/av/science-environment-62013030
MacLeod 2021, The global threat from plastic pollution
Mandy Oaklander, 2019. https://time.com/5601359/microplastics-in-food-air/
Lin 2016, Impacts of microplastics on plankton, Environ. Sci.: Processes Impacts, 18, 160-163.

Heart Wrenching Moment Turtle has Straw Pulled from Her Nose

Thank goodness the research team found the poor turtle and spotted the obstruction! It's absolutely appalling that it it's a straw from human's disregard for sea life. This distressing footage shows the dangers of plastic waste and the detrimental effects it can have on sea creatures if disposed of irresponsibly. A male Olive Ridley sea turtle was discovered with a 12 cm plastic straw lodged inside its nose in Costa Rican waters. A research team spotted & rescued the turtle and explained, alongside a video of the removal procedure, that they first believed the foreign object was a parasitic worm. They then set about attempting to remove it with the limited tools & without using anesthetic at their disposal and discovered that it was in fact a straw. The team used a pair of pliers to pull the object from Turtle nose. BY PEOPLES STORY

Aditya John at https://vimeo.com/140911141

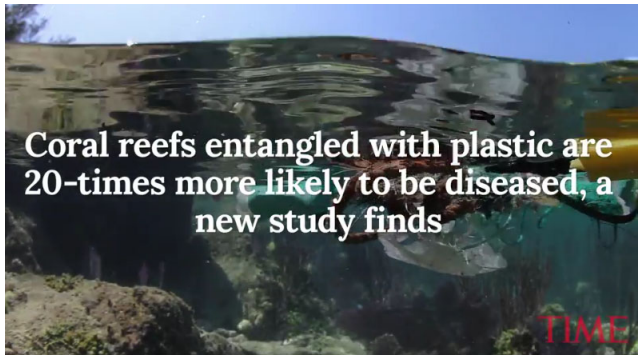
Filmed in 2015 off the coast of Costa Rica, the footage shows marine biologists **Christine Figgener** and **Nathan Robinson** extracting a plastic straw from the nostril of a male olive ridley sea turtle

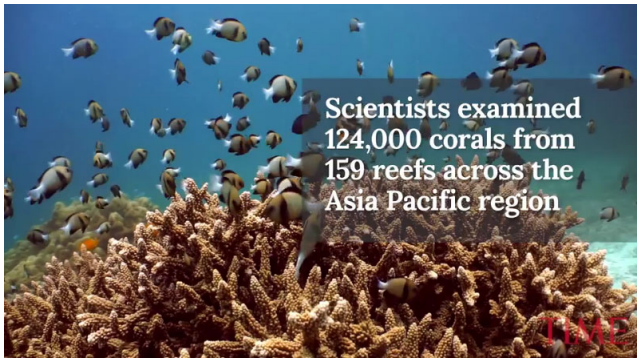
https://www.youtube.com/watch?v=suPt9SGXG34

Plastic bags look like, smell like, and move like jellyfish.

Plastic Garbage in the Pacific Ocean

A patch of plastic garbage in the pacific ocean amounts to twice the size of Texas, a new study says. By Laignee Barron March 23, 2018. Around 1.8 trillion bits of plastic waste have accumulated along a single stretch of the Pacific Ocean between Hawaii and California, an exponential increase since the 1970s, a new study shows. Plastic debris typically collects in one of five "patches" around the world. The largest such repository, known as the Great Pacific Garbage Patch, has amassed so much plastic pollution that if it was heaped together it would amount to twice the size of Texas, according to research by Ocean Cleanup, a Dutch nonprofit. After a three-year study, Ocean Cleanup found the amount of plastic amassing in the Pacific could be as much as 16 times higher than previously reported. Trawling the seas for floating plastic waste, the research team retrieved bottle caps, discarded fishing nets, toys and degrading containers. The 80,000 tons of litter estimated to have gathered in the patch translates to 250 discarded pieces per person around the world.



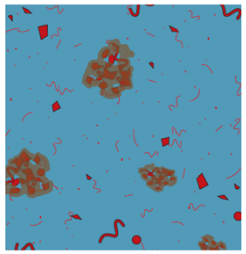


http://time.com/5212078/great-pacific-garbage-patch-plastic-pollution-study/

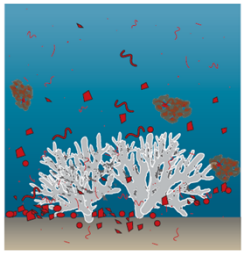
The Global Threat from Plastic Pollution

A Remote ocean surface and coastlines
Ocean gyres are reservoirs for plastic debris and currents can transport plastic to remote and ecologically sensitive coastlines.

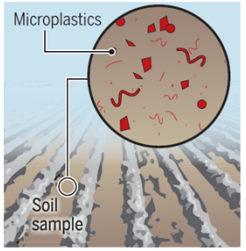
B The water column
Neutrally buoyant plastic and plastic aggregates with organic matter accumulate in the water column of the ocean and lakes and can be taken up by organisms.



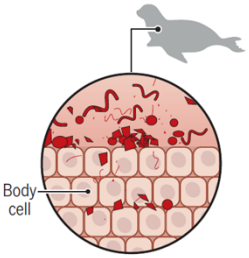
C The deep sea
Sinking plastic accumulates on the seafloor in conditions ideal for long-term preservation in benthic ecosystems and the sedimentary crust.



D Soils
Plastic applied to cropland as mulch and with contaminated compost accumulates and may be slowly released as weathered microplastic.



E The body
Ingested or inhaled particles can accumulate in body cavities, release fragments and chemicals, and potentially penetrate epithelial layers and tissues.



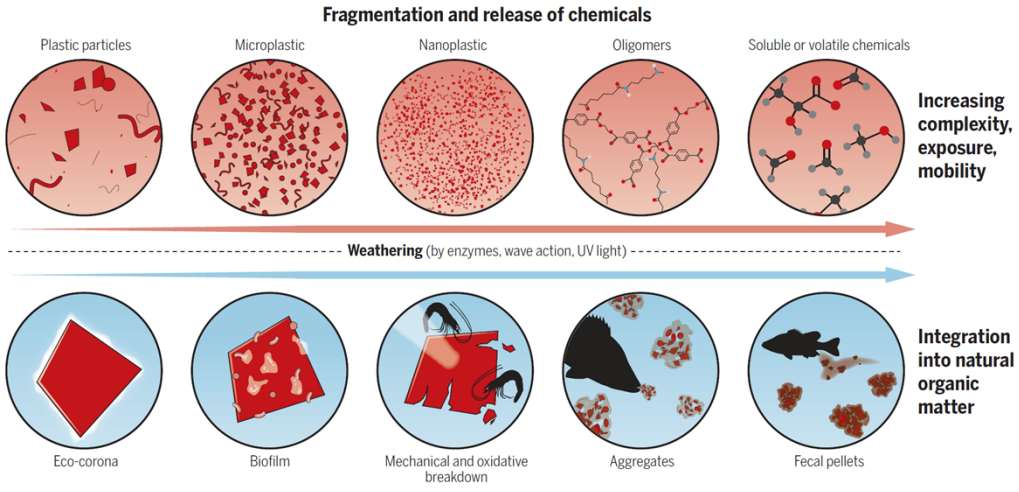


Fig. 2. Weathering processes of poorly reversible plastic pollution in the environment. Weathering proceeds along two co-occurring and synergistic pathways of fragmentation and release of chemicals, and biofouling and oxidation.

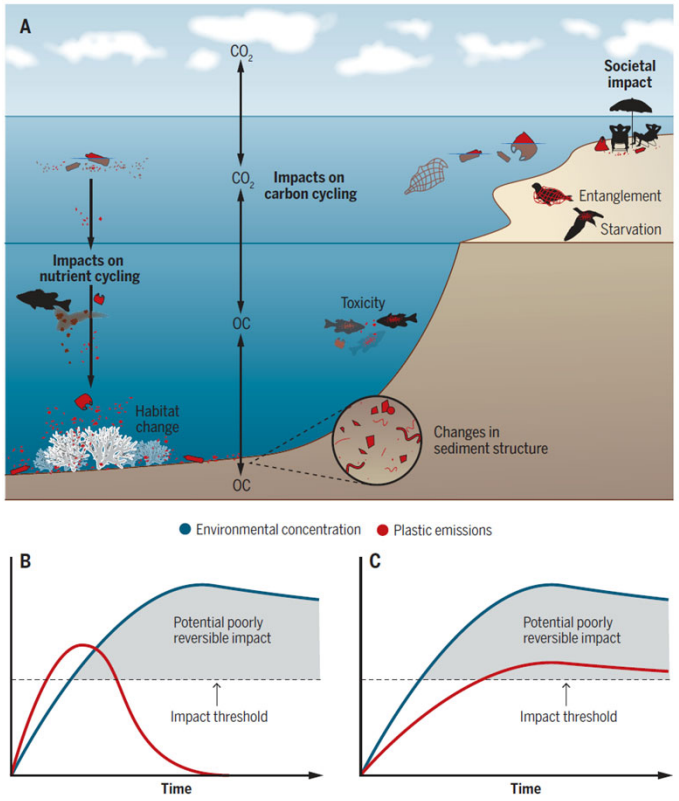


Fig. 3. Diverse potential long-term global impacts of accumulating and poorly reversible plastic pollution. (**A**) Potential impacts include geophysical impacts on carbon cycling, nutrient cycling, soil habitats, and sediment habitats; co-occurring biological impacts on endangered/keystone species and (eco)toxicity; and societal impacts resulting from the public's perception of environmental quality and policy changes. (**B** and **C**) Illustration of how plastic pollution accumulating over an impact threshold can lead to practically irreversible impacts. In (B), plastic pollution has a long residence time in the environment, and therefore concentrations do not respond to emission reductions. In (C), plastic pollution is reversible in the environment (for example, as a result of cleanup actions or degradation), but concentrations remain above the impact threshold because emissions cannot be effectively controlled. CO_2, carbon dioxide; OC, organic carbon.

MacLeod 2021, The global threat from plastic pollution

Plastic Waste Makers Index

1 Despite rising consumer awareness, corporate attention, and regulation, there is more single-use plastic waste than ever before — an additional 6 million metric tons (MMT) generated in 2021 compared to 2019 — still almost entirely made from fossil fuel-based "virgin" feedstocks. The top 20 list of petrochemical companies producing virgin polymers bound for single-use plastic remains effectively unchanged.

While global capacity to produce these virgin polymers is expected to grow slower than the historical rate (2.7% CAGR in 2021-27 versus 3.9% in 2005-20), this still equates to an additional 60 MMT by 2027, of which we expect 17 MMT to be bound for single-use plastics.

2 Single-use plastic is not only a pollution crisis but also a climate one. Cradle-to-grave (Scope 1, 2 and 3) greenhouse gas emissions (GHG) from single-use plastics in 2021 were equivalent to ~450 million metric tons of carbon dioxide (MMT CO_2e), more than the total GHG emissions of the United Kingdom.

Most emissions are produced by the oil and gas and petrochemical industries in the "upstream" part of the lifecycle. Mechanical recycling reduces cradle-to-grave emissions by at least 30 to 40% compared to producing polymers from fossil fuels by avoiding upstream emissions. While the emissions reduction opportunities from recycling are significant, they can only be part of the solution towards a net zero plastics economy.

3 Recycling is failing to scale fast enough and remains, at most, a marginal activity for the plastics sector — from 2019-21, growth in single-use plastics made from virgin polymers was 15 times that from recycled feedstocks. Only strong regulatory intervention with economic incentives can solve what amounts to market failure.

Petrochemical companies are (naturally) only expanding into recycling in markets where the economic conditions are (somewhat) more favourable. These are markets where policies are more progressive and demand for recycled plastics stronger. However, across all polymers and technologies, only 3 MMT of additional on par recycling capacity is expected to be brought online by 2027 (0.7 MMT by the petrochemical industry).

4 Within the petrochemical industry there are two outliers: Taiwan's Far Eastern New Century and Thailand's Indorama Ventures are making strong commitments to recycling and are also now producing on par recycled polymers at scale.

A further eight companies have recently set ambitious 2030 recycled targets of at least 20% of production. Compared to the first edition of the *Plastic Waste Makers Index (2021)*, there are signs that the industry in general is taking circularity more seriously, but this will only amount to greenwashing if representations are not made good with action and investment.

Three big interventions could deliver a step change in single-use plastic waste and associated greenhouse gas emissions

	POLYMER PRODUCERS	INVESTORS
1. **Limit fossil fuel plastic production and consumption**	Include Scope 1, 2 and 3 emissions from plastic polymers in net zero climate targets and strategies.	Actively engage with investees (or use voting rights) to stop the building of new fossil fuel-based polymer facilities, or divest.
2. **Increase plastic products and materials that are designed for circularity and are circulated in practice**	Set a minimum 20% target by 2030 for recycled vs fossil fuel feedstock in polymer production.	Demand clear, ambitious and time-bound targets for recycled vs fossil fuel feedstock in polymer production from every producer.
3. **Eliminate plastic leakage to the environment across the lifecycle through environmentally sound waste management**	Invest in or partner with plastic waste collection, sorting and recycling systems and capacities, with a focus on high-leakage countries.	Lend public support for policies that will create economic conditions for more investment in plastics collection, sorting and recycling (e.g., through the Business Coalition for a Global Plastics Treaty).

Charles 2023, Plastic waste makers index 2023

https://cdn.minderoo.org/content/uploads/2023/02/04205527/Plastic-Waste-Makers-Index-2023.pdf

Single-use plastics – plastic packaging, and disposable plastic items such as bags, straws and cutlery that are used once then thrown away – represent the largest plastics application category and account for a third of all plastics consumed globally. Evidence shows that single-use plastics are also the most damaging to people and the planet.

They are the primary component of mismanaged plastic waste, which is either burned at the roadside, harming human health, or dumped on land and into rivers, from where they disperse to the ocean and harm marine life directly, or indirectly as they degrade into micro- and nano-sized particles over months, years and decades. Emissions from the production, use and disposal of single-use plastics are significant in their contributions both to climate change and air pollution. Almost all single-use plastics contain chemical additives that enhance performance and aesthetics, several of which are known to be harmful to health – at a huge social cost – and many more whose potential toxicity is unknown.*

Quantifying Nanoplastics in Soil-Cultured Plants

Quantifying Nanoplastics in Soil-Cultured Plants Based on a Microcombustion Calorimeter

Hanwen Chen, Xin Zhang,* Shuping Xing, Zhipeng Hao, Baodong Chen, and Yong-Guan Zhu

Cite This: *Environ. Sci. Technol. Lett.* 2023, 10, 1130−1134

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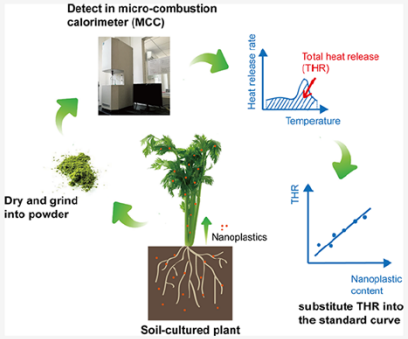
ABSTRACT: Nanoplastics have been detected in a variety of plants and threaten plant growth. To further investigate the physiological damage of nanoplastics to plants and their translocation in plants, it is crucial to quantify the nanoplastics in the plant. However, until now, no studies have reported on how to quantify nanoplastics in soil-cultured plants. Here, we proposed to determine the polyethylene (PE) and poly(methyl methacrylate) (PMMA) contents in soil-cultured plants using a microcombustion calorimeter (MCC). Since the thermal properties of nanoplastics were different from those of plants and soil, this method was not affected by the environmental background. The linear relationships were developed between the sample total heat release (THR) and nanoplastic proportions. Generally, the application of MCC to quantify PE and PMMA resulted in low detection limits (LODs), quantification limits (LOQs), and high spiked recoveries. The method also achieved a high level of accuracy (relative standard deviation and A type uncertainty), demonstrating the feasibility of the proposed method. This is the first report to quantify nanoplastics in soil-cultured plants based on MCC. It provides the possibility for rapid quantification of nanoplastics in plants and thus allows in-depth research of the behavior of nanoplastics in a soil−plant system.



KEYWORDS: *Soil-cultured plants, nanoplastic content, rapid quantification, microcombustion calorimeter, total heat release*

3.1. Feasibility of Measuring Plant Nanoplastics Using MCC.

Since the total heat release (THR) of pure plant powder was a constant value of 9.10 ± 0.07 kJ/g, the application of microcombustion calorimeter (MCC) to quantify nanoplastics in plants did not require removal of the plant background by digestion, which was the greatest advantage of this method. When the plant samples contained nanoplastics, the THR of the sample changed linearly with the nanoplastic content. Therefore, the relationships between the sample THR and the percentage of plant nanoplastics can be developed.

Furthermore, it should be noted that the amount of nanoplastics absorbed by plants was limited. Therefore, in order to confirm whether the method could be used for nanoplastic quantification in plants, it is necessary to determine the low detection limits (LODs) and quantification limits (LOQs) of MCC analysis.

For PE measurement, the LODs of MCC ranged from 0.0035% to 2.7020% and the LOQs ranged from 0.0117% to 9.0068%. For PMMA measurement, the LODs of MCC ranged from 0.0802% to 1.9088% and the LOQs ranged from 0.2675% to 6.3625%. The LOQ for PE determined by MCC was significantly higher than that for PMMA ($P < 0.05$), suggesting that the MCC method was more sensitive to PMMA. Compared with PE crystals, PMMA was amorphous and had a lower vaporization point. In this case, the PMMA vapor could be captured by the detector in the combustion chamber within a shorter time.

Chen 2023, Quantifying nanoplastics in soil-cultured plants based on a microcombustion calorimeter

Unexpected Surge in Single-Use Plastics

Single-Use Plastics During the Pandemic

People are rethinking single-use plastics during the pandemic. By Vanessa Taylor, 2020

While a lot of attention has been paid to the temporarily cleaner skies many cities are seeing due to coronavirus, the ongoing pandemic may also undo some progress that the sustainability movement saw this year. Just two months ago, New York became the third state in the U.S. to ban single-use plastic bags and now, due to coronavirus fears, people are going back to plastics.

In mid-March, Maine postponed a plastic bag ban that was supposed to go into effect on Earth Day, citing concerns that reusable bags could transmit the virus. Those concerns were echoed on March 31, when New Hampshire Governor Chris Sununu announced a temporary ban on reusable bags, requiring all retail stores go back to single-use paper or plastics. Fears over reusable bags are understandable while there are still so many unknowns when it comes to coronavirus transmission.

It's understandable that people are currently skeptical of reusable bags. Grocery store workers are essential and deserve all the protection that they can get. But some advocates worry that these temporary bans could become something longer lasting.

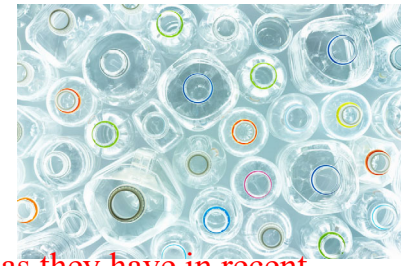
“Some people will call it disaster capitalism,” Ivy Schlegel, a senior research specialist for Greenpeace USA, told The Verge. “Using this moment where everything is in chaos and people are legitimately concerned about public health to turn back the clock to go back to a world where plastic is the norm, rather than right now where reusables are becoming the norm in many places.”

https://www.mic.com/p/people-are-rethinking-single-use-plastics-during-the-pandemic-22760592

Plastic waste problem ‘amplified’ by the pandemic: A push to reduce single-use plastic in takeout food packaging in Chicago is on hold. To get an idea of the impact of increased takeout dining, we invited an expert to a picnic.

https://chicago.suntimes.com/2020/11/11/21558733/styrofoam-plastic-waste-takeout-delivery-restaurants-coronavirus-pandemic-covid-chicago-recycling

Yet Another Consequence of the Pandemic: More Plastic Waste



This new normal means mountains of single-use plastic—and few places to put it but the dump.

You take out your recycling, figuring that plastic wrap will find new life as plastic wrap elsewhere. The reality is it will become trash, because, this being capitalism, it wouldn't be economically feasible to recycle it even at the best of times. But now, with the coronavirus pandemic worsening, even stalwart recyclables like bottles and cans and cardboard are, in many places, going straight to the dump.

The recycling industry has been suffering from a trio of maladies. First, given that plastic is oil, when oil prices fall—as they have in recent years—plastic gets cheaper to make. If oil, and therefore plastic, is cheap to begin with—and the coronavirus crisis has thoroughly cratered the price of oil—it doesn't make economic sense for a company **to process and sell recycled materials if they end up being more expensive than the virgin plastic** another company is making. The second reason is that, for decades, the US sold mountains of recyclable materials to China for processing. But in 2018, China said no thanks to all that anymore and banned imports of plastic and mixed paper. "The third is what no one notices, that the quality of the waste is going down," says Szaky. This is known as "lightweighting," and it was happening long before the pandemic began. By making plastic bottles thinner, the manufacturer saves money by using less plastic. But, Szaky says, "it becomes progressively less profitable for a garbage company to bother recycling."

Recycling isn't a panacea; indeed, it was the plastic industry's push for recycling that got us into this mess. **By shifting the blame for plastic pollution onto the consumers, the industry manipulated us into thinking the problem was ours to solve.** The solution for the past few decades has been to **encourage individuals to recycle, not to demand that the industry stop churning out so much single-use plastic**. That narrative could be crumbling, though, as scientists continue to uncover the pervasiveness of plastic pollution: Sea creatures' stomachs are filling up with plastic bags, and microplastics are blowing from cities onto pristine mountaintops.

The trouble is that our modern society wouldn't exist without the stuff—it's just too damn useful. Big investments from industries and governments could develop better recycling technologies and more easily recyclable plastics that would increase the profitability of recycling. But it matters, too, whether we think of plastics as essentially disposable or recyclable. "The bottom line is, no matter how much government funding is allocated toward recycling efforts," says Meidl, "there first needs to be a significant paradigm shift in human behavior where **plastic is deemed as a resource and not a waste**."

Matt Simon, 2020, https://www.wired.com/story/coronavirus-pandemic-recycling-crisis/

Discarded Face Masks

Discarded face masks pictured washed up on Soko Islands in Hong Kong, China.

Elastic ear loops need to be cut before throwing the mask away to prevent birds, fish, and other wildlife from becoming entangled in the plastic straps.

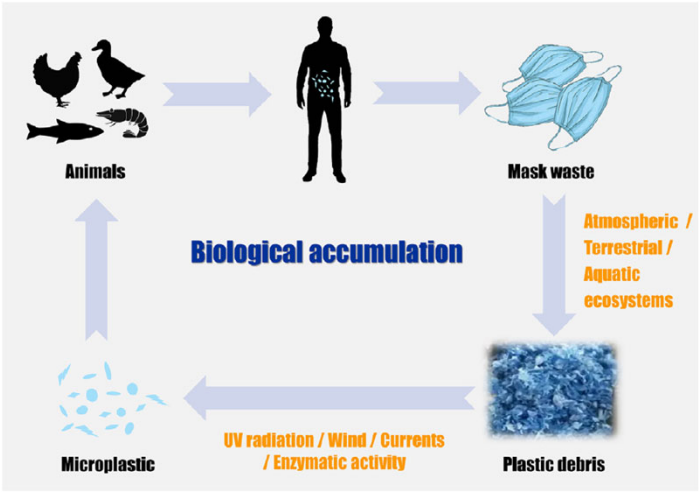


Fig. 2. A schematic diagram of the transmission of microplastics into the environment and through the food chain.

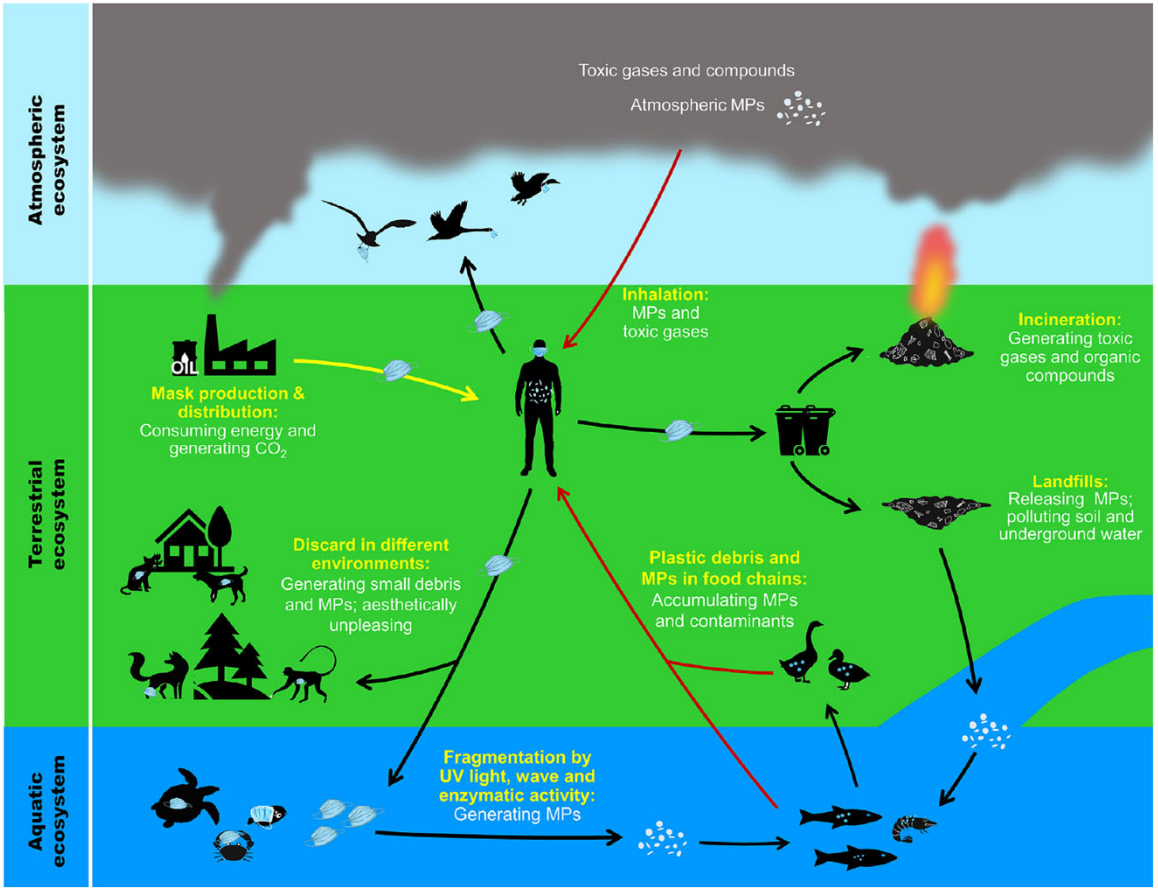


Fig. 1. Massive production and use of face masks have resulted in different pollutants and carbon dioxide (CO_2) emissions. Yellow arrow: face mask production and distribution require petroleum-based raw materials, petrol, workforce, and electricity, which consume energy and release CO_2. Black arrows: face masks discarded in waste containers are incinerated or landfilled with other plastic wastes, which generate harmful gases, toxic compounds, and microplastics (MPs), which can move through the soil and underground water environments. Red arrows: masks discarded in outdoor environments can generate small debris and MPs, which can move through terrestrial, aquatic, and atmospheric ecosystems, thus, threatening wildlife through entanglement and ingestion, causing injury or ecotoxicological effects. These pollutants can accumulate along food chains, thereby resulting in MP pollution in human food resources. Moreover, atmospheric MPs and other toxic gases can be inhaled by terrestrial animals, including humans.

Wang 2023, Global face mask pollution- threats to the environment and wildlife, and potential solutions

Avoiding Contacts with Bare Hands

2020: At the beginning of COVID

Family Express: A Local Gas Station

Plastic Degradation

Hungry Mealworms Can Recycle Styrofoam Trash

New findings suggest mealworms could be the solution to our big plastic problem. Rob Jordan-Stanford

The papers, published in Environmental Science and Technology, are the first to provide detailed evidence of bacterial degradation of plastic in an animal's gut. Understanding how bacteria within mealworms carry out this feat could potentially enable new options for safe management of plastic waste.

"There's a possibility of really important research coming out of bizarre places," says Craig Criddle, a professor of civil and environmental engineering who supervises plastics research by Wu and others. "Sometimes, science surprises us. This is a shock."

Mealworms of the sea

Another area of research could involve searching for a marine equivalent of the mealworm to digest plastics, Criddle says. Plastic waste is a particular concern in the ocean, where it fouls habitat and kills countless seabirds, fish, turtles, and other marine life.

More research is needed, however, to understand conditions favorable to plastic degradation and the enzymes that break down polymers. This, in turn, could help scientists engineer more powerful enzymes for plastic degradation, and guide manufacturers in the design of polymers that do not accumulate in the environment or in food chains.

Criddle's plastics research was originally inspired by a 2004 project to evaluate the feasibility of biodegradable building materials. That investigation was funded by the Stanford Woods Institute's Environmental Venture Projects seed grant program. It led to the launch of a company that is developing economically competitive, nontoxic bioplastics.

https://www.futurity.org/mealworms-styrofoam-1015252-2/ https://www.futurity.org/mealworms-plastic-2238762/
https://www.newsweek.com/plastic-eating-caterpillars-bacteria-1490656 https://www.the-scientist.com/news-opinion/beetle-larvae-can-survive-on-polystyrene-alone-67251
https://www.mnn.com/earth-matters/animals/blogs/plastic-eating-caterpillar-waxmoth-plastivores-eat-and-digest-plastic-bags
https://www.sciencealert.com/scientists-identify-a-microbe-that-can-break-down-hard-to-recycle-plastics?utm_campaign=AppleNews&utm_medium=referral&utm_source=AppleNews
https://www.sciencefocus.com/nature/meet-the-waxworm-a-plastic-eating-caterpillar-that-could-solve-our-waste-problem/?utm_campaign=Meet+the+waxworm%2C+a+plastic+eating+caterpillar+that+could+solve+our+waste+problem&utm_medium=referral&utm_source=AppleNews

These Plastic-chomping Caterpillars Can Help Fight Pollution

Katie Hunt, 2020

The tiny waxworm went from zero to hero in 2017 when researchers discovered the caterpillar could potentially help solve one of the world's most pressing environmental problems: plastic waste. The creature can chomp through plastic, even polyethylene, a common and non-biodegradable plastic currently clogging up landfills and seas. Now scientists have a much better understanding of how the grub is able to do this -- and it comes down to its gut bacteria or microbiome. The findings, which were published in the journal Proceedings of the Royal Society B , could guide efforts to find an effective biodegradation system to tackle plastic waste.

The caterpillars can live on a diet of plastic bags.

"We found that waxworm caterpillars are endowed with gut microbes that are essential in the plastic biodegradation process, " said Christophe LeMoine, an associate professor and chair of biology at Brandon University in Canada.

Not an immediate solution

In the wild, the larvae of the greater wax moth is considered a pest, because it acts as a parasite in bee colonies, eating away at the wax from honeycomb. Its plastic-eating skills were discovered accidentally when an amateur beekeeper in Spain plucked some of the pests from her beehives and put them in a plastic bag. The worms eventually ate little holes in the bag, chewing through the plastic at an alarming rate. Federica Bertocchini, the beekeeper, who also happened to be a scientist at the Institute of Biomedicine and Biotechnology of Cantabria, then put together a study to see just how good the little grubs were at breaking down plastic. The team found the wax worms broke down polyethylene plastic bags faster than other methods.

LeMoine said the waxworms were not an immediate solution to plastic pollution, with still more work to be done to understand how the caterpillars and the microbes in their digestive tract work together before it can be adapted and replicated on a large scale. "Basically, the microbiome and host work synergistically with one another for effective plastic metabolism. Rather than a single species of bacteria it is most likely several species working together to facilitate this process," he said. "While there has been some good progress in figuring out some of the key components, there are still a few more puzzles to solve before this can be effectively used to solve our plastic problem, so it's probably best to keep reducing plastic waste while this gets all figured out," he added.

https://www.cnn.com/2020/03/04/world/caterpillars-plastic-scn/index.html https://www.popularmechanics.com/science/animals/a31229764/caterpillar-eats-plastic/
https://www.cnn.com/2020/03/30/world/bacteria-degrades-plastic-scn-trnd/index.html

Wax worm saliva and the enzymes therein degrade polyethylene

Plastic degradation by biological systems with re-utilization of the by-products could be a future solution to the global threat of plastic waste accumulation. Here, we report that the saliva of *Galleria mellonella* larvae (wax worms) is capable of oxidizing and depolymerizing polyethylene (PE), one of the most produced and sturdy polyolefin-derived plastics. This effect is achieved after a few hours' exposure at room temperature under physiological conditions (neutral pH). The wax worm saliva can overcome the bottleneck step in PE biodegradation, namely the initial oxidation step. Within the saliva, we identify two enzymes, belonging to the phenol oxidase family, that can reproduce the same effect. To the best of our knowledge, these enzymes are the first animal enzymes with this capability, opening the way to potential solutions for plastic waste management through bio-recycling/up-cycling.

Wax worm saliva oxidizes PE film

Saliva, broadly defined here as the juice present in the anterior portion of the digestive apparatus, was collected from the ww mouth and tested on a commercial PE film (Fig. 1A). After three consecutive applications of 30 µl of GmSal for 90 min each, Confocal Raman microscopy/Raman spectroscopy (RAMAN) analysis indicated polymer oxidation, accompanied by a general deterioration of the film (Fig. 1B). This is evident in the overlapping with the PE control (Fig. 1C, D), which reveals the expected PE signature profile. As a further control, the saliva of another lepidopteran larva, *Samia cynthia*, was applied on the PE film, and no oxidation was generated (Fig. 1E). The changes produced by the GmSal in a few hours-long applications are similar to those generated by environmental factors after months or years of exposure to weathering[39,40]. The Fourier Transformed Infrared Spectroscopy (FTIR) analysis confirmed the oxidation profile (Fig. S1). The changes in PE chemical composition revealed by the spectroscopy techniques suggested that molecules other than the long PE polymeric chain formed upon the contact with GmSal.

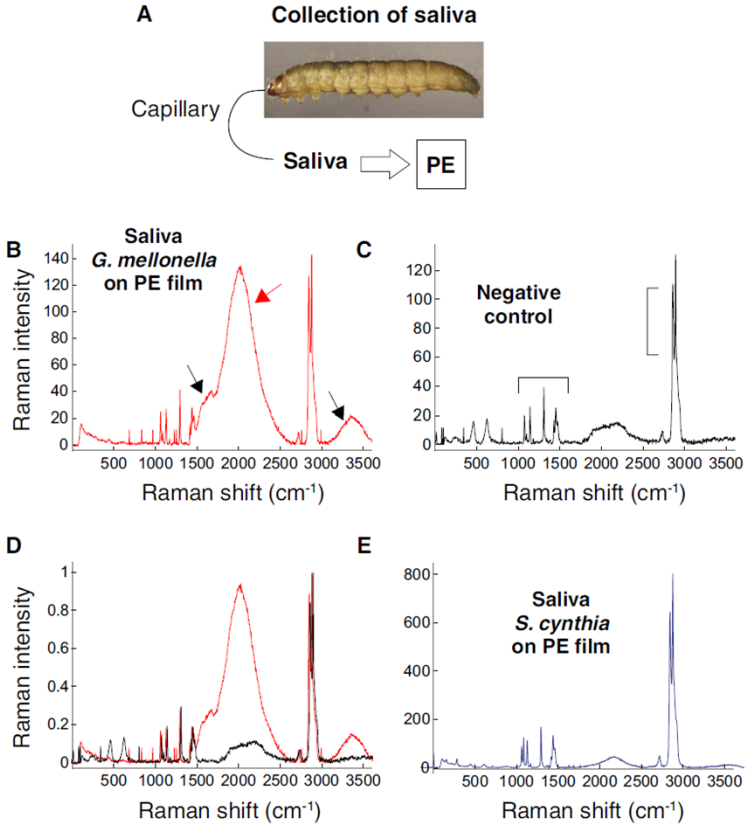
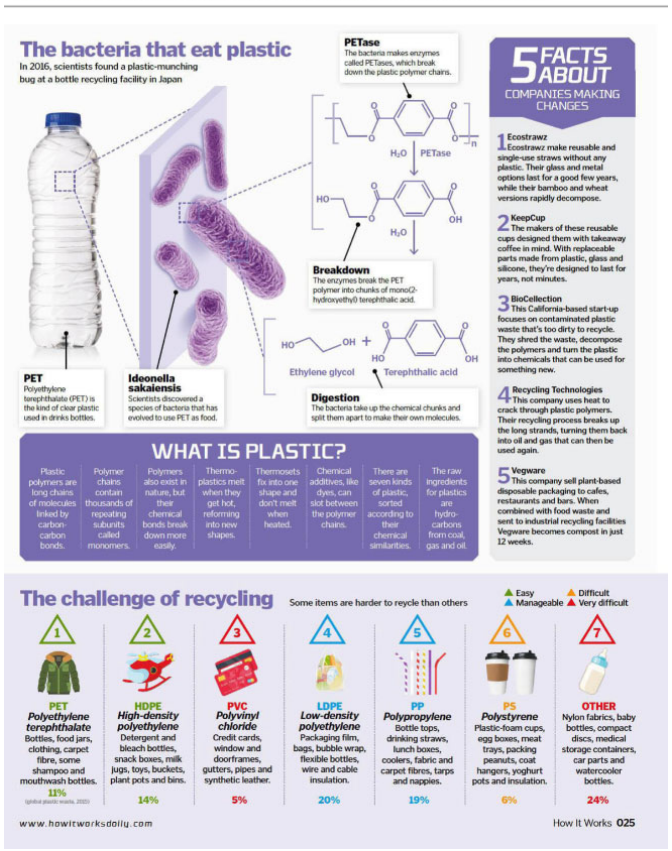


Fig. 1 | Galleria mellonella saliva (GmSal) collection and functional study. A Scheme of saliva collection and application. B–E RAMAN analysis of PE film. B PE film treated with GmSal: 3 applications of 90 min, 30 µl each. The peaks between 1500 and 2400 cm^{-1} indicate different collective stretching vibrations due to the presence of other organic compounds, sign of PE deterioration (red arrow). Oxidation is indicated between 1600 and 1800 cm−1 (carbonyl group) and 3000–3500 cm^{-1} (hydroxyl group) (black arrows). C Control PE film. Brackets indicate the peaks that characterize PE (PE signature), corresponding to the bands at 1061, 1128, 1294, 1440, 2846, and 2880 cm^{-1}. D Overlapping profiles (B and C). E PE film treated with Samia cynthia saliva.

Sanluis-Verdes 2022, Wax worm saliva and the enzymes therein are the key to polyethylene degradation

The Plastic Problem



WHY WON'T PLASTIC BIODEGRADE? Microbes quickly get to work on organic waste, like paper and vegetable peelings, but they can't get to grips with plastic. This might seem odd, as we make plastic from oil, which comes from the remains of ancient plants and animals, but it's all down to the way plastic is made. Natural polymers use chemical links called peptide bonds, while **plastic polymers contain carbon-carbon bonds. These bonds are much stronger, and that's both a gift and a curse**. Most of the enzymes living things use to break organic molecules down can't manage to break these links. This helps to make plastics so durable, but it also makes them hard to get rid of. **There are only a handful of organisms, including some fungi and bacteria, capable of breaking them down**. scientists are still working out how best to use them. Ironically, if more organisms learn this trick, it could put the durability of vital plastic structures under threat.

Approximately 2.1 billion tons of waste is dumped globally every year.

How It Works, Issue 120. January 2019, pp. 22-29

Microplastic Removal and Biodegradation by a Fungus

ABSTRACT: The threat and predominance of microplastics (MPs) in marine environments has prompted a growing interest in their interactions with microorganisms that naturally colonize them (i.e., the plastisphere). This study investigates the interaction of *Alternaria alternata*—a fungus native to the Mediterranean Sea—with polystyrene (PS) MPs, focusing on the potential of the fungus to remove and degrade MPs in seawater. We first designed and constructed a custom laboratory setup in which an immobilized benthic fungal mat, contained in temperature-controlled glass vials, was exposed to ~1.7 μm weathered MPs ranging in size from 0.45 to 30 μm. This scenario emulates environmental conditions occurring in the benthic layer of seagrass habitats. We observed a 96% reduction in PS MP particle concentration within 24 h in the presence of a live fungus, which was significantly higher than the removal of the MP from sedimentation or exposure to inactivated fungus. Micro- and nanoscale visualizations illustrate the capture and entrapment of MPs within the fungal biomass. The fungus displayed selectivity, favoring PS over polyethylene terephthalate (PET) and polypropylene (PP). Further analyses indicated the formation of a transformation product following interaction between the fungus and PS MPs, indicating that active fungal interaction, rather than gravitational settling, was the dominant driver of MP removal. In addition, thermogravimetric analysis revealed structural alterations within the fungal cell wall upon exposure to PS-based MPs, further supporting the hypothesis of PS utilization by the fungus. Overall, this study offers new insights into the use of the fungus *A. alternata* for the biological decomposition of PS MPs and serves as an effective natural method for removing MP from seawater without disrupting the ecological balance.

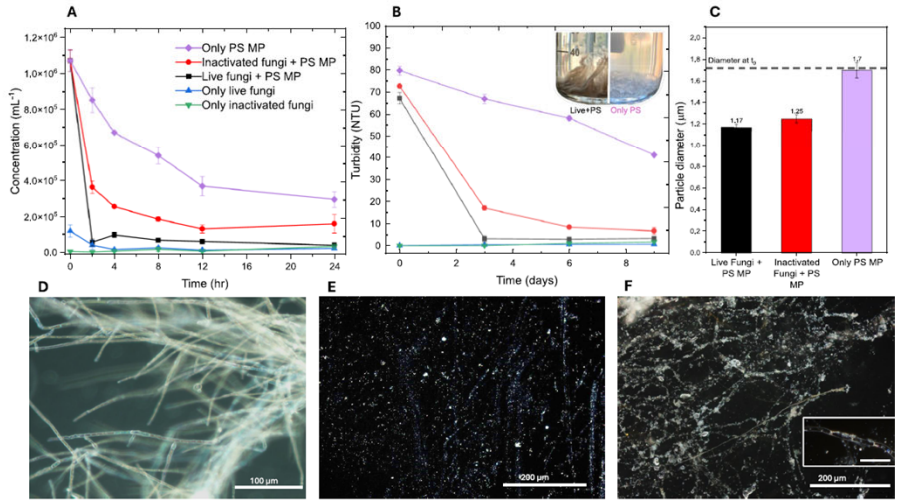


Figure 2. (A) Removal kinetics of polystyrene (PS) microplastic (MP) from simulated seawater in isolation (purple) and in the presence of inactivated fungi (red) and live fungi (black). Two additional control experiments were conducted to assess the particulate biomass contribution of live (blue) and inactivated (green) fungi. (B) Removal kinetics measured indirectly via turbidity measurements. Inset provides a visual indication of turbidity loss in the presence of the fungi compared to control sample of PS MPs only. (C) PS particle mean diameter at the onset and after 24 h of interaction with a live fungus (black) and inactivated fungus (red) as well as in isolation (purple). (D) Light microscopy image of live fungus, (E) PS MPs suspended in seawater solution, and (F) fungus with PS MPs in seawater (inset: close-up on fungus hyphae with adhered microplastic). Removal kinetic experiments were conducted in triplicates, and error bars represent the standard deviation of particle count (or turbidity) results.

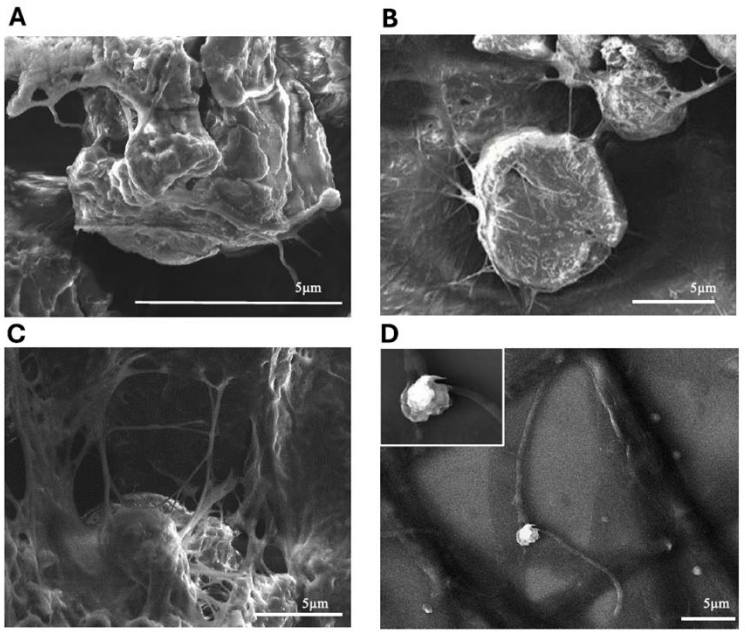


Figure 4. Scanning electron microscope (SEM) micrographs of a typical interaction between polystyrene (PS) microplastic and live fungi (A–C) and inactivated fungi (D).

Schindler 2025, Microplastic removal and biodegradation by native Mediterranean fungus Alternaria alternata

Enzymes' Power for Plastics Degradation

Biodegradation uses the natural ability of microorganisms, such as bacteria and fungi, to metabolize complex organic compounds found in petroleum, converting them into less harmful or toxic compounds.

However, biodegradation by microorganisms also presents challenges. Several factors, including the composition of the oil, environmental conditions (such as temperature, pH, and nutrient availability), and the presence of competing microorganisms, can impact the effectiveness of the process. Thus, the degradation of certain petroleum elements, such as polycyclic aromatic hydrocarbons (PAHs), occurs more slowly and requires specific microbial associations. An additional challenge is to translate the results achieved in the laboratory to real field conditions, considering the complexity of environmental systems.

Figure 1 illustrates some of the listed bacteria and the primary groups of hydrocarbons that they degrade. These species are representative, but there are others within these genera with similar capabilities. Selection depends on the environment and type of contamination. These bacteria are particularly effective when used in microbial consortia, as each one acts on different classes of compounds, promoting a more complete degradation of the oily fraction.

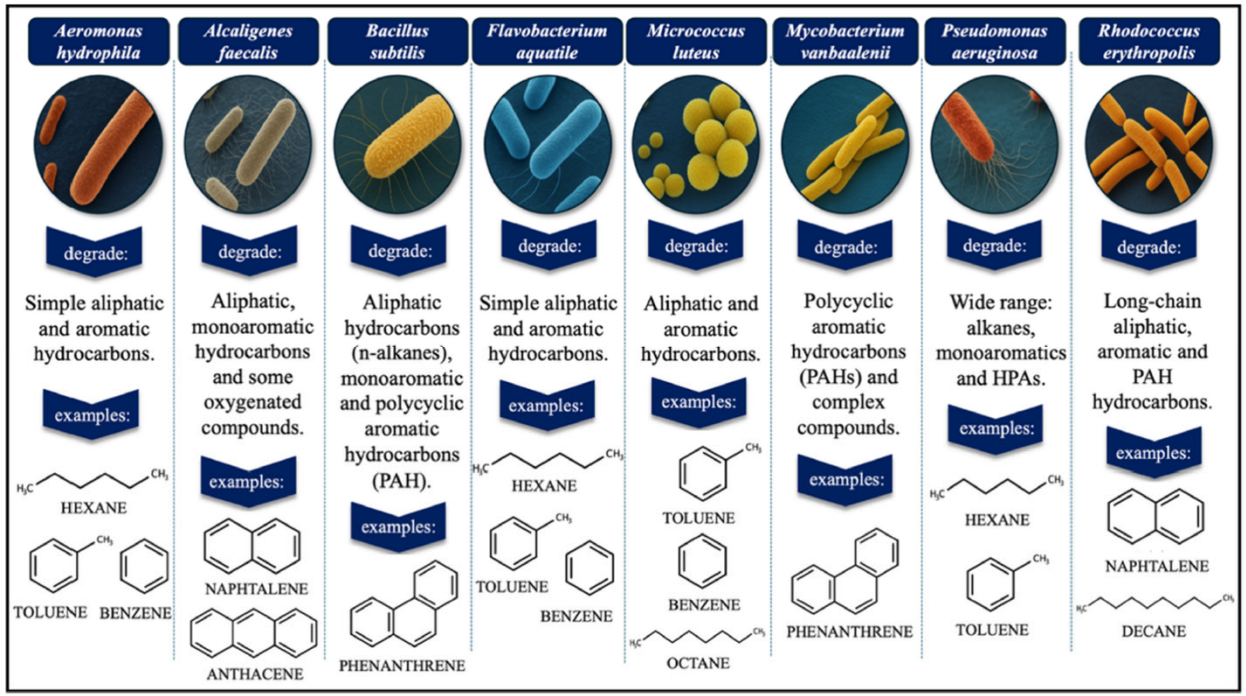


Figure 1. Representative species of some bacteria with biodegradation capabilities for some specific groups of hydrocarbons. Each species can act in the degradation of more than one organic compound and at different stages of the biotransformation of these substrates.

de Sousa Júnior 2025, Microbial enzymatic pathways for petroleum biodegradation in aquatic environments

Plastic Degradation Trends

Table 2: List of different microorganisms with their enzymatic capability for degradation of polymers.

Microorganisms	Enzymes	Plastics	References
Bacteria			
Pseudomonas sp. E4	Alkane hydroxylase	LMWPE (Polyethylene)	[56]
P. putida AJ	Alkane hydroxylase	Vinyl Chloride (Polystyrene)	[57]
P. chlororaphis	Polyurethanase	Polyester (PUR)	[58]
P. aeruginosa	Esterase	Polyester (PUR)	[59]
P. protegens BC2-12	Lipase	Polyester (PUR)	[60]
P. fluorescen	Protease	Polyester (PUR)	[61]
Pseudomonas sp.	Lipase	PET	[49]
Pseudomonas sp. AKS2	Esterase	PES	[24]
P. stutzeri	PEG dehydrogenase	Polyethylene glycol (PEG)	[47]
P. vesicularis PD	Esterase	Polyvinyl alcohol (PVA)	[48]
R. arrizus	Lipase	PEA, PBS, and PCL	[31]
P. stutzeri	Serine hydrolase	PHA	[62]
Tremetesversicolor	Laccase	Nylon, PE	[63]
Rhodococcusequi	Aryl acylamidase	PUR	[64]
Brevibacillusborstelensis	Unknown	PE	[65]
Thermomonosporafusca	Unknown	PVC	[66]
Schlegelellathermo-depolymerans	Unknown	Poly(3-hydroxybutyrate-co3-mercaptopropionate)	[67]
Fungi			
Aspergillusniger	Catalase, Protease	PCL	[31]
Fusarium	Cutinase	PCL	[62]
Aspergillusflavus	Glycosidase	PCL	[31]
Amycolaptosis sp.	Manganese peroxidase	PLA,PE	[62]
Penicilliumfuniculosum	Unknown	PHB	[31]
White-rot fungus IZU-154	Manganese peroxidase	Nylon	[68]
Agromyces sp.	Nylon hydrolase	Nylon-6 (oligomers)	[69]
Acremonium sp.	Unknown	PHB, poly[3HB-co-(10 mol%) 3HV]	[70]
Cephalosporium sp.	Unknown	PHB	[71]
F. solani strain 77-2-3	Unknown	PCL, cutin	[72]
P. funiculosum QM301	Unknown	PEA, PPA, PBA	[73]

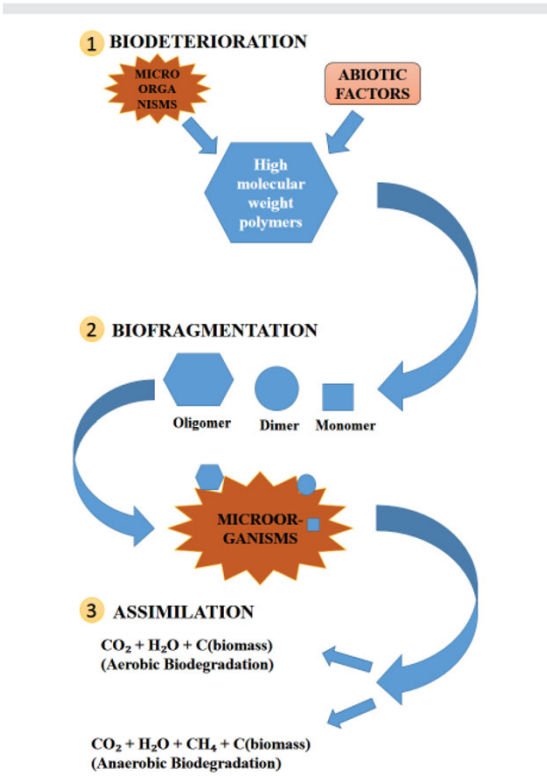


Figure 2: General schematic illustration of polymer biodegradation under aerobic and anaerobic conditions.

Iram 2019, Usage of potential micro-organisms for degradation of plastics

Plastic Degrading Enzymes: PET Depolymerase

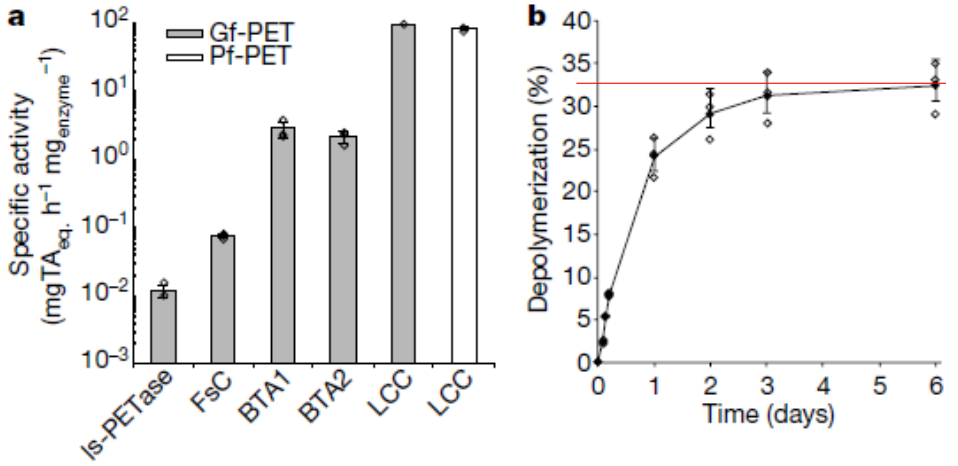


Fig. 1. LCC outperformed all other evaluated PET hydrolases during PET depolymerization assays. **a,** Comparison of the specific hydrolysis activity towards amorphous Gf-PET by: Is-PETase or FsC in 50 mM glycine NaOH buffer, pH 9, at 40 °C; BTA-hydrolase 1 or BTA-hydrolase 2 (BTA1 and BTA2 respectively) in 1 M potassium phosphate buffer, pH 8, at 65 °C; and LCC in 100 mM potassium phosphate buffer, pH 8, at 65 °C. The hydrolysis of Pf-PET by LCC in 100 mM potassium phosphate buffer, pH 8, at 65 °C is also shown. Equimolar amounts of purified proteins were used (6.9 $nmol_{protein}$/gPET and 2 g_{PET}/L_{buffer}). **b,** Detailed hydrolysis kinetics for Pf-PET depolymerization by LCC, as described in **a**.

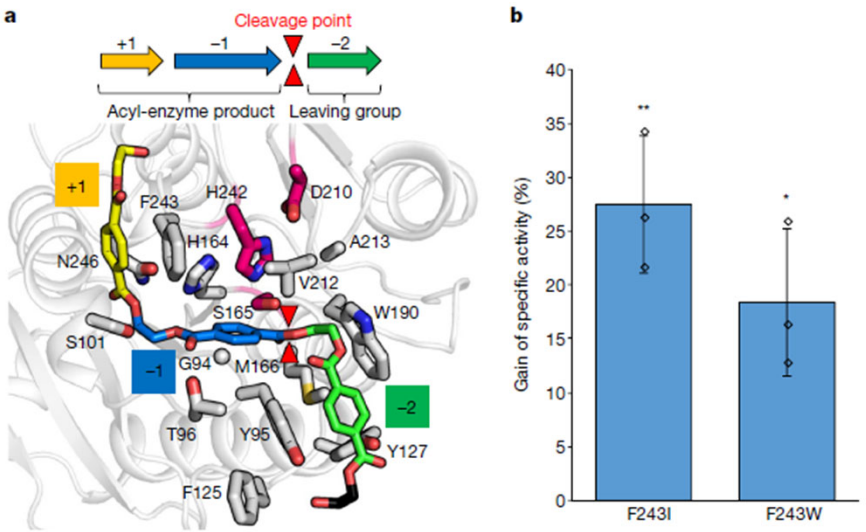
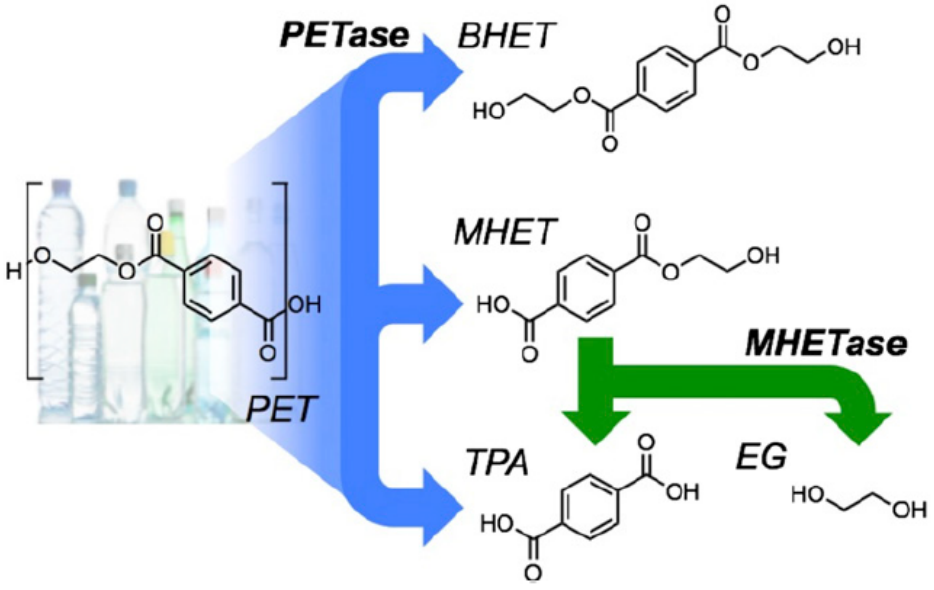


Fig. 2. Improvement of the PET-depolymerization specific activity of leaf-branch compost cutinase (LCC) after mutagenesis by saturation of the residues in contact with a 2-HE(MHET)$_3$ substrate. **b,** Calculated percentage improvement in specific activity of Pf-PET depolymerization by the F243I and F243W variants compared with wild-type LCC at 65 °C (6.9 $nmol_{protein}/g_{PET}$ and 2 g_{PET}/L_{buffer}).

Tournier, 2020, An engineered PET depolymerase to break down and recycle plastic bottles. Nature 580, 216–219 (2020).

Characterization and Engineering of a Plastic-Degrading Aromatic Polyesterase

Recently, a newly discovered bacterium, Ideonella sakaiensis 201-F6, was shown to exhibit the rare ability to grow on poly(ethylene terephthalate) (PET) as a major carbon and energy source. Central to its PET biodegradation capability is a secreted PETase (PET-digesting enzyme). Here, A 0.92 Å resolution X-ray crystal structure of **PETase** reveals features common to both **cutinases and lipases**. PETase retains the ancestral α/β-hydrolase fold but exhibits a more open active-site cleft than homologous cutinases. By narrowing the binding cleft via **mutation** of two active-site residues to conserved amino acids in cutinases, PET degradation was improved, suggesting that PETase is not fully optimized for crystalline PET degradation, despite presumably evolving in a PET-rich environment. PETase degrades another semiaromatic polyester, polyethylene-2,5-furandicarboxylate (PEF), which is an emerging, bioderived PET replacement with improved barrier properties. In contrast, **PETase does not degrade aliphatic polyesters**, suggesting that it is generally an aromatic polyesterase. These findings suggest that additional **protein engineering** to increase PETase performance is realistic and highlight the need for further developments of structure/activity relationships for biodegradation of synthetic polyesters.



Mutation (natural selection) takes time.
Protein engineering (artificial selection) is faster.

Fig. 1. PETase catalyzes the depolymerization of PET to terephthalic acid (TPA) and bis(2-hydroxyethyl)-TPA (BHET), and mono(2-hydroxyethyl) terephthalic acid (MHET). MHETase converts MHET to TPA and ethylene glycol (EG).

Austin 2018, Characterization and engineering of a plastic-degrading aromatic polyesterase, Proceedings of the National Academy of Sciences May 2018, 115 (19) E4350-E4357.
https://www.popsci.com/bacteria-enzyme-plastic-waste

Plastic Degrading Enzymes: PET Depolymerase

Present estimates suggest that of the 359 million tons of plastics produced annually worldwide, 150–200 million tons accumulate in landfill or in the natural environment. Poly(ethylene terephthalate) (PET) is the most abundant polyester plastic, with almost 70 million tons manufactured annually worldwide for use in textiles and packaging. The main recycling process for PET, via thermomechanical means, results in a loss of mechanical properties. Consequently, de novo synthesis is preferred and PET waste continues to accumulate. With a high ratio of aromatic terephthalate units—which reduce chain mobility—PET is a polyester that is extremely difficult to hydrolyze.

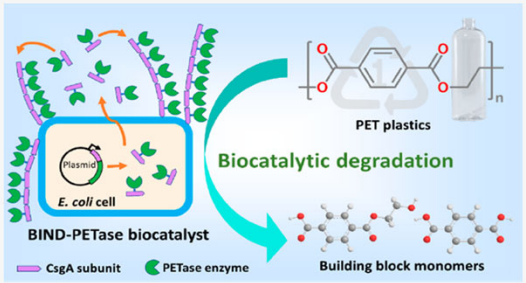
Given that crystalline PET has been found to be subject to only limited depolymerization by cutinase enzymes, we used a commercially available amorphous PET (Gf-PET, from the supplier Goodfellow) to compare the activity of several enzymes reported previously to hydrolyse PET in their optimal conditions. These enzymes were *Thermobifida fusca* hydrolases 1 and 2 (BTA1 and BTA2), *Fusarium solani pisi* cutinase (FsC), *Ideonella sakaiensis* PETase (Is-PETase) and **leaf-branch compost cutinase (LCC)**. LCC outperformed all other enzymes tested, reaching an initial PET-specific depolymerization rate of 93.2 $mg_{TAeq.}/h{\cdot}mg_{enzyme}$ at 65 °C (Fig. 1a). We found LCC to be at least 33 times more efficient than any other enzyme tested (Fig. 1a and 1b), while also demonstrating the highest thermostability, with a determined melting temperature of 84.7 °C. This depolymerization performance of LCC at 65 °C was slightly lower when using bottle-grade PET (Pf-PET) as a substrate, with an initial PET-specific depolymerization rate of 81.9 $mg_{TAeq.}/h{\cdot}mg_{enzyme}$. While approaching the glass transition temperature, known to maximize PET chain mobility and enzymatic depolymerization, the LCC reaction stopped after 3 days at 65 °C with a Pf-PET conversion level of only 31%. We observed no inhibition by the depolymerization products ethylene glycol and terephthalic acid at the concentrations that would be obtained at 100% Pf-PET depolymerization, and Pf-PET crystallinity was unchanged after 6 days at 65 °C (10% crystallinity, as measured by differential scanning calorimetry). Moreover, the initial kinetics could be restored by adding LCC to the stopped reaction, implying that the thermostability of LCC was most likely to be the limiting factor, notwithstanding its high melting temperature when free in solution. To optimize depolymerization yields, we sought to **improve both the activity and the thermostability of LCC through enzyme engineering**.

Tournier 2020, An engineered PET depolymerase to break down and recycle plastic bottles. Nature 580, 216–219 (2020).

Enzymatic Degradation of Polyethylene Terephthalate Plastics

ABSTRACT: The extensive production and use of polyethylene terephthalate (PET) have generated an enormous amount of plastic waste, which potentially threatens the environment and humans. Enzyme biocatalysis is a promising green chemistry alternative, relative to the conventional fossil-derived production process, to achieve plastic waste treatment and recycling. In this work, we created a biocatalyst, BIND-PETase, by genetically engineering the curli of an *Escherichia coli* cell with a functional PETase enzyme for biocatalytic degradation of PET plastics. BIND-PETase could degrade PET to generate degradation products at the concentration level of greater than 3000 μM under various reaction conditions. The effects of key reaction parameters, including pH, temperature, plastic substrate mass load, and surfactant addition were characterized. BIND-PETase was reusable for PET degradation and remained stable with no significant enzyme activity loss when stored at both 4 °C and room temperature for 30 days (Student's t test, $p > 0.05$). Notably, BIND-PETase could enable the degradation of PET microplastics in wastewater effluent matrix. Moreover, BIND-PETase could depolymerize highly crystalline postconsumer PET waste materials under ambient conditions with degradation efficiency of 9.1% in 7 days. This study provides a new horizon for developing environmentally friendly biocatalytic approaches to solve the plastic degradation and recycling challenge.

KEYWORDS: *Biocatalysis, enzymatic depolymerization, plastic waste, biofilm-integrated biocatalyst, polyethylene terephthalate (PET), curli*



Biofilm-integrated nanofiber display (BIND)

BIND-PETase Was Capable of PET Microplastic Degradation in Wastewater and Postconsumer PET Waste Depolymerization. Wastewater treatment plants (WWTPs) contribute substantially to the plastic pollution in aquatic environments.[39] Although the current WWTP processes could remove microplastics, given the tremendous volume of effluent, a significant amount of microplastics (~5.00×10^5 to 1.39×10^{10} particles/day) could still be released with effluent into the receiving water systems.[39−42] PET accounts for ~4%−35% of the microplastics discharged.[39]

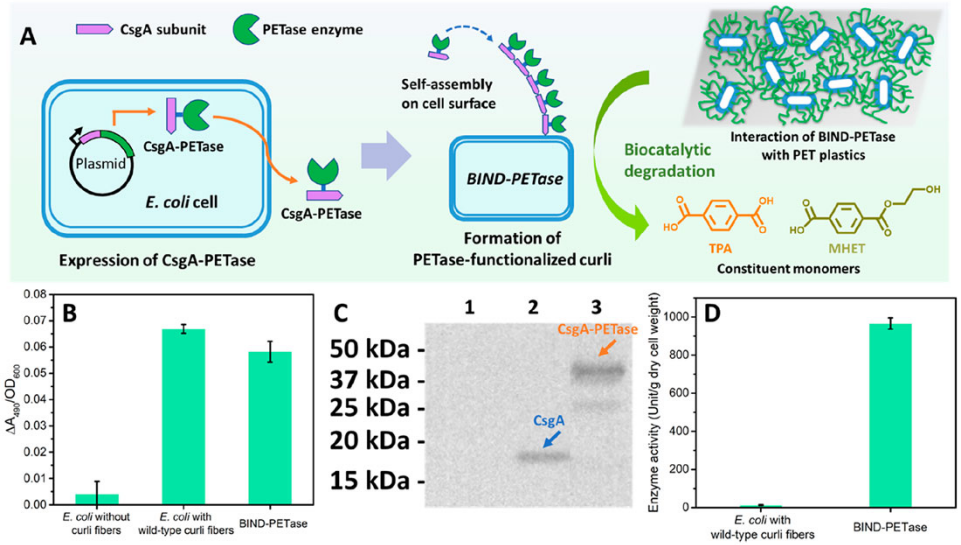


Figure 1. Construction and characterization of the BIND-PETase biocatalyst. (A) Schematic diagram for the design of BIND-PETase for biocatalytic degradation of PET. (B) Congo red binding assay. The experiments were conducted in triplicate, and values represent the mean ± standard error. (C) Western blot analysis. The blue and orange arrows indicate the wild-type CsgA subunit and CsgA-PETase fusion, respectively. (D) Enzyme activity of the BIND-PETase biocatalyst. One unit (U) of enzyme activity was defined as the amount of enzyme that catalyzes the hydrolysis of 1 μmol of pNPB substrate per minute under the conditions specified in Section S5. The experiments were conducted in triplicate, and values represent the mean ± standard error.

Zhu 2022, Enzymatic degradation of polyethylene terephthalate plastics by bacterial curli display PETase

PET Hydrolase

Enzymatic depolymerization of PET provides a milder and more environmentally friendly alternative operating at temperatures below 80 °C and neutral pH in aqueous conditions.

PET hydrolases are classified into two types: type I, derived from fungi, and type II, derived from bacteria. The PET hydrolases have an α/β hydrolase fold and catalytic triad (Ser-His-Asp) at the catalytic center, like that of serine protease. Cutinases, which are the hydrolases of the wax layer of plants, are applied in the textile and detergent industries for fiber modification and removal of hydrophobic stains, contributing to more eco-friendly processing methods.

The first enzyme reported to degrade PET fibers was a cutinase from *Thermobifida fusca*, and cutinase is also an enzyme with high potential industrial applications in PET enzymatic degradation. **Problems with enzyme catalysis include the low rate of reaction and limited accessibility to the crystal region of PET**. To solve this problem, high-activity variants of PET-hydrolyzing enzymes have been developed. The most well-known variant is LCC-ICCG, a variant derived from leaf and branch compost cutinase (LCC), which was reported in 2020. 90% depolymerization of 200 g of PET per kilogram of reaction mixture was achieved by LCC-ICCG in 9.3 h at pH 8 and 72 °C.

Genetic engineering?
Benefit/Risk Ratio

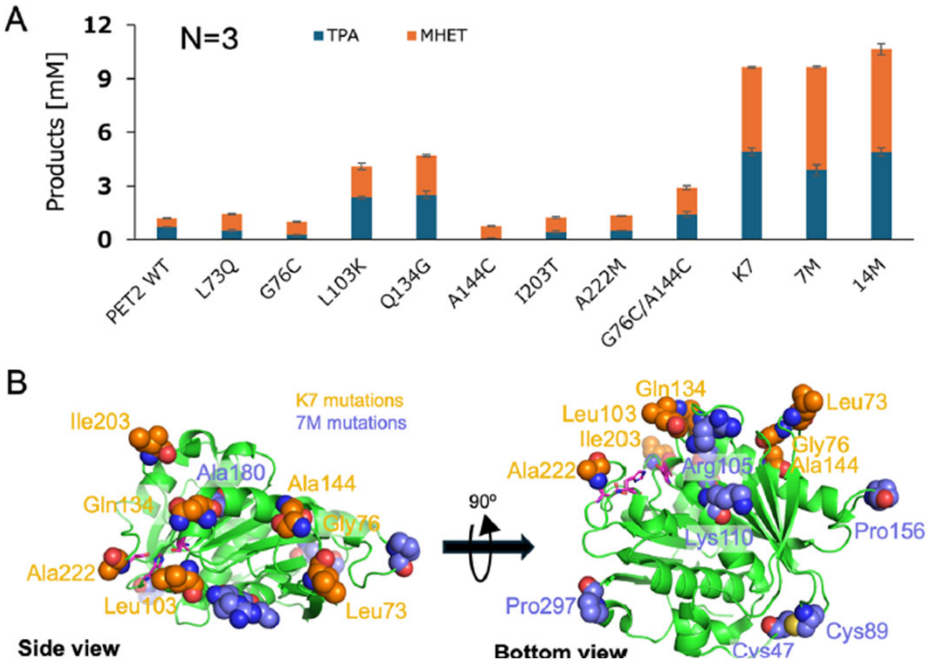


Figure 1. PET degrading activities of PET2 WT and variants and mutation positions of PET2-K7 and PET2-7M. (A) Effects of the single mutations on activities and activities of the combined variants PET2-K7, PET2-7M, and PET2-14M (combination of K7 and 7M). PET powders were degraded at 60 °C and pH 8.0 for 24 h. (B) Mutation positions of PET2-K7 and PET2-7M. The crystal structure of PET2-7 M (PDB ID: 7ECB) is shown in green cartoons, and the mutation positions of PET2-K7 and PET2-7M are shown as orange and blue spheres, respectively. The catalytic triad is indicated by a purple stick.

Matsuzaki 2025, Development and productioin of moderate-thermophilic PET hydrase for PET bottle and fiber recycling

Plastic Degradation Trends

A large amount of data on physical (i.e., density, surface roughness, weight loss over time), thermal [i.e., melting temperature (T_m), glass transition temperature (T_g)], and mechanical (i.e., modulus) properties have been measured along with molecular weight changes. Overall, the database contained >110 polymer samples with >5000 descriptors. Bulk property descriptors included density, weight-average molecular weight (M_w), number-average molecular weight (M_n), dispersity (M_w/M_n), T_g, melting temperature (T_m), % crystallinity, and enthalpy of melting (i.e., amount of energy required in J/g). Molecular level descriptors included types of carbon, oxygen, and nitrogen atoms using the concept of hybridization (i.e., sp^3, sp^2) and the % of these atoms in the polymer. To capture architectural features on the molecular level, the database denoted the number of hydrogens per monomer, number of CH_3, CH_2, and CH groups per monomer, the number of cyclic rings, and % atoms in cyclic rings. **Hydrophobicity** was investigated to quantify the oil-like or water-repellent attribute of each polymer on a continuum.

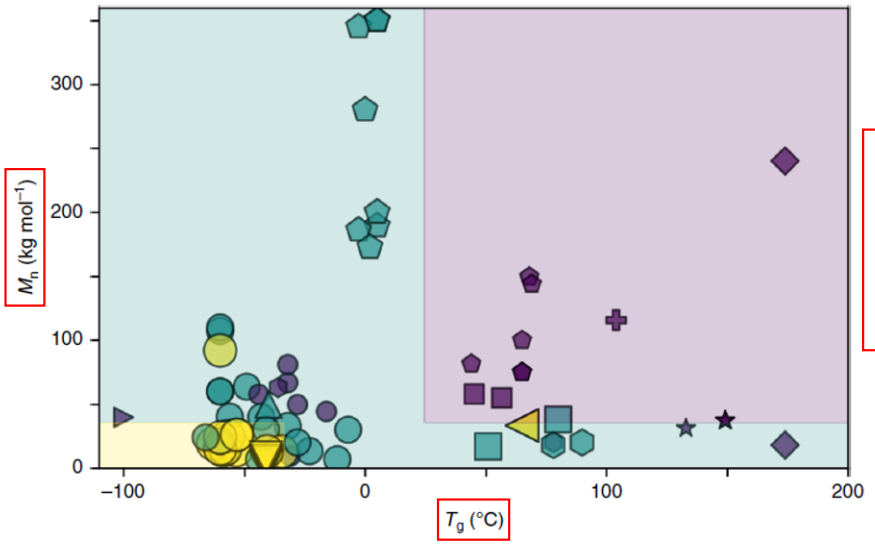


Fig. 4. Graphical representation of decision tree. The shaded areas reflect prediction zones that correspond to fast (yellow), medium (green), and slow (purple) degradation.

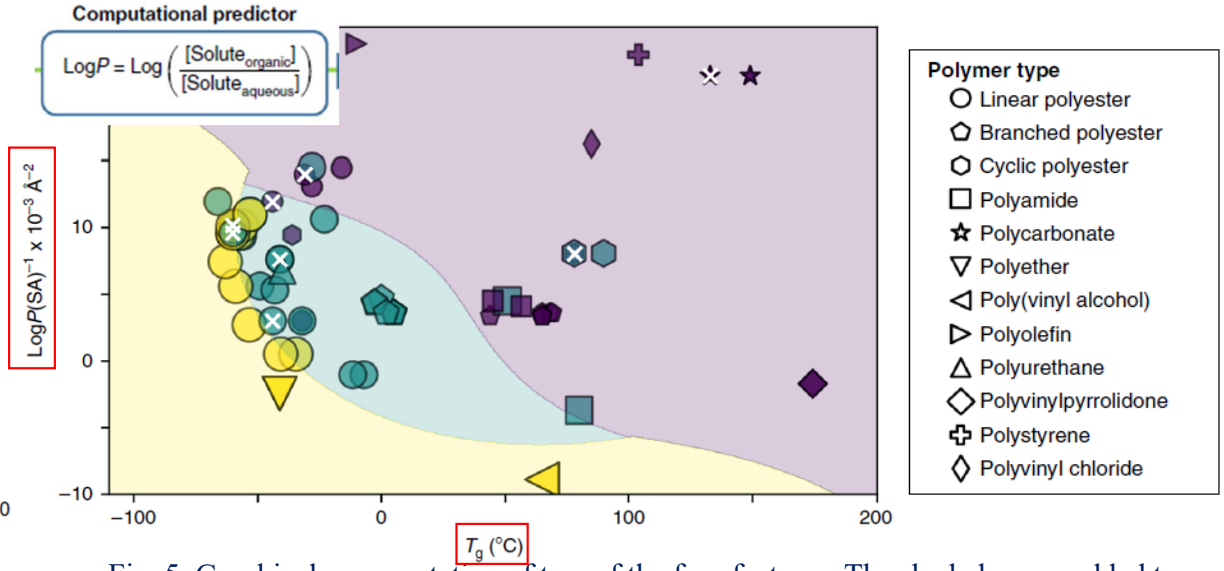


Fig. 5. Graphical representation of two of the four features. The shaded areas, added to visually generalize the degradation regions, correspond to fast (yellow), medium (green), and slow (purple) degradation. Incorrect predictions from the classification tree are denoted with an 'x'. SA=Surface area.

K. Min, J.D. Cuiffi, & R.T. Mathers 2020, Ranking environmental degradation trends of plastic marine debris based on physical properties and molecular structure, Nature Communications, 11: Article number: 727 (2020)

Plastic Degradation by Embedded Enzymes

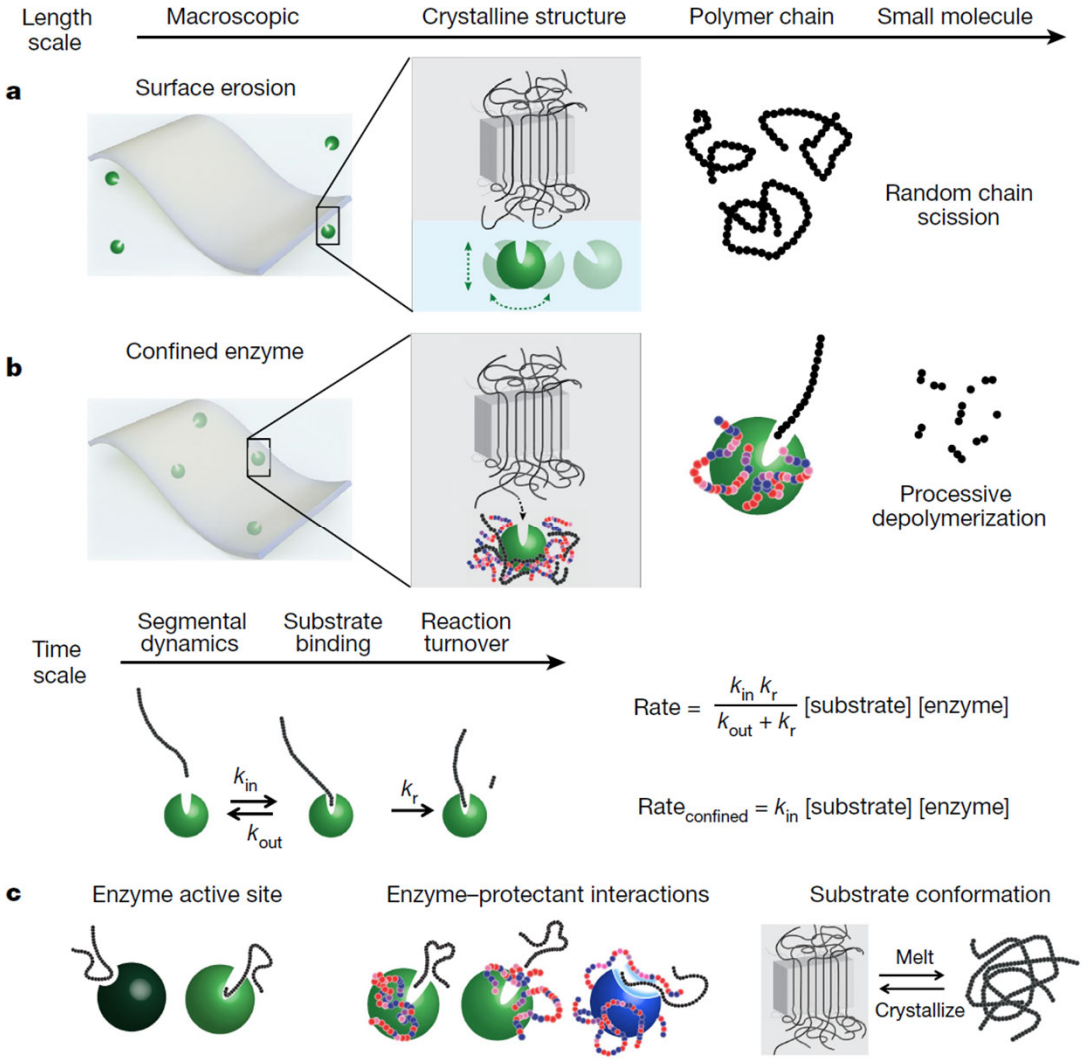


Fig. 1 | Biocatalysis with **embedded enzyme** for polymer degradation. a, b, Schematic illustrating two degradation pathways: plastic surface erosion with random chain scission (a) and chain-end binding-mediated processive depolymerization when enzymes are nanoscopically confined to co-localize with polymer chain ends in the amorphous domain (b).

The enzyme protectants (RHPs) are used to mediate enzyme–polymer interactions for dispersion and are rendered as chains of multi-coloured beads. b, The reaction kinetic changes where macromolecular substrate binding becomes the rate-limiting factor with confined enzymes. The variables shown in b represent rate constants of a polymer chain diffusing into (k_{in}) and out of (k_{out}) the enzyme active site, and the catalytic reaction rate constant (kr). The reaction kinetics change where macromolecular substrate binding becomes the rate-limiting factor with confined enzymes ($k_{in} << k_r$).

c, Additional factors that modulate biocatalysis in solid states, as well as enzymatic reactions towards programmable polymer degradation. Left, a surface-exposed active site can readily bind chain segments, whereas a deep, narrow binding site prefers chain ends. Middle, the enzyme protectants (RHPs) can stabilize an enzyme, block the active site or complex with a surface-exposed binding site to implement processivity. Right, semi-crystalline polymer chain conformation affects degradation rate.

DelRe 2021, Near-complete depolymerization of polyesters with nano-dispersed enzymes

Enzymes' Power for Plastics Degradation

CONTENTS

Tournier 2023, Enzymes' power for plastics degradation

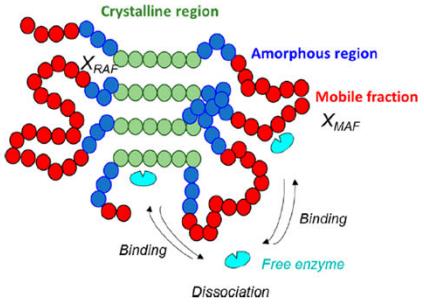
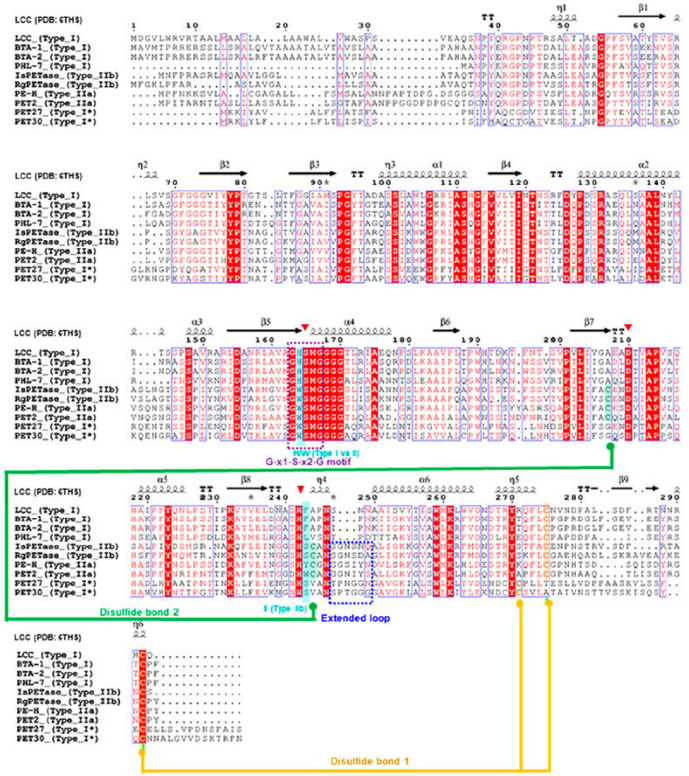


Figure 12. Schematic representation of PET hydrolysis by PET hydrolase. PET hydrolase binds to the surface of PET and acts on the mobile fraction of amorphous regions (X_{MAF}) when the rigid amorphous fraction (X_{RAF}) of amorphous regions as well as the crystalline regions of PET remain recalcitrant to depolymerization. Each sphere represents a monomer of MHET.



ıre 7. Multiple sequence alignment of selected bacterial PET hydrolases. Amino acid sequences of 10 selected PET-degrading enzymes of each · (e.g., type I, type IIa, type IIb, and type I*) are compared. Secondary structure elements are shown based on the LCC X-ray structure (PDB 4S). Multiple amino acid sequences were aligned using ClustalW. Representation was done using ESPript.[147] Catalytic residues are indicated by triangles, disulfide bridges are marked in yellow and in green for that defining the type II PET hydrolases. The extended loop defining type II I* is highlighted in navy blue. The G-x1-S-x2-G motif is indicated in purple, with x1 = W for type IIa, IIb, and I* and x1 = H for type I. The S ning type IIb is highlighted in cyan color.

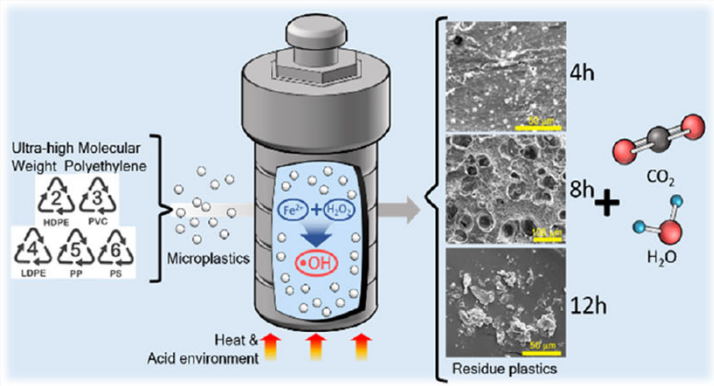
Degradation of Microplastics by a Thermal Fenton Reaction

Degradation of Microplastics by a Thermal Fenton Reaction

Kunsheng Hu, Peng Zhou, Yangyang Yang, Tony Hall, Gang Nie, Yu Yao, Xiaoguang Duan,* and Shaobin Wang*

Cite This: *ACS EST Engg.* 2022, 2, 110–120

ABSTRACT: Microplastics (MPs) are ubiquitous in the environment and are infiltrating the food chain, causing potential risks to living beings. However, current methods of MP removal from an aqueous environment are limited by low efficiency. Advanced oxidation processes (AOPs) are emerging techniques for MP purification. Herein, a hydrothermal coupled Fenton system is developed for decomposition of ultrahigh-molecular-weight polyethylene, achieving 95.9% weight loss in 16 h and 75.6% mineralization efficiency in 12 h. The high effectiveness is attributed to the synergy of hydrothermal hydrolysis, proton-rich environment, and massive production of hydroxyl radicals. The system is also efficient to remediate different petroleum-based plastics and maintains high efficiency in practical water bodies. Characterizations revealed a two-stage degradation process: chain unfolding/stretching and oxidation, giving rise to the formation of carbonyl groups and decreased crystallinity of MPs during the hydrothermal treatment. The chain stretching stage is pivotal to the whole treatment because it remarkably facilitates subsequent chain cleavage and Fenton oxidation. This study provides a new approach to removing MPs in water bodies and new insights into MP degradation by the AOP technology.



KEYWORDS: *microplastics, hydrothermal treatment, Fenton reaction, two-stage degradation, advanced oxidation technology*

Hu 2025, Degradation of microplastics by a thermal Fenton reaction

Characterization Techniques of Polymer Aging

Characterization Techniques of Polymer Aging: From Beginning to End

Rui Tian,*,⊥ Kaitao Li,⊥ Yanjun Lin, Chao Lu,* and Xue Duan

Cite This: https://doi.org/10.1021/acs.chemrev.2c00750

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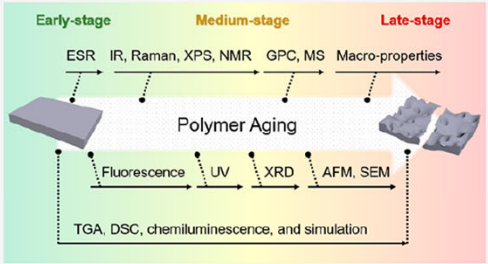
ABSTRACT: Polymers have been widely applied in various fields in the daily routines and the manufacturing. Despite the awareness of the aggressive and inevitable aging for the polymers, it still remains a challenge to choose an appropriate characterization strategy for evaluating the aging behaviors. The difficulties lie in the fact that the polymer features from the different aging stages require different characterization methods. In this review, we present an overview of the characterization strategies preferable for the initial, accelerated, and late stages during polymer aging. The optimum strategies have been discussed to characterize the generation of radicals, variation of functional groups, substantial chain scission, formation of low-molecular products, and deterioration in the polymers' macro-performances. In view of the advantages and the limitations of these characterization techniques, their utilization in a strategic approach is considered. In addition, we highlight the structure−property relationship for the aged polymers and provide available guidance for lifetime prediction. This review could allow the readers to be knowledgeable of the features for the polymers in the different aging stages and provide access to choose the optimum characterization techniques. We believe that this review will attract the communities dedicated to materials science and chemistry.



Tian 2023, Characterization techniques of polymer aging- From beginning to end

Plastic Recycle

Plastic Recycle in Local Cities

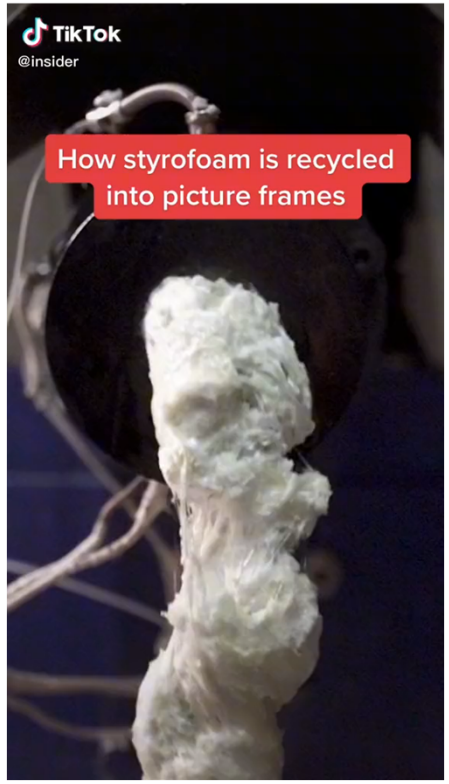
Plastic Resin Identification Codes

Plastic Resin Identification Codes

1 PETE	2 HDPE	3 PVC	4 LDPE	5 PP	6 PS	7 OTHER
Polyethylene Terephthalate	**High-Density Polyethylene**	**Polyvinyl Chloride**	**Low-Density Polyethylene**	**Polypropylene**	**Polystyrene**	**Other**
Common products: soda & water bottles; cups, jars, trays, clamshells	Common products: milk jugs, detergent & shampoo bottles, flower pots, grocery bags	Common products: cleaning supply jugs, pool liners, twine, sheeting, automotive product bottles, sheeting	Common products: bread bags, paper towels & tissue overwrap, squeeze bottles, trash bags, six-pack rings	Common products: yogurt tubs, cups, juice bottles, straws, hangers, sand & shipping bags	Common products: to-go containers & flatware, hot cups, razors, CD cases, shipping cushion, cartons, trays	Common types & products: polycarbonate, nylon, ABS, acrylic, PLA; bottles, safety glasses, CDs, headlight lenses
Recycled products: clothing, carpet, clamshells, soda & water bottles	Recycled products: detergent bottles, flower pots, crates, pipe, decking	Recycled products: pipe, wall siding, binders, carpet backing, flooring	Recycled products: trash bags, plastic lumber, furniture, shipping envelopes, compost bins	Recycled products: paint cans, speed bumps, auto parts, food containers, hangers, plant pots, razor handles	Recycled products: picture frames, crown molding, rulers, flower pots, hangers, toys, tape dispensers	Recycled products: electronic housings, auto parts,

http://mediaroom.wm.com/recycle-more-or-recycle-better/

Polystyrene Styrofoam recycling

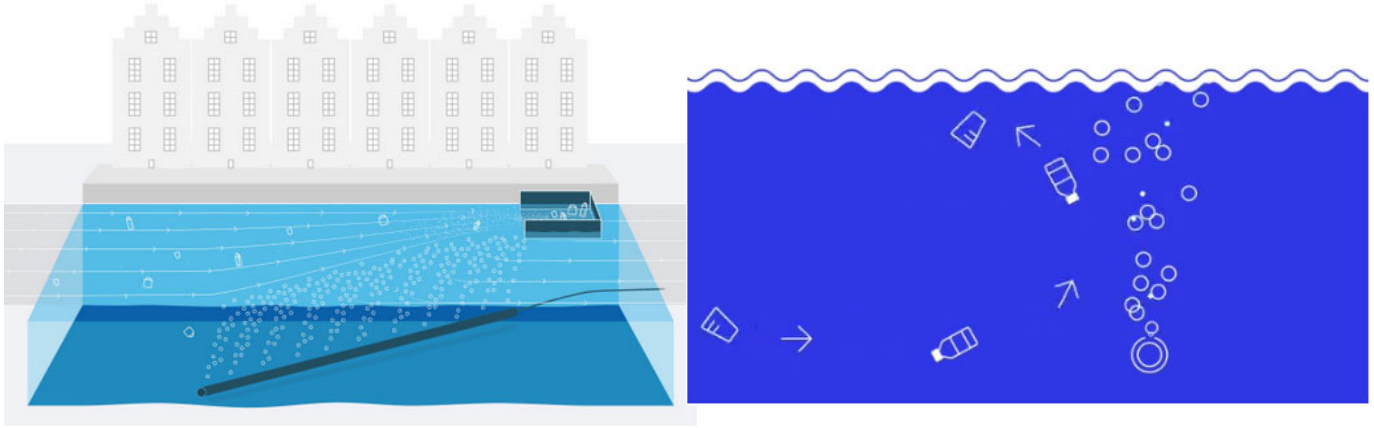


More info in the "Plastics Resin Codes" file.
https://plastics.americanchemistry.com/Plastic-Resin-Codes-PDF/

The Great Bubble Barrier to Prevent Plastic Dumping into the Ocean

A simple burst of bubbles is keeping this canal clear of plastic.

In Amsterdam, the Great Bubble Barrier is a simple solution to plastic pollution: creating an invisible barrier that helps collect the trash that ends up in the water.



https://www.fastcompany.com/90454481/a-simple-burst-of-bubbles-is-keeping-this-river-clear-of-plastic?partner=rss&utm_campaign=rss+fastcompany&utm_content=rss&utm_medium=feed&utm_source=rss

Production, Use, and Fate of All Plastics Ever Made

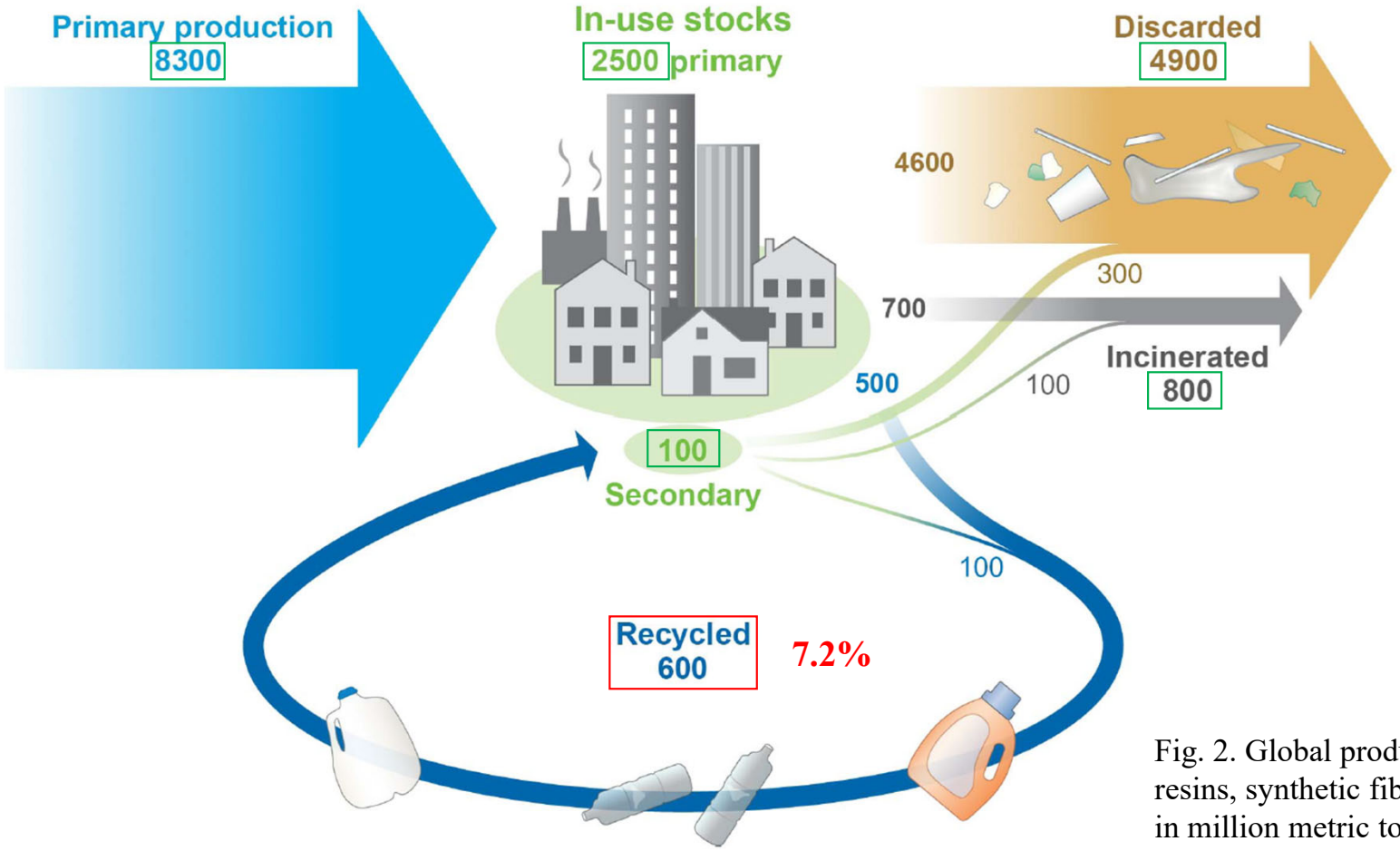


Fig. 2. Global production, use, and fate of polymer resins, synthetic fibers, and additives (1950 to 2015; in million metric tons).

Geyer 2017, Production, use, and fate of all plastics ever made

Designing Plastics for Assembly and Disassembly

Closing the plastics loop

Plastics (polymers) could be designed so that the monomers they are built from can be retrieved. Some plastics can also biodegrade for certain niche applications or when environmental leakage occurs. Monomers may be feedstocks for synthesizing added-value products such as surfactants or new polymers or turned back to their original polymer. Enzymatic or chemical catalysis can prevent property deterioration from this process.

1 Design polymers for monomer recovery

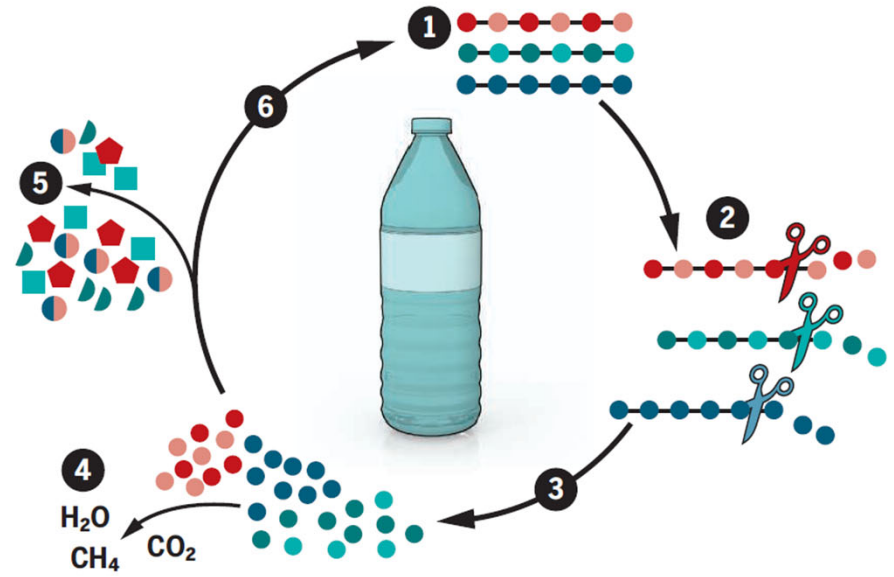
2 Site-specific bond cleavage

3 Further disassembly into monomers

4 Biodegradation in the biosphere

5 Synthesis of added-value products in the technosphere

6 Synthesis of polymers from recovered monomers



Building blocks (monomers) Polymer-specific molecular scissors New polymers

Copolymer α Copolymer β Homopolymer γ

Kakadellis 2021, Achieving a circular bioeconomy for plastics

Truth of Plastic Recycle

'Horrible Hybrids': The Plastic Products that Give Recyclers Nightmares

From singing birthday cards to baby food pouches, a growing trend of mixing materials is making recycling even harder.
The musical cards, which play a recording when opened, look like plain cardboard. The insides are laced with cheap electronics and toxic batteries – making them a nightmare to dispose of. "I call them 'horrible hybrids'," said Heidi Sanborn, who heads up the National Stewardship Action Council, a network of groups that seeks to get manufacturers to take responsibility for the proper disposal of the products they sell. "They are made of multiple materials or materials that are impossible to recycle. It's a mushing of things."

Tiny batteries. Singing cards include toxic electronic waste. Not only do they include toxic electronic waste, but when the small batteries get crushed in the machinery inside recycling plants, they have been frequently known to cause fires.

Plastic pouches. Another growing menace for recyclers are the plastic pouches increasingly used to hold everything from laundry detergent pods to cereals and juices. This flexible packaging is made with many thin layers of different types and colors of plastic and is sometimes layered with foil and wax. **They are pretty much impossible to recycle**. And they are apt to end up in the ocean and take decades to biodegrade.

Plastic labels. Another bugaboo for recyclers is the increasing use of **non-recyclable wrappers around perfectly recyclable bottles and cans**. For instance most spray cleaners come in bottles made of high-density polyethylene, which can be readily recycled. But **first consumers must remove the spraytops**, as they are made from different plastics and are not recyclable. Then consumers must find a way to **pry off the brightly-colored, printed plastic wraps** that packagers are increasingly wrapping around bottles to make the labeling more attractive.

https://www.theguardian.com/environment/2020/apr/20/plastic-products-recyclers-single-use?CMP=oth_b-aplnews_d-1

Read the Fine Print

Not all plastics are recyclable. Read the fine print.
The plastic industry pretends to care about recycling, but it's a tactic to shift responsibility onto consumers while the industry can still produce new plastics for greater profit.

2020

Recyclable Not Recyclable

Plastic Bottle

vs

Plastic Label

2022

2024-2026

2026

Recycling of Multilayer Plastic Packaging Materials

Walker 2020, Recycling of multilayer plastic packaging materials

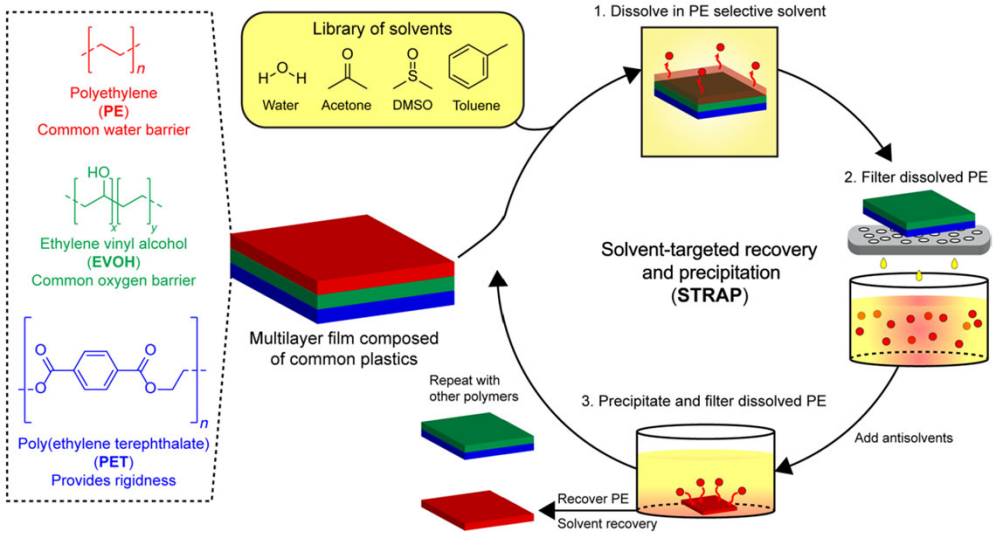


Fig. 1. Overview of the STRAP process. Schematic representation of a multilayer plastic film consisting of three common polymer resins, and key steps in the solvent-targeted recovery and precipitation (STRAP) process for segregating these component resins into pure, recyclable streams using a series of solvent washes.

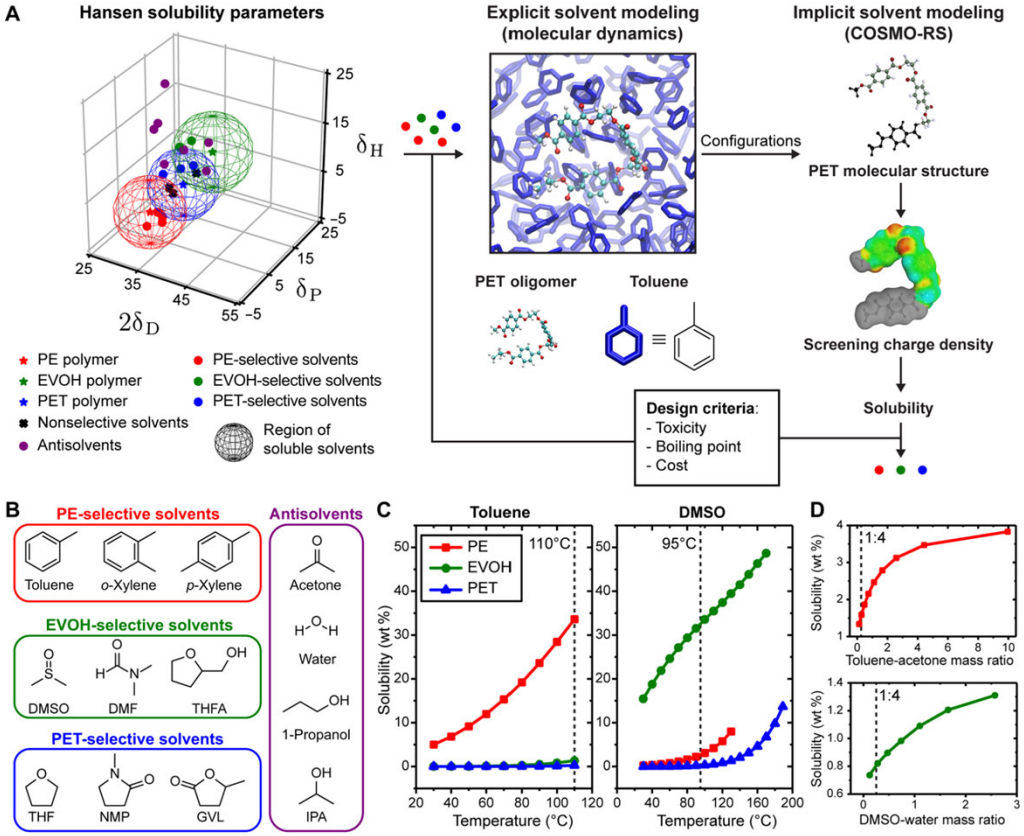


Fig. 2. Computational tools used to guide the solvent selection for the STRAP process. (A) Process of selecting solvents using a combination of HSPs, classical MD simulations, and COSMO-RS calculations. The solubility of PE, EVOH, and PET was estimated using HSPs for 22 common solvents (values in Supplementary Materials). Solvents selective to each polymer were then used for subsequent calculations. Classical MD simulations were performed to provide input oligomer configurations for COSMO-RS, which uses ab initio methods to calculate the screening charge density of each molecule. COSMO-RS calculations then determine thermodynamic properties, such as solubilities. (B) PE-, EVOH-, and PET-selective solvents and antisolvents (in which none of the polymers are soluble) determined from HSP calculations. DMSO, dimethyl sulfoxide; DMF, N,N-dimethylformamide; THFA, tetrahydrofurfuryl alcohol; THF, tetrahydrofuran; NMP, N-methylpyrrolidinone; GVL, γ-valerolactone; IPA, isopropyl alcohol. (C) Predicted solubility versus temperature for PE, EVOH, and PET in pure toluene (PE selective) and DMSO (EVOH selective) computed using COSMO-RS. (D) Predicted solubility versus solvent-antisolvent mass ratio for PE (red curve) and EVOH (green curve). Acetone and water were used as antisolvents for the dissolution of PE and EVOH, respectively. Black dashed lines in (C) and (D) are the temperatures and mass ratios selected for the STRAP process.

Humans have met their superior foe: Plastics & the Plastic Industry

The plastic industry claims that consumers are responsible for the plastic pollution.
"It's mostly consumers' responsibility." (Jean-Michel Cousteau (Ocean Futures Society)
"If we don't buy, they won't make it." (Brian Porter, VP, Ernest Packaging Solutions)

Tobacco industry claimed that smoking was perfectly safe.

Plastic industry has created an illusion that plastics will have no pollution because of this meaningless green symbol.

Plastic Recycling Is Fake, So What the Hell Am I Supposed to Do?
The vast majority of plastic does not actually get recycled into anything else.

Basically, the plastic industry is saying that the consumers should believe that we are the bad guys.

https://tubitv.com/movies/507686/plastic_paradise_the_great_pacific_garbage_patch
https://melmagazine.com/en-us/story/plastic-recycling-do-plastics-actually-get-recycled

Plastics Recycling Difficulties

Plastic Types

After the plastics are separated from other materials, they **need to be stored by type**. The separated plastics can be reused easily, as those are far superior to mixed plastics. The separated plastics are **washed** (and optionally sterilized), and ground or shredded into a pellet (small piece) or flake form that can be melted and molded for new use.

Importance of Separating Different Types of Plastics

Single type of polymers produce high quality products compared with blended polymers.

Separation of Different Plastics

Bar codes encoding each plastic, Spectroscopic analysis, Density (in solution), by Consumers

Removing Dirt from Plastics

The presence of dirt can be critical for spinning recycled plastics into fibers, as the dirt may block the pores of the spinners easily. Washing may not remove all dirt. Dissolving and filtering is difficult and expensive.

Recycled Plastics

They can be used for many applications, especially where tensile strength is not critical.

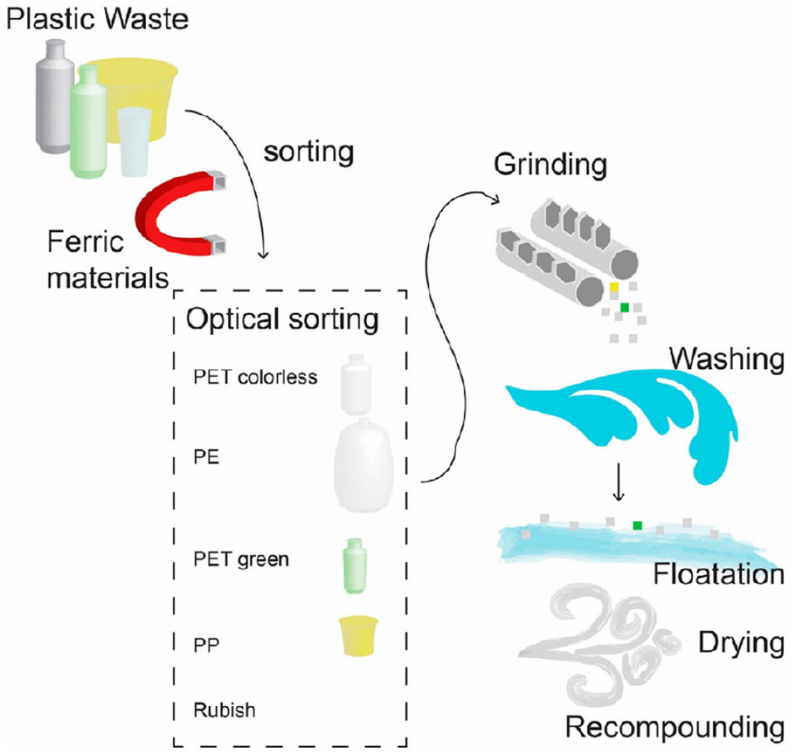


Figure 7. Schematic illustrating the general steps for the recovery of plastic waste to plastic feedstock through mechanical recycling. The transportation steps are not included for simplicity. There are a variety of additional processes possible in recompounding to maximize the performance of the recovered plastic.

Vogt 2021, Why is Recycling of Postconsumer Plastics so Challenging

Plastic Wars: Industry Spent Millions Selling Recycling - To Sell More

Plastic Wars (PBS Frontline: March 31, 2020) https://www.pbs.org/wgbh/frontline/film/plastic-wars/

A wall of plastic trash at Garten Services in Salem, Ore., is headed to the landfill.

Plastics industry had "serious doubt" recycling would ever be viable.

Starting in the late 1980s, the plastics industry promoted recycling through ads, recycling projects and public relations, telling people plastic could be and should be recycled. But their own internal records dating back to the 1970s show that industry officials long knew that **recycling plastic on a large scale was unlikely to ever be economically viable**. A report sent to top industry executives in April 1973 called recycling plastic "costly" and "difficult." It called sorting it "infeasible," saying "there is no recovery from obsolete products."

The industry promoted recycling to keep plastic bans at bay.

Despite this, the industry promoted recycling as a way to beat back a growing tide of antipathy toward plastic in the 1980s and '90s. The industry was facing initiatives to ban or curb the use of plastic. Recycling, the former officials told NPR and Frontline, became a way to preempt the bans and sell more plastic.

More recycling means fewer profits for oil and gas companies.

The more plastic is recycled, the less money the industry will make selling new plastic. And those profits have become increasingly important. Companies have told **shareholders** that profits from using oil and gas for transport are expected to decline in coming years with better fuel efficiency and the increasing use of electric cars. Plastic production overall is now expected to triple by 2050, and once again, the industry is spending money on ads and public relations to promote plastic and recycling. Plastic is now more prevalent than it's ever been and harder to recycle. Gas prices remain at historic lows, making new plastic cheaper than recycled plastic. Efforts to reduce plastic consumption are mounting nationwide, but any plan to slow the growth of plastic will face an industry with billions of dollars of future profits at stake.

Laura Sullivan, 2020. https://www.npr.org/2020/03/31/822597631/plastic-wars-three-takeaways-from-the-fight-over-the-future-of-plastics

Wishcycling Could Be Hurting Your Recycling Efforts

It's a bad habit, but you have the power to stop it. Lauren Phillips, 2020

"Wishcyclers might ask themselves, 'should I?' or 'shouldn't I?' when deciding where to put an item but ultimately place it in that familiar blue bin and assume that the recycling company will know what to do with it."

Whether you mean to or not, you may be tossing items in your recycling bin that can't actually be recycled. In doing so, you pass the problem of figuring out how to dispose of difficult-to-recycle items on to local recycling facilities, creating more challenges for them. "At best, these items are pulled out of the recycling stream and sent to the landfill," Walters says. "At worst, they can cause harm to recycling workers or damage the equipment, causing it to break down.

So what can you do to stop wishcycling? First, one of the main tenets of a zero waste lifestyle applies. Second, do your research. Check Earth911 and Recycling Simplified to learn how to properly dispose of certain items and to better understand what can be tossed into your curbside recycling bin. The truth is, most facilities and services focus on everyday materials or consumptive goods (often single-use items) such as aluminum cans and plastic bottles, not metal pots and pans or other long-lasting items. Read up on what your local recycling center does and doesn't accept and commit to following those rules. **With a little self-education and some determination, you can stop wishcycling, too**.

https://www.realsimple.com/home-organizing/green-living/what-is-zero-waste
https://earth911.com/
https://recyclingsimplified.com/
https://www.realsimple.com/home-organizing/green-living/wishcycling

Use of Recycled Plastic

Emily Southey, May 2020

Bembien Creates Bags Made Entirely Out of Recycled Plastic

Brooklyn-based accessories brand Bembien is known for its handmade, artisanal bags. Recently, they introduced an extra special collection.

Dubbed the Jolene collection, this eco-friendly line features bags made out of 100% recycled plastic. All plastic has been sourced from the beaches of Bali, Indonesia. The official description for the handbags reads, "A bag with heart. Entirely hand-woven with plastic recycled off the beaches of Bali and repurposed into a gorgeous bag to treasure forever."

Why was the plastic sourced from Bali of all places? According to Bembien's website, the gorgeous tropical island of Bali is currently facing a devastating plastic pollution problem that threatens the local ecosystem and marine life. This has led to the establishment of many local initiatives aimed at alternate ways of reducing and recycling the plastic. Bali is also one of only a handful of places in the world that has completely banned single-use plastic.

To show support for their mission and to reduce their own carbon footprint, Bembien decided to create the Jolene collection. "We support their efforts and designed the Jolene to turn a heartbreaking problem into a beautiful solution," reads Bembien's website.

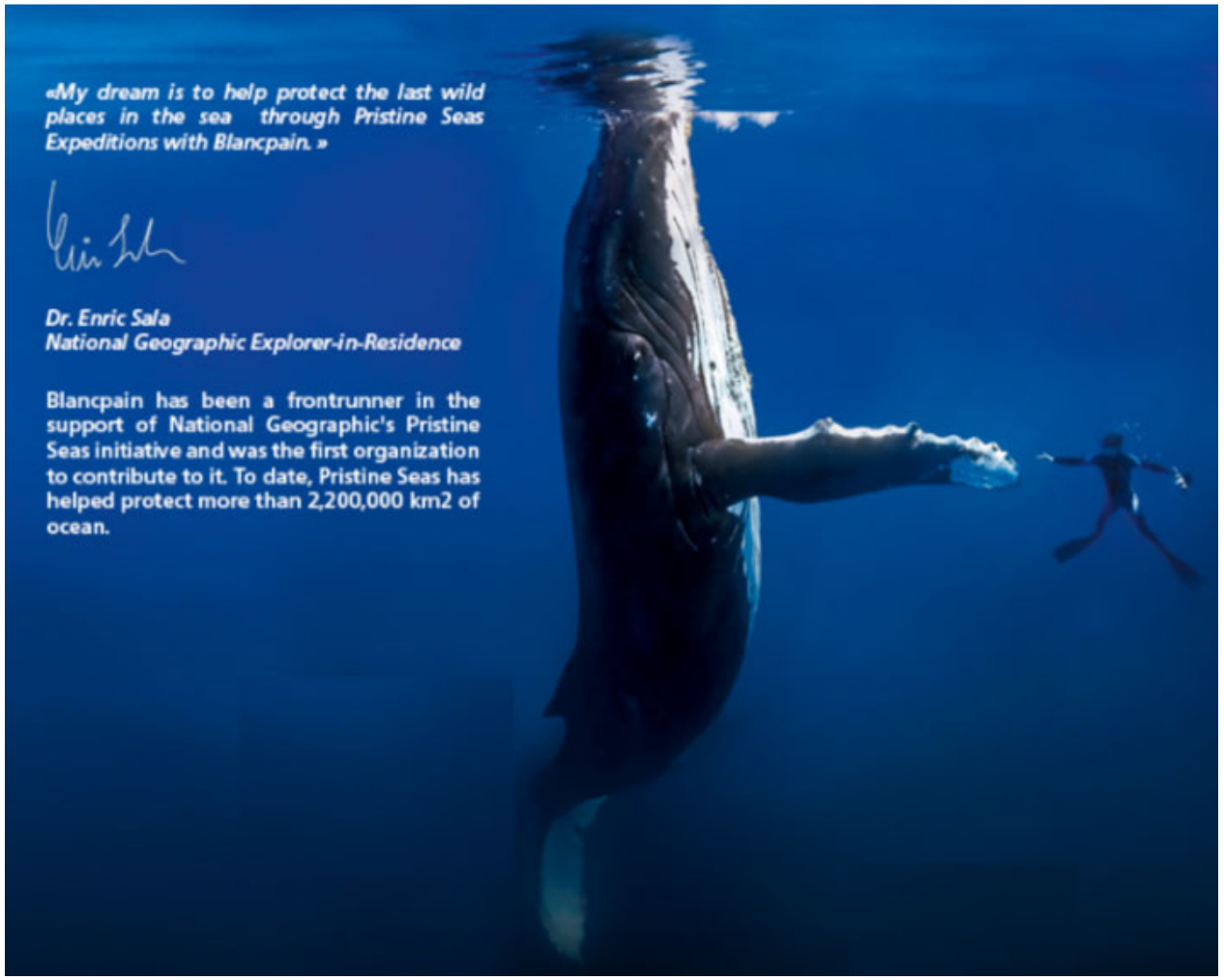
Bembien's Jolene bag is available in two sizes, large and small. Both are made out of 100% hand-woven recycled plastic. They are also both available in the same array of colours, which include rose, cherry, pearl, black, and cobalt. The small Jolene bag retails for $175 USD, while the larger version costs $210 USD. Either size is perfect for summer, especially for a day at the beach.

The Jolene handbags are available for purchase on Bembien's website, as well as at select retailers, including Madewell.

https://www.bembien.com/shop/jolene-bag-small
https://settingmind.com/bembien-creates-bags-made-entirely-out-of-recycled-plastic/

Saving the Planet through Plastic Solution

Pristine Seas



Recycled Plastic Roads: Pave a future out of the plastic problem by turning it into a kind of tarmac.

We live in a world where over 400 million tons of plastic are produced each year. Of this volume, 75 per cent gets thrown away, damaging ocean life and packing landfills full. Recycling these materials has become more important than ever, and one way people are beginning to tackle this problem is by creating roads out of plastic.

Recycled roads can use up to 684,000 plastic bottles or nearly 2 million single-use plastic bags in every kilometre. Comparing current roads to the properties we see in a plastic bottle, you may wonder how these roads fare in safety. Tests have shown that including plastic into road mixtures actually improves strength, it proving to be twice as strong and withstanding heavy traffic.

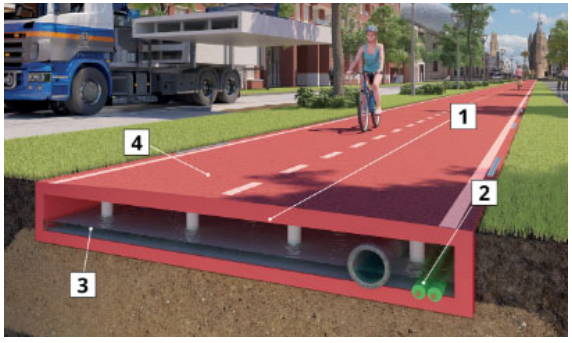
The reason for their improved durability is thought to be the flexible properties of plastic. Their bounce-back ability after displacement from weight gives them an almost self-repairing property that asphalt roads lack. As well as this, the roads continue to establish the same essential qualities such as being weatherproof while reducing flaking and potholes.

Using alternative materials, such as plastic, these recycled roads combat two issues at once. While putting waste material to use instead of damaging surrounding environments, these roads also cut down on the amount of bitumen used to make asphalt roads. Creating more sustainable roads, less oil will be demanded for production, as fossil fuels are rapidly depleting. For each ton of bitumen that plastic replaces in these roads, a ton of carbon dioxide is reduced in production. And why stop at plastic for alternative and sustainable sources? Further projects include the use of old tires and even the waste products from olive oil extraction.

How roads can be more eco-friendly

Creating a structurally sound road from plastic seems like a complex task. **First the plastic bottles, bags and other items are washed and cut down into small pellets**. These are melted at soaring temperatures of 170 °C to combine with the asphalt mix. The resulting blend is used by workers to layer smooth roads as they usually would.

Plastic Road: Absent asphalt



Roads today don't necessarily need to include asphalt at all, as a cycle path in the Netherlands has shown.

1. Safer cycling: It's equipped with monitoring sensors for temperature and traffic, and the path is designed to create safety for the city's many cyclists.
2. City infrastructure: Cables and pipes can easily feed through the cavity beneath the road.
3. Not slippery when wet: Designed by 'Plastic Road', the path reduces slippery surfaces by draining rainwater inside its structure.
4. Tough surface: Requiring the equivalent of 500,000 bottle caps in plastic, the 30-metre path is three times as durable as previous paths.

How It Works, Issue 134. January 2020

Plastics are Forever! No biodegradation

2,000,000 plastic bottles used in the U.S. every 5 minutes (2010)

In the United States, it is estimated that roughly 137 million plastic water bottles are used every single day.

Every Hour: ~5.7 million bottles.
Every Minute: ~95,000 bottles.
Every Second: ~1,500 bottles.

Manufacturing the bottles to meet this daily U.S. demand requires more than 17 million barrels of oil annually—enough to fuel over a million cars for a year.

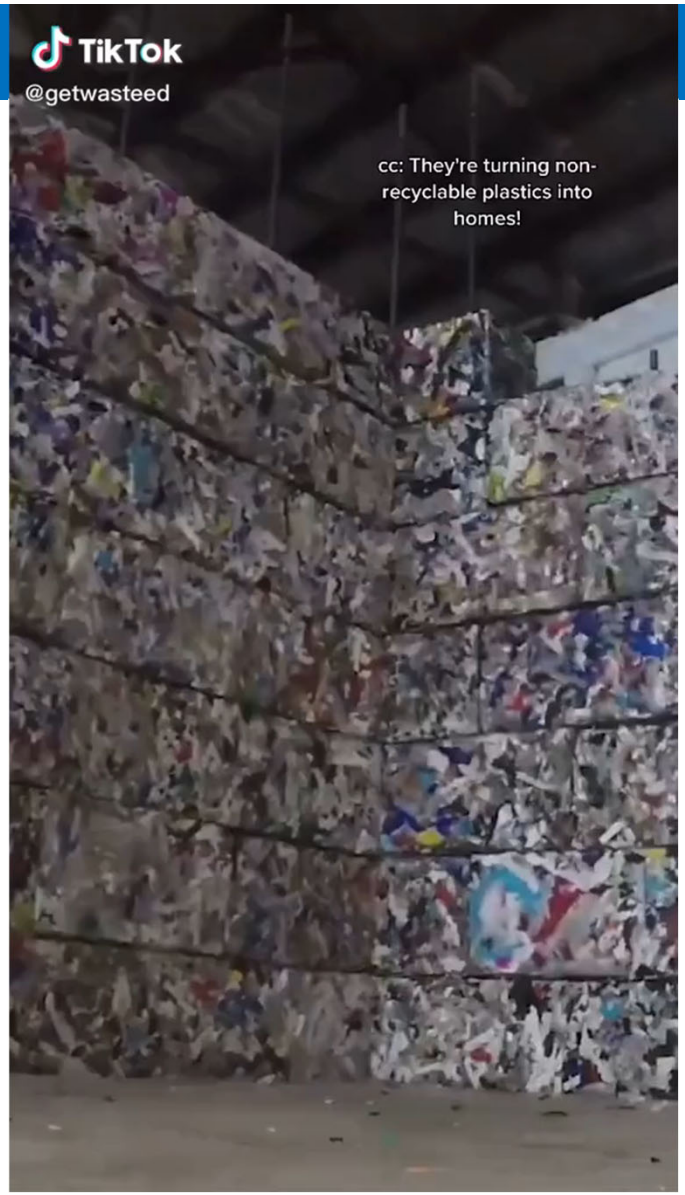
https://ohelobottle.com/blogs/blog/how-many-plastic-water-bottles-are-used-in-the-usa-every-year

‘Plastic roads’ are paved with good intentions

Pennsylvania Department of Transportation contract workers lay pavement made partially with recycled plastic at Ridley Creek State Park in Delaware County. A growing number of states are testing whether mixing asphalt with plastic waste, which would have ended up in landfills, can create long-lasting pavement. Photo from the Pennsylvania Department of Transportation.

By Jenni Bergal (January 1, 2023)
https://www.marylandmatters.org/2023/01/01/plastic-roads-are-paved-with-good-intention/

Plastics are Forever! No biodegradation



The Future

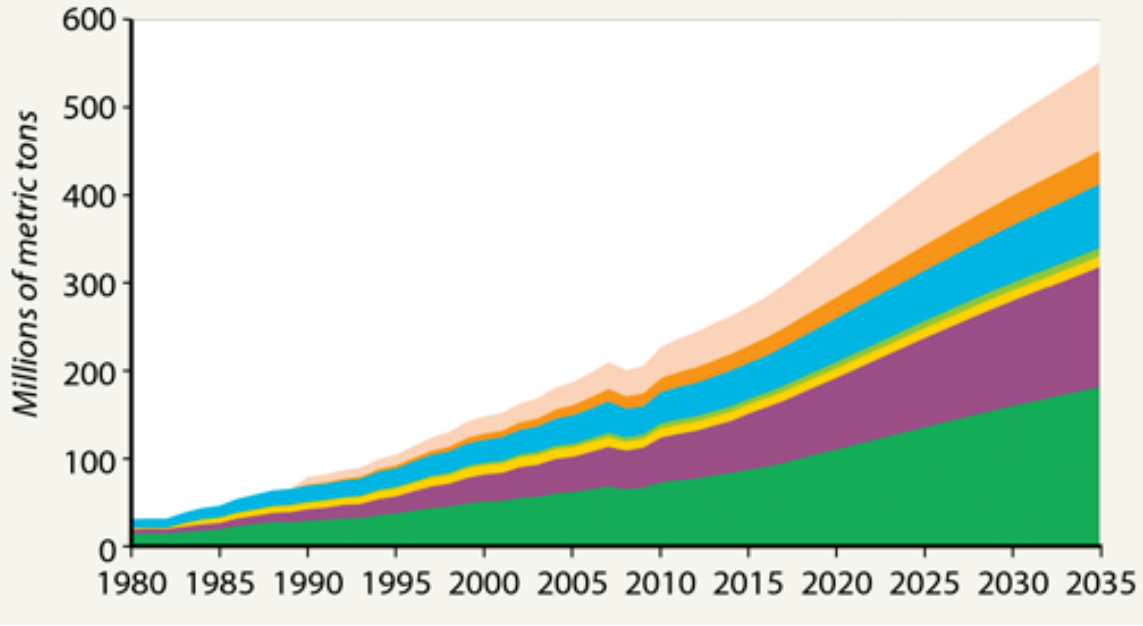
Flattening the Curve & Remove the Curve

Plastics Demand Rising

Analysts at IHS Markit forecast global plastics demand to grow on average 3.5 to 4 percent per year over the coming years.

GLOBAL PLASTICS DEMAND

In millions of metric tons, by type, 1980 projected to 2035



The Future with 100% Biodgradable Plastics

- **Polyethylene terephthalate fiber** is often blended with wool or cotton for cloth and clothing
- **Polyethylene terephthalate resin** is used in food packaging, water bottles and clothing
- **Polyvinyl chloride** is used in thin coatings, pipes and exterior household siding
- **Expanded polystyrene** is used in electrical consumer goods packaging, insulating panels for construction, and floatation material
- **Polystyrene** is used in sheet materials, molded products, insulated foam packaging and cups
- **Polypropylene** is used for molded parts, electrical insulation, packaging and fibers for clothing
- **Polyethylene** is used in packaging and insulation

https://www.kqed.org/science/1956117/business-is-booming-but-public-anger-toward-plastics-grows-with-environmental-harms

Flattening the Curve & Remove the Curve

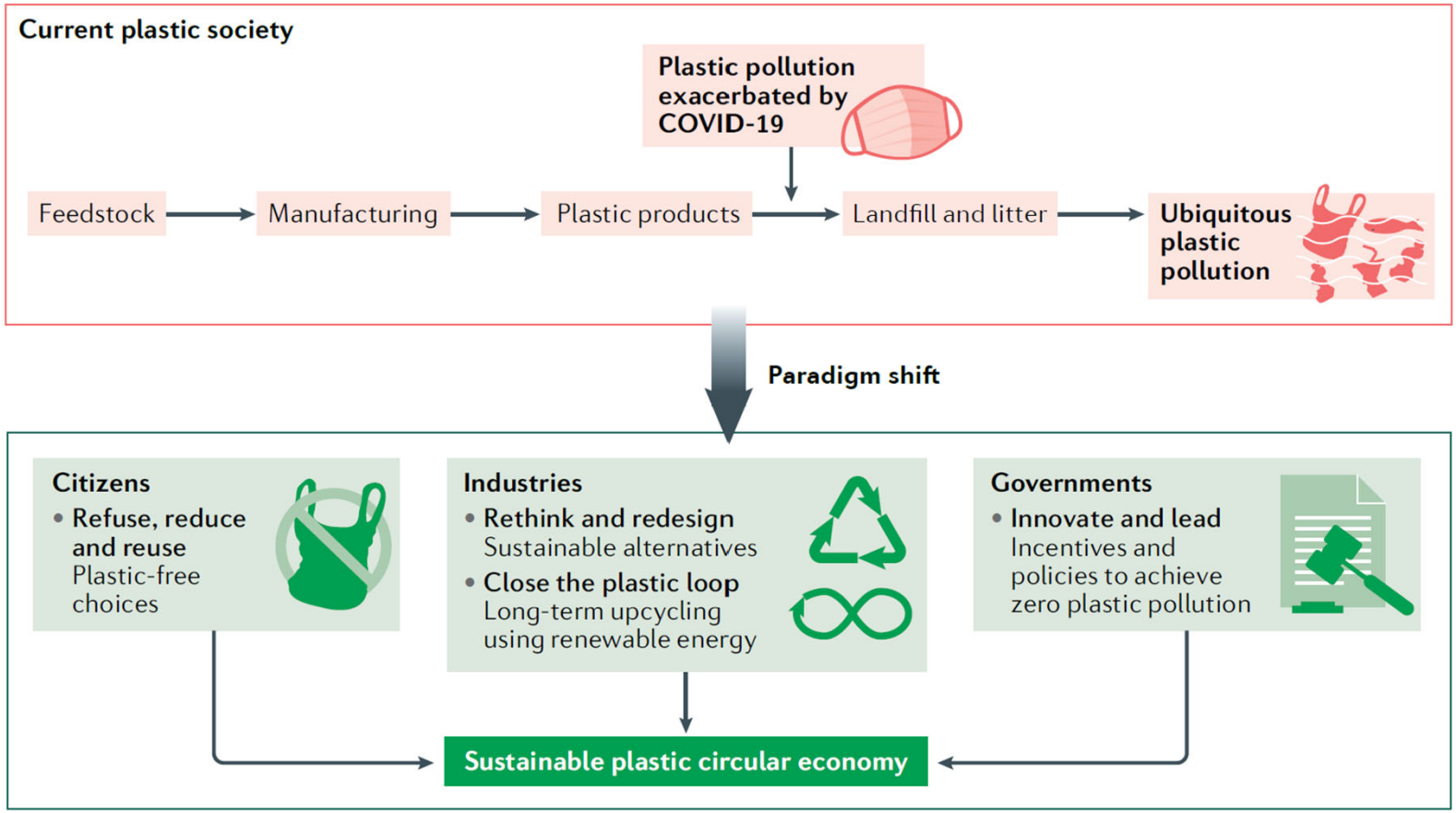


Fig. 1 | A proposed shift towards a circular plastic economy. Global plastic pollution has been exacerbated by the COVID-19 pandemic. Sustainable plastic use should be prioritized, with the aim to create a circular plastic economy.

Yuan 2021, The COVID-19 pandemic necessitates a shift to a plastic circular economy

The Story of Plastic

https://www.youtube.com/watch?v=iO3SA4YyEYU