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FACT SHEET

LINES WE DON'T WANT TO CROSS: SYNTHETIC CHEMICALS AND PLASTICS THREATEN PLANETARY HEALTH

While the public may be aware that synthetic chemicals and plastics can harm human and environmental health, it is less well known that these substances may be endangering the healthy functioning of the Earth system as a whole.[1] Thanks in part to the overproduction and inadequate regulation of synthetic chemicals and plastics, the planet is in a higher risk zone where "irreversible changes to Earth's life support systems" are more likely to occur.[2] Urgent action is needed to reduce both the production and toxicity of synthetic chemicals and plastics to bring the planet back into a safer, more stable balance.

CROSSING PLANETARY BOUNDARIES PUTS OUR EARTH SYSTEM AT RISK

Many different natural systems operating and interacting on a planetary scale are necessary to support contemporary human societies, and together comprise what we call the "Earth system."[3] We see these system interactions at work when nutrients cycle through the soil or when insects pollinate crops so we can grow food. A collapse—or increased instability—in one system will have ripple effects across the whole Earth system. To evaluate the health of these systems, scientists have been examining nine "planetary boundaries" marking the "safe" parameters of the various systems that maintain the Earth's stable functioning.[4] Information gathered under this planetary boundary framework shows that modern human activity has placed pressures on many of Earth's basic systems and has reached a scale that could trigger both gradual and abrupt global environmental changes if we do not alter course.

Climate change and biodiversity loss are just two of nine "planetary boundaries" that define parts of the Earth system scientists now recognize as critical to maintaining the conditions for the ability for human societies to be able to survive and thrive (see Table 1).

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For more information, please contact:
Renée Sharp
rsharp@nrdc.org

TABLE I: THE NINE PLANETARY BOUNDARY THREATS[5]	
Climate change	Greenhouse gas emissions alter the climate, affecting numerous planetary systems.
Ozone depletion	Synthetic chemicals deplete stratospheric ozone critical for ultraviolet (UV) radiation protection.
Atmospheric aerosol loading	Tiny aerosol particles in the atmosphere impact health, rainfall, and climate.
Ocean acidification	Dissolved CO_2 acidifies the oceans and harms marine life and ecosystems.
Freshwater change	Large scale freshwater use and ecosystem modification can destabilize ecological, atmospheric, and biogeochemical processes.
Land system change	Widespread forest, wetland, and grassland conversion has cascading impacts, particularly on the regulation of climate.
Biosphere integrity	Biodiversity loss and extinctions threaten ecosystem function and resilience.
Biogeochemical flows	Altered nitrogen and phosphorus flows have major climate and marine impacts.
Novel entities	Synthetic chemicals, plastic, and other novel entities[6] can cause global harm and impact the basic functioning of the other boundaries.

Crossing a planetary boundary does not necessarily mean that the planet has crossed a threshold beyond which there is irreparable harm to the Earth system, but rather that humanity is in risky territory. Staying within these planetary boundaries ensures what scientists call "a safe operating space,"[7] while exceeding any of them could be highly problematic or even "catastrophic."[8]

Crossing a planetary boundary can also sometimes be reversed. While the term "planetary boundaries" has only been in use for the past 15 years, the concept is not new. When atmospheric scientists discovered the "ozone hole" in the mid-1980s, they recognized that this was a serious threat to planetary health that, if not reversed, would have devastating impacts on humans, plants, and animals.[9] At the extreme, life on Earth as we know it would not be possible without protection from the ozone layer.[10] After the international community signed a global treaty phasing out many ozone-depleting substances, the ozone layer has largely recovered.

While we may have reversed the course on ozone depletion, there is we are on the wrong side of six of the nine planetary boundaries: climate change, biosphere integrity (which uses biodiversity loss as an indicator), biogeochemical flows, land system change, freshwater change, and novel entities.[11]

SYNTHETIC CHEMICALS AND PLASTICS ARE NOVEL ENTITIES OF GLOBAL CONCERN

Scientists are raising the alarm about exceeding the planetary boundary for novel entities, a category that includes synthetic chemicals and plastics, other human-made creations, and naturally occurring elements like heavy metals for which humans have dramatically mobilized and increased exposures.[12] These substances can affect earth system functioning through physical, chemical, and biological mechanisms.[13] Neither plastic nor chemical pollution can be easily cleaned up, and the impacts of the global contamination from both are vast and just beginning to be understood. They

A seal with a discarded plastic flying disc stuck tightly round its neck resting on a beach in Horsey Gap, Norfolk, England.

pose planetary risks through global, ubiquitous impacts on the health and development of humans and other organisms that ultimately affect ecosystem functioning and structure. These novel entities may also have impacts on other planetary boundaries; for example, more than 99 percent of plastics and many synthetic chemicals are made from climate change-causing fossil fuels.[14]

SYNTHETIC CHEMICALS ARE A PLANETARY HEALTH THREAT

Chemical production and pollution have increased dramatically in recent years; synthetic chemical manufacturing nearly doubled between 2000 and 2017, and chemical contamination is now found virtually everywhere scientists look—even in remote, uninhabited locations.[15] In 2019 6.6 trillion pounds of synthetic chemicals were produced just in the United States.[16]

Both the volume and the variety of synthetic chemicals being produced are increasing extraordinarily fast.[17] A detailed survey of chemical inventories from around the world found that about 350,000 synthetic chemicals have been registered for production and use over the past several decades.[18] Toxic chemicals are in our air, our food, and our water.[19] They are found in human blood, breast milk, placentas, tissues, and organs.[20] Harmful chemicals are also contaminating fish, birds, amphibians, reptiles, mammals, and other wildlife worldwide, and have reached the Arctic, the Antarctic, and the slopes of the highest mountains on Earth.[21]

Synthetic chemicals such as phthalates, bisphenol A (BPA), and vinyl chloride have been linked to a staggering array of adverse human health effects including cancer, reproductive harm, asthma, birth defects, neurotoxicity, and early mortality.[22] In wildlife, toxic chemicals have been linked to declines of salmon, marine mammal, bee, and bird populations, among many other troubling impacts.[23] While not all synthetic chemicals are harmful, many are—and many more have not been sufficiently studied to know whether they are safe.[24] Adding to the problem, scientists and the public do not even know what chemicals and mixtures are being used in many commercial applications, as that information is often held as “confidential” by industry.[25]

An aerial view of an oil refinery in Texas City, just south of Houston on Galveston Bay, Texas.

Scientists agree that synthetic chemical pollution is harming human health and impinging on the functioning and resilience of ecosystems.[26] Considering the weight of the evidence, including the increased rates of certain human diseases and disorders as well as wildlife and insect population declines that are linked to toxic chemical exposures, some scientists


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conclude that the totality of synthetic chemical pollution is endangering the integrity of the global ecosystem as a whole.[27]

It is against this backdrop that scientists are pointing to the following indicators that planetary boundaries have already been exceeded for synthetic chemicals:

- **Irreversible contamination from PFAS "forever chemicals."** Per- and polyfluoroalkyl substances (PFAS) are a group of over 12,000 synthetic chemicals, many of which are harmful at ultra-low concentrations and are linked to cancer, hormone disruption, liver and thyroid problems, reproductive harm, abnormal fetal development, and interference with vaccine effectiveness.[28] PFAS contaminate water, human bodies, and wildlife worldwide.[29] PFAS can easily circulate in the environment and are now present in rainwater around the world at concentrations that exceed the maximum amount of PFAS allowed in drinking water in the United States and Denmark.[30] PFAS are known as "forever chemicals" due to their ability to resist destruction and remain in the environment for decades, centuries, or millennia, leading to what has been termed "practically irreversible" contamination.[31]
- **Beyond capacity for global assessment and monitoring.** Approximately 350,000 chemical substances are in use in global commerce, yet the vast majority have not been adequately tested for safety—if they have been tested at all—and are not monitored in the environment.[32] For example, in the small subset of 23,000 chemicals that were registered under the European Union's REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) regulation by December 2020, approximately 80 percent had yet to be assessed for safety.[33] Half of the scientific studies conducted over the past 20 years examining the effects of chemicals on non-human organisms have focused on just 65 substances.[34] Furthermore, most toxicity testing has focused on the potential health impacts of single chemicals, while humans and wildlife are exposed to complex chemical mixtures on a daily basis—and some chemicals can interact with each other in ways that amplify their individual effects.[35] In addition, very few studies consider potential larger Earth system effects. We are now in a situation where the rate at which synthetic chemicals are produced and released far outstrips the global capacity to assess and monitor them. That means we could be spewing synthetic chemicals into the environment that pose threats on a scale similar to that of ozone-depleting chemicals, or worse, but we do not have the capacity to recognize the threat, much less address it.[36]
- **Capacity to impact other planetary boundaries.** Synthetic chemical production and pollution can directly and indirectly impact other planetary boundaries including climate change, ozone depletion, and biosphere integrity.[37] For example, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride are synthetic chemicals with very high global warming potential, in some cases having tens of thousands of times more power (per molecule) to cause climate change than carbon dioxide.[38] The chemical sector is also the third-largest industrial consumer of fossil fuels, and therefore a major contributor to climate change.[39] While chlorofluorocarbons (CFCs) are the most well-known ozone depleting substances, there are around 100 synthetic chemicals that are known to harm the ozone layer.[40]

In addition to the concerns outlined above, scientists are raising serious questions about whether hormone-disrupting chemicals (which are commonly used in plastic) are causing sharp declines in sperm count and fertility, which could threaten the future of human reproduction.[41] As one scientific paper noted, we should have learned this lesson after our experience with ozone-depleting substances, noting that these "very useful synthetic chemicals that were thought to be harmless. . . had unexpected, dramatic impacts on the stratospheric ozone layer. In effect, humanity is repeatedly running such global-scale experiments but not yet applying the insights from previous experience to new applications."[42]

In some isolated cases, society has already taken steps to address the planetary boundary threats posed by chemical pollution. For example, 198 countries have signed the Montreal Protocol, an international treaty designed to address chemical-driven ozone depletion, after mounting evidence showed that certain synthetic chemicals were damaging the stratospheric ozone layer.[43] Significantly more action will be needed at the state, federal, and international levels to ensure that synthetic chemicals stop threatening planetary health.

PLASTICS ARE A PLANETARY HEALTH THREAT

Global annual production of plastic has increased exponentially over the past 65 years, growing from 2 million metric tons in 1950 to 460 million metric tons in 2019.[44] Much of this plastic quickly becomes waste, and plastic waste is found everywhere, including the farthest reaches of the Arctic, the deep seabed, and even in clouds and the atmosphere.[45] An estimated 242 million metric tons of it is generated globally every year, and the United States is one of the top generators.[46] Plastic pollution has been linked to everything from infertility and cancer in humans to severe injury and death in wildlife.[47]

During production, transportation, use, recycling, disposal, and when leaked into the environment, plastics shed and break down into microplastics—tiny pieces of plastic that are less than 5 millimeters long.[48] Microplastics have been found to pose digestive, reproductive, and respiratory hazards in mice, and are suspected to cause similar hazards in humans.[49] Microplastics have been found in the heart, lungs, organs, breast milk, placentas, stool, and blood of humans.[50] Plants can absorb microplastics through their roots, and these tiny plastic particles are contaminating foods such as apples, carrots, potatoes, rice, and milk.[51] The United Nations Environment Programme has estimated that there are 51 trillion microplastic particles in the ocean—500 times more than stars in our galaxy.[52]

Plastics can also release harmful compounds into our air, food, water, and the environment both during everyday use and at the end of their life.[53] The thousands of chemicals used to make different kinds of plastic include carcinogens, hormone disruptors, obesity-causing compounds, and substances that can cause harm to the liver, brain, kidneys, and the cardiovascular, immune and reproductive systems; many others are unstudied.[54]

Plastic pollution is largely irreversible.[55] It is too widespread and diffuse to realistically clean up, and it is simply not possible to remove such contaminants from the blood and tissues of billions of organisms. There is a "global toxicity debt" associated with plastic pollution: even if we stopped producing and using plastics today, the related toxicity could still *increase* in the future because it can take decades for some discarded plastics to break down into microplastics and release the toxic chemicals they contain into the environment.[56]

The dead and decomposing body of a black footed albatross chick, its stomach filled with plastic, found at the Midway Atoll National Wildlife Refuge on the Hawaiian archipelago.

Plastic pollution on a lake in Da Nang, Vietnam.

It is against this backdrop that many scientists are pointing to the following indicators that planetary boundaries are threatened or have already been exceeded for plastics:

- **Pressure on multiple Earth systems.** Plastic pollution is putting significant pressure on many of the Earth's systems and contributing to the crossing of multiple planetary boundaries.[57] For example, plastics contribute to climate change throughout their life cycle, beginning with the extraction of fossil fuels required to create most plastic products.[58] Their presence in the atmosphere may be affecting cloud formation and, therefore, weather and global temperatures.[59] Scientists also speculate that as microplastic concentrations increase in the ocean, they may impact the ability of the ocean to sequester carbon, thereby exacerbating climate change.[60] The widespread production and use of plastics—and the ubiquity of microplastics in the environment—also has the potential to impact ocean acidification, biogeochemical flows, ozone depletion, land system change, freshwater change, and, as discussed below, ecosystem functioning and biodiversity loss.[61]
- **Impaired ecosystem functioning.** Plastics are already negatively impacting wildlife and have the potential to seriously impair ecosystem functioning in a vast array of ways.[62] Marine mammals, fish, sea turtles, birds, and other wildlife get entangled in plastic waste. At least 1,565 species have been found to accidentally ingest plastic, which can lead to starvation, intestinal blockages, organ damage from leaching toxic chemicals, and death.[63]

  Microplastic particles may change the composition of the critical soil microorganisms that underpin many food webs.[64] The surface of microplastics can harbor harmful bacteria and viruses (because they remain in the environment for a long time), which can be carried into remote areas.[65] Microplastics also absorb toxic chemicals already in the environment, leading to the accumulation of toxic contaminants in the tissues of organisms.[66] In short, plastics are having an undeniably detrimental effect on biosphere integrity.
- **Exceeding capacity for global assessment and monitoring of chemicals involved in plastic production.** Manufacturing plastic products use thousands of chemicals that have not been sufficiently tested for toxicity.[67] In 2023, the United Nations Environmental Programme compiled data from two recent studies and found that more than 13,000 chemicals are used to make plastic.[68] One-quarter of them are considered to be of moderate to very high concern owing to their links to cancer, developmental harm, hormone disruption, and other health effects.[69] Another 46 percent of the chemicals used in plastic do not have government agency hazard classifications, meaning that their safety may not be known.[70] In 2024, researchers from Norway and Switzerland compiled an even more extensive database and found that over 16,000 chemicals are used to make plastics.[71] Scientists working in this area noted, "there is a general lack of transparency regarding substances present in plastics."[72] This vast number of chemicals is simply beyond our capacity to test and monitor.

The plastics crisis has become so acute that nations around the world agreed in 2022 to begin negotiations on a global plastics treaty to address plastic pollution.[73] How such an agreement will ultimately reduce the threats posed by plastic remains to be seen, but the treaty negotiation process is an unprecedented opportunity for action toward this goal.

RECOMMENDATIONS

As one recent study noted, "getting back within the safe operating space can only be achieved through globally capping emissions of novel entities at a rate that is commensurate with the physical and chemical capacity of the Earth system."[74] It is also critical to recognize that, in addition to their larger impacts to the Earth system, the overproduction and inadequate regulation of synthetic chemicals and plastics are having disproportionate impacts on front-line communities, which are suffering serious harms from the toxic air and water pollutants emitted by production and disposal facilities.[75] Protecting these communities and protecting our planetary systems can be achieved through ambitious policy efforts.

However, scientists and intergovernmental bodies alike agree that an "end of pipe" approach focused on managing plastic waste alone will not solve the planetary boundary threats.[76] Instead, we should look upstream and limit the overall production of synthetic chemicals and plastics, and

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immediately eliminate those that are causing the most harm to people and the planet. This will require a new approach to the chemicals and plastics that we make and use, where we:

- **Employ an "essential-use" approach** where toxic chemicals and plastics are produced and used only when they are currently unavoidable, and only until safer alternatives—including non-chemical alternatives—are developed.[77] Releases and exposure to toxic chemicals in these currently unavoidable applications should be minimized.
- **Engage in chemical simplification** where we use fewer, safer, and better-studied chemicals to make products and materials.[78]
- **Transform the chemical industry** toward safer and more sustainable chemicals, feedstocks, materials, products, and production processes—and require full transparency with respect to which chemicals are being used in products, and what pollutants are being emitted into air and water.[79]

POLICY RECOMMENDATIONS

Enacting this new approach will require policymakers at all levels of government to rethink our relationship to synthetic chemicals and plastics, through the following actions:

- **Enact a strong global plastic treaty** that includes caps on plastic production, measures to limit toxic chemicals and particularly problematic plastics, and safeguards against false solutions such as so-called "chemical recycling" which generate toxic air contaminants and large quantities of hazardous waste.[80]
- **Overhaul chemical policy** to cap synthetic chemical production, allow only non-toxic chemicals and materials on the market (aside from time-limited "essential uses"), regulate chemicals as groups rather than one-by-one, and account for cumulative impacts human health and ecological impact assessment processes.
- **Ban the most toxic, unnecessary, and problematic forms of plastics**, as detailed in NRDC's fact sheet "The Worst of the Worst: High Priority Plastic Materials, Chemical Additives, and Products to Phase Out."[81] Reduce and minimize all forms and uses of fossil fuel-based plastic in favor of alternatives that are safe and sustainable by design. This can take the form of laws that ban single-use plastics, particularly toxic plastics, as well as intentionally added microplastics, among others.
- **Require full transparency** throughout the process of production, use, and disposal for the chemicals used in plastic and other consumer products.
- **Set a baseline** against which to measure synthetic chemical and plastic reduction by mandating complete inventories of current synthetic chemical and plastic production.

- **Prioritize the elimination of high hazard chemicals,** especially those that are persistent, bioaccumulative, mobile, and/or toxic, including PFAS.
- **Increase investment** in the development of safer and more sustainable chemicals and materials, as well as solutions that reduce plastic production such as non-toxic reuse and refill systems.
- **Adopt policies for synthetic chemicals and plastics** at the state, federal, and local levels that set targets for the reduction of chemical and plastic production, similar to climate action plans that set goals for greenhouse gas reductions.
- **Prioritize actions that address multiple planetary boundary threats**, as the Earth system works as an interconnected whole. Working to stabilize the climate, for example, while ignoring the planetary boundary threats posed by synthetic chemicals and plastics will allow continued peril for the system as a whole, and increase impacts on vulnerable communities.
- **Work together with environmental justice communities** to ensure that any solutions help to alleviate the disproportionate impacts and health harms that low-income communities, communities of color, and other vulnerable populations continue to experience.

Overuse of toxic and dangerous novel entities poses as great a risk to our planet as climate change, the hole in the ozone layer, or biodiversity loss, and we cannot afford to continue producing synthetic chemicals and plastics as though nothing has changed. By taking these steps, governments, policymakers, manufacturers, and companies can immediately reduce the planetary boundary threats posed by synthetic chemicals and plastics.

A family enjoying a zero-waste outdoor picnic with reusable plates and utensils.

ENDNOTES

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