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SYSTEMIQ

Invisible Ingredients

Tackling toxic chemicals in the food system

About this publication

About Systemiq

Systemiq is a systems change company that works with businesses, policymakers, investors and civil society organisations to reimagine and reshape the systems that sit at the heart of society - energy, nature and food, materials, built environment, and finance - to accelerate the shift to a more sustainable and inclusive economy. Founded in 2016, Systemiq is a certified B-Corp with offices in Brazil, France, Germany, Indonesia, the Netherlands, and the UK.

Find out more at www.systemiq.earth or via LinkedIn

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The Grantham Foundation also funded a companion piece by Deep Science Ventures, which assessed a wider set of toxic chemicals and associated health and environmental concerns.

This is available for download at:
https://www.deepscienceventures.com/toxicity

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Authors and acknowledgements

Systemiq core team

Felix Cornehl, Laura Picot, Liselotte Wisman, Nadhira Ratnasari, Rupert Simons.

Contributors

The authors would like to thank the following contributors and reviewers for taking the time to provide valuable comments. The contributors and their institutions do not necessarily endorse the report's findings.

Adam Tomassi-Russell	PhD, Deep Science Ventures
Albert McGartland	PhD, Institute for Policy Integrity at NYU School of Law; former US Environmental Protection Agency (EPA)
Anne Robertson	Director, Institute for Preventive Health
Apolline Roger	ClientEarth
Christos Symeonides	Senior Advisor, Plastics and Human Health, Minderoo Foundation
Chuck Benbrook	PhD, Heartland Health Research Alliance
David Andrews	PhD, Environmental Working Group
David LeZaks	PhD, Ursa Collective
David A. Wirth	Boston College Law School, Professor of Law
Emily Carey Perez de Alejo	Defend Our Health
Erik Millstone	Professor of Science Policy, University of Sussex
Harry Macpherson	Deep Science Ventures
Henry Rowlands	Director, Institute for Preventive Health
J. Christopher States	PhD, Center for Integrative Environmental Health Sciences, University of Louisville School of Medicine
Jane Muncke	PhD, Food Packaging Forum
Jonatan Kleimark	PhD, ChemSec
Kizzy Charles Guzman	Center for Environmental Health
Linda Birnbaum	PhD, DABT, ATS; Scientist Emeritus and Former Director, National Institute of Environmental Health Sciences and National Toxicology Program Scholar in Residence, Duke University
Maricel Maffini	PhD, independent consultant (former Natural Resources Defense Council, The Pew Charitable Trusts, Tufts University School of Medicine)
Philip J. Landrigan MD	Pediatrician and public health physician; Professor of Global Public Health and Director, Global Observatory on Planetary Health at Boston College; medical consultant, Centre Scientifique de Monaco
Pina Fritz	Deep Science Ventures
Rachel Feller	Edacious
Scott Faber	Adjunct Professor, Georgetown University of Law, Environmental Working Group
Shanna Swan	PhD, Action Science Initiative, School of Medicine at Mount Sinai
Tracey Woodruff	University of California San Francisco (professor and program director); former US EPA

Systemiq contributors

Arushi Chopra, George Darrah, Guido Schmidt-Traub, Jeremy Oppenheim, Yoni Shiran.

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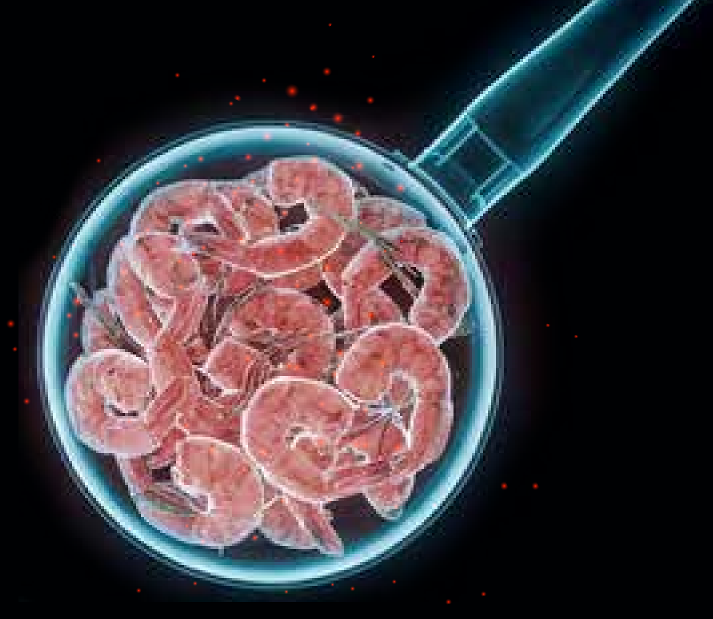
Executive summary



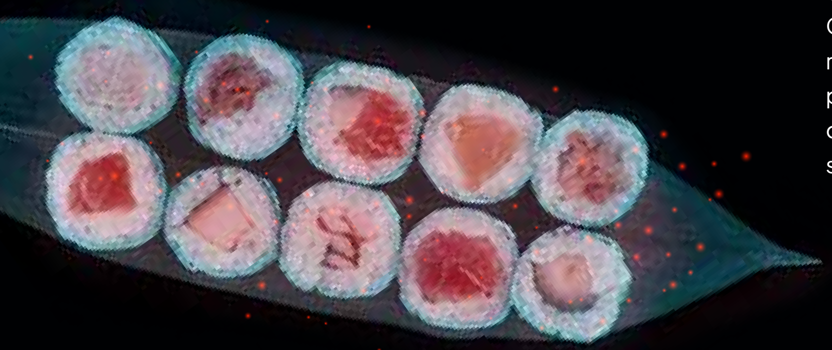
Toxic chemicals pose a hidden threat to global health, economies, and ecosystems.

Synthetic chemicals are deeply embedded in modern food systems. They are intentionally used in fertilizers and pesticides, in processing aids and equipment, and in packaging and coatings. They also enter the food system unintentionally due to chemical reactions or breakdown products; or as contamination from soil, water, or air pollution. This is particularly problematic as, over the years, many of these substances have proven hazardous to humans and the environment.

Industrial chemicals are regulated far less stringently than pharmaceuticals.[1] While the manufacturers of new drugs must prove their safety and efficacy before they can enter the market, industrial chemicals are permitted on the market until harm is demonstrated. This reactive model has resulted in decades-long inaction and repeated "regrettable substitutions"—where one hazardous compound is replaced by another with a similar structure and effects.

Two interrelated failures lie at the heart of this problem. **Unmanaged hazards** are insufficiently regulated chemicals which are already known to be hazardous (e.g., toxic, persistent, bioaccumulative, and/or endocrine disrupting). **Unknown safety captures** the thousands of substances in use that have never been adequately tested, leaving large blind spots in public health protection.

This report assesses the harms caused by four groups of toxic chemicals and the reduction potential for each. Proven solutions could significantly reduce **synthetic pesticide** use and phase out exposure to **phthalates** and **bisphenols**, which are currently found in everyday products such as plastic food containers and food-handling gloves. They could also drastically cut production and environmental concentrations of **PFAS**—so-called "forever chemicals" that have become ubiquitous in the environment due to their use across the economy—as a first step toward full phaseout.



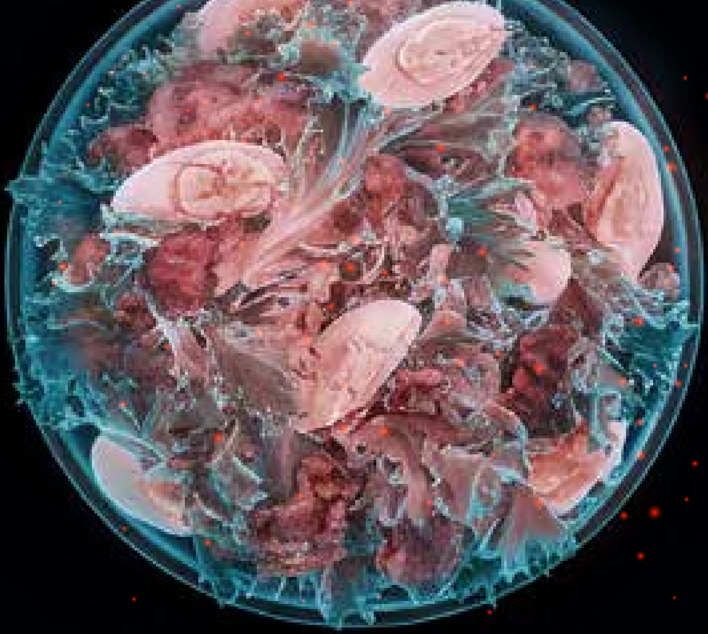
The latent costs of inaction: disease, fertility loss, and environmental damage

Chemical exposure is a major but preventable driver of noncommunicable diseases (NCDs). It begins before birth and shapes lifelong trajectories, contributing to higher rates of cancer, reproductive disorders, neurodevelopmental conditions, and metabolic disease. The global food system-related health burden from a subset of phthalates, bisphenols, pesticides, and PFAS is estimated at **$1.4–$2.2 trillion annually**—roughly **2–3% of global gross domestic product** (GDP) or approximately the profits of the world's 100 largest publicly listed companies.[2]

Toxic chemicals impair fertility in both men and women. Exposure during fetal development, infancy and reproductive years can have lasting effects on fertility and overall health. If current exposure persists, there could be **200–700 million fewer births globally between 2025 and 2100**—at the high end, equivalent to the entire population of Southeast Asia. While this could be reduced by up to 40-60% through the universal availability of fertility treatment, the cost would range between $26–79 billion per year. These impacts compound demographic headwinds, not only endangering public health but also undermining the long-term foundations of economic and social resilience.

Even a narrow accounting of ecological impacts—meeting water safety standards for PFAS and pesticides plus agricultural losses—implies costs of at least $640 billion per year worldwide; but most ecosystem damage (e.g., soil degradation and biodiversity decline) remains unpriced. Given the persistence and mobility of many substances, reduced use of hazardous chemicals is the only viable path to protect the natural capital on which our food systems depend. These figures are conservative, considering only a subset of hazardous compounds and a limited set of harms.

Four groups of toxic chemicals widely used across food systems — phthalates, bisphenols, pesticides and PFAS — are imposing up to $3 trillion a year in preventable costs:

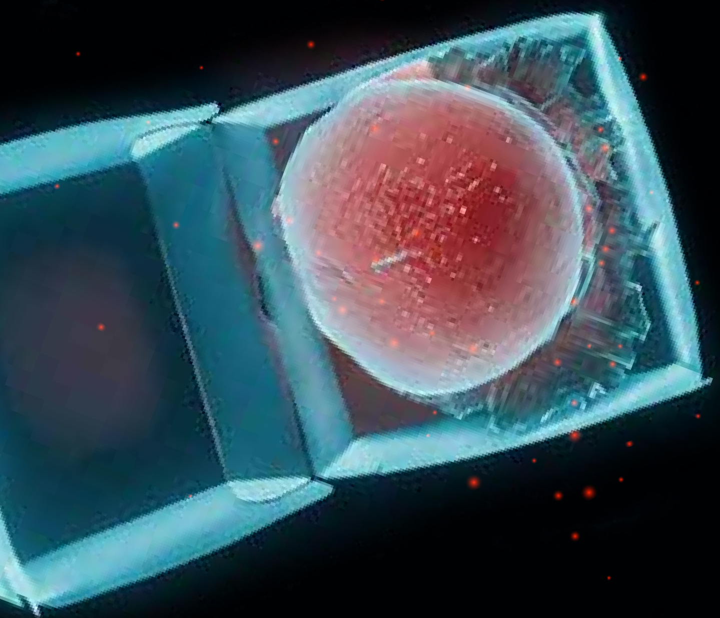


$1.4–$2.2T
Annual healthcare costs

$640B
Annual ecological damage

3–4%
Of global GDP in total avoidable costs

200–700M
Fewer births globally
between 2025 and 2100



Phaseout is both possible and potentially profitable

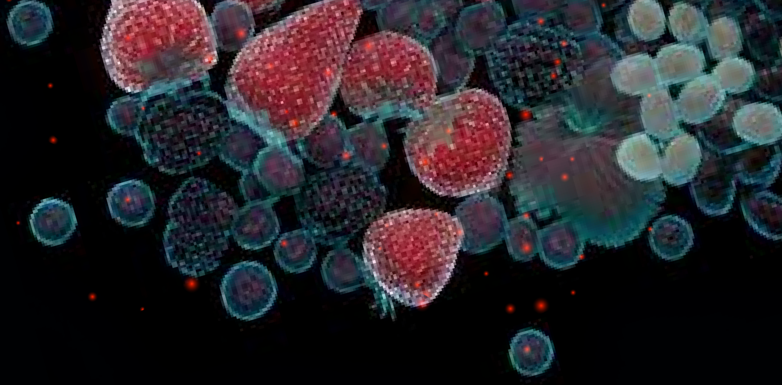
However, this burden is not inevitable. As an example of what is possible, the Montreal Protocol eliminated ozone-depleting chlorofluorocarbons (CFCs) through clear timelines, corporate innovation, and global cooperation. Today, international alignment on chemical safety is gaining momentum. The 2023 Global Framework on Chemicals set shared goals to phase out hazardous substances and promote safe-by-design innovation, establishing a foundation for coordinated national and regional action.

Solutions are within reach and achievable at manageable cost

The good news is that solutions exist, and many are already being applied. The cases examined in this report demonstrate through empirical, real-world experience that regulation works, that reduced exposure to toxic chemicals is possible, and that reduction prevents disease and saves lives.

A practical **solutions hierarchy guides effective action**, as follows:

- **Eliminate or prevent** unnecessary uses of hazardous chemicals.
- **Redesign** systems to minimize need.
- **Substitute** with safer alternatives.
- **Remediate** legacy contamination, which is least efficient but still crucial—particularly to tackle high-exposure pathways.



This report investigates four major groups of toxic chemicals:

Phthalates—proof of regulatory success:
EU restrictions have **cut the volume of certain hazardous phthalates placed on the market by 90% since 2010**, with sharp declines in human exposure and minimal economic disruption. This demonstrates the effectiveness of regulation and the potential for similar reductions across the globe, while underscoring the need for continued evaluation as new evidence on remaining compounds emerges.

Bisphenols—the next frontier:
Adopting improved review methods to assess the full range of scientific evidence available, the **European Food Safety Authority slashed the tolerable daily intake of bisphenol A (BPA) by a factor of 20,000**, resulting in EU bans of BPA "and other hazardous bisphenols or hazardous bisphenol derivatives" in all food contact materials.[3] This decision was based on a rigorous assessment that available alternatives are both technically and commercially feasible, setting the stage for more widespread regulation globally.

Pesticides—shifting to a low-toxicity system:
Harm reduction requires a **dual focus on toxicity and volume**. The UN Global Framework on Chemicals and the UN Global Biodiversity Framework include targets to reduce toxicity from pesticides, which should drive down the use of the most hazardous ingredients and compounds. Established farming techniques can be complemented by emerging technologies to facilitate a shift to low-toxicity pest control systems that do not compromise yields or agricultural economics. Transition pathways differ across major markets, as they have different agricultural contexts and regulatory starting points:

- **EU:** A volume reduction of **up to 80%** is feasible—about half of this is achievable with net savings through **precision application and integrated pest management (IPM)**, with organic farming and safer substitutions playing supplementary roles.
- **Brazil:** In an agricultural sector characterized by large farms and high pesticide use, **large-scale precision technology and bio-based substitutes** can achieve a volume reduction of up to 80%, at relatively higher near-term costs compared to the EU.
- **India:** Rather than volume reductions, here the emphasis is on **toxicity reduction and IPM**, tailored to a smallholder farming model and relatively lower pesticide use, but higher exposure levels resulting from more manual pesticide application.

PFAS—an intergenerational challenge:
The **elimination of all PFAS is the only viable strategy**, as these substances persist for decades to centuries, remediation is not feasible, and **environmental contamination accounts for 80% of human exposure.** Our recommendation is to set phaseout targets now—with time-limited, essential-use derogations only where necessary—to accelerate scaleup and innovation. Our analysis indicates 42% of PFAS volumes could be phased out by 2030 under this approach. By 2040, newly viable alternatives could replace around 95% of PFAS volumes, representing a market of at least $15 billion in the EU alone.

A safer future will pay for itself:

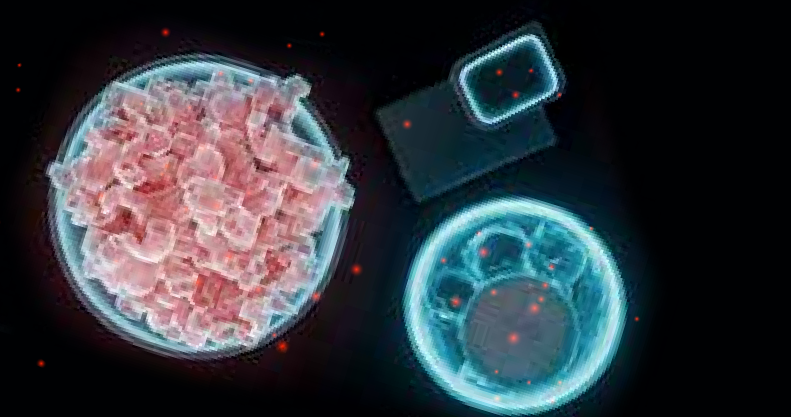
Global action could **cut health and ecological costs by ~70%, or around 3% of global GDP** ($1.9 trillion per year). Compared to these savings, the costs of action are minuscule. For instance, reducing the use of PFAS and pesticides in the EU has benefit-cost ratios of around 100:1 and 100:3.5, respectively. Beyond avoided harms, reduction of toxic chemicals could boost productivity, mitigate litigation and cleanup liabilities, and unlock innovation. Producers already have the expertise and supply chains to **lead the way in safe-by-design markets.**

↓70%

reduction in health and ecological costs via global action on toxic chemicals

↓$1.9T

potential annual saving (around 3% of global GDP)



Moving forward: binding commitments and a path to profit

The invisible harms of the past call for visible leadership today. Achieving this transition demands combined action from regulators, industry, and investors, as well as citizens and public interest nongovernmental organizations (NGOs). The phaseout of toxic chemicals is not only an environmental and health imperative; it is also a **promising economic opportunity**. Making the transition financially attractive will be critical for success. Experience shows that when transition aligns with commercial logic, it becomes self-perpetuating and accelerates accordingly. Above all, **clear, binding phaseout timelines** should be the main tool through which change is realized, affording certainty to industry, expediting cost declines through scale, and stimulating innovation. This will ensure that industry—including manufacturers and users of toxic chemicals—sees a path to profitability from the production and use of safe alternatives, so that market mechanisms end up driving the phaseout.

Three mutually reinforcing strategies are needed:

- **Unmanaged risks:** Adopt **group-based bans; strengthen enforcement** through biomonitoring and monitoring of chemicals in food and other exposure pathways; **prohibit the production and export** of domestically banned or severely restricted substances; and align measures internationally via the **Global Framework on Chemicals**, drawing on lessons from the Montreal Protocol (clear timelines, innovation support, fairness for developing countries).
- **Unknown safety gap:** Shift to hazard-based, precautionary regulation, requiring **pre-market proof of safety**; conduct **systematic reviews** that integrate independent evidence; and mandate **post-market surveillance** capturing mixture, transgenerational, and epigenetic effects.
- **Cross-cutting enablers:** Reform **fiscal and regulatory incentives** (e.g., taxes, extended producer responsibility (EPR), insurance, subsidies) to reward lower toxicity; target public spending toward **time-bound innovation missions and procurement guarantees**; and embed **hazard literacy** and **safe-by-design** principles in education for chemists, engineers, and material scientists.

This agenda is ambitious but achievable. With clear timelines, aligned incentives, and focused innovation, governments, firms, and investors can sharply reduce exposure to harmful chemicals, strengthen ecosystems, and open up sizable markets for safer materials—all at a fraction of the cost that toxic chemical use currently poses to health, fertility, and the environment.

Traffic light for safer chemicals in the food system

STOP using toxic chemicals we already know are harmful

- Ban and phase out highly hazardous chemical groups with clear deadlines
- Strengthen enforcement through biomonitoring, food & water testing, and supply chain transparency
- Prohibit production and exports of chemicals restricted domestically
- Strengthen liability frameworks so producers are incentivized to identify and phase out hazards

PREVENT toxic chemicals reaching people and ecosystems

- Adopt precautionary, hazard-based regulation
- Require pre-market proof of safety based on independent scientific assessment ("no data, no market" principle)
- Monitor unforeseen harms through post-market surveillance
- Apply systematic review methods to weigh all scientific evidence transparently

REALIGN incentives and redesign systems

- Reform fiscal and regulatory incentives to reward lower toxicity.
- Fund time-bound innovation missions to accelerate solutions in hard-to-replace uses or critical exposure pathways
- Drive product & system redesign to eliminate unnecessary chemical use
- Embed hazard literacy and safe-by-design principles in STEM education and industry training

When governments and industry act across all three levers, toxic exposure can fall dramatically — improving health, fertility, and ecosystem resilience.

1 Introduction

Imagine a newly developed chemical—hypotheticon—that is introduced to the market as a safe and versatile compound. It is quickly incorporated into all manner of everyday products, from household cleaners to food packaging, and is widely used worldwide. But within a few years, doctors begin to notice a horrifying pattern: thousands of babies are being born with severe malformations, traced back to high exposure to hypotheticon in the womb. The crisis triggers social and political upheaval, eroding confidence in the systems meant to protect public health.

The scandal is so severe that governments across the world take action. From this point onwards, no new chemical can be sold without extensive, independent testing to prove its safety before market entry. The tragedy of hypotheticon becomes a milestone in chemical regulation—a catastrophe that sets a new global standard of precaution.

Here's the twist: while hypotheticon does not exist, these events have nonetheless played out in real life. This story is not about an industrial chemical, but about thalidomide—a drug prescribed to pregnant women in the late 1950s and early 1960s that caused severe birth defects in thousands of children. The thalidomide disaster revolutionized pharmaceutical regulation;[4] however, no such watershed has yet been reached for industrial chemicals.

Toxic chemicals are ubiquitous in the food system and beyond

Chemicals are ubiquitous in nearly everything we eat. They protect crops from pests, give packaging strength and flexibility, and give food longer shelf life. Their diversity is striking: over 15,000 pesticide ingredients have been registered for use in the US alone[5] and more than 12,000 food contact chemicals are intentionally used for production and packaging worldwide.[6] They are also worryingly mobile: more than 5,000 chemicals—including many that were not intentionally added—have been found to migrate from packaging and other food contact uses into food, onto human skin, and in some cases into the air.[7] These and other chemicals were never designed to be part of human diets, yet they leach into food from packaging and accumulate as residues in soil and water. This reveals a paradox of modern food production: the very substances that underpin our modern global food system have also made exposure to synthetic chemicals universal.

5,000+ chemicals have been found to migrate from packaging and other food contact uses into food, onto human skin and into the air

Many of these chemicals have proven to be toxic, posing escalating risks to human health and development, fertility, ecological resilience, and the security of the food system itself. Some persist for decades or even centuries; others break down more quickly but remain harmful through continuous use and high exposure. Their presence in food items and the environment makes it impossible to avoid them; while the heaviest health burdens fall on populations least able to shield themselves.

Since 2000, global capacity to produce chemicals, plastics, and pesticidal active ingredients has almost doubled. This trend illustrates why toxic exposure is not an isolated issue but part of a systemic overshoot of the planetary boundary for novel entities, with serious implications for both human and ecological resilience. This report explores how governments, industry, investors, and civil society can effectively tackle this challenge.

A tale of two regulatory systems

While awareness of the health and environmental impacts of industrial chemicals is growing, the frameworks designed to manage them remain dangerously permissive. By contrast, pharmaceuticals have been strictly regulated since the 1960s, when the thalidomide scandal shocked governments into requiring proof of safety and efficacy before any new medicine could be sold.

Industrial chemicals, however, are governed by a risk-based system that allows them to be sold until harm is demonstrated. This approach assumes chemicals are safe at "acceptable exposure levels" unless proven otherwise, when in fact there may be no safe level of exposure.[8] All too often, this approach ignores inherent hazards such as persistence, bioaccumulation, or endocrine disruption.[i] It also treats each substance in isolation, overlooking the combined or cumulative effects of chemical mixtures. Meanwhile, when narrow bans are introduced, they often trigger "regrettable substitutions," where substances that have proven harmful are replaced by almost-identical alternatives, perpetuating similar risks under different names. In practice, this has led to decades-long delays in the removal of harmful substances from markets. Successful campaigns—from Rachel Carson's ground-breaking *Silent Spring*,[9] which led to the DDT ban in the 1960s,[10] to the phaseout of leaded petrol in the 1970s[11] and the elimination of CFCs under the 1987 Montreal Protocol[12]—have been hard-fought exceptions to the rule.

Today, more than 350,000 chemicals and mixtures have been registered for production and use worldwide.[13] Just a small fraction of these have ever undergone systematic hazard assessment and fewer still have been restricted or phased out.[14] For instance, only around 128 "chemicals of concern" are covered by UN treaties.[15,16] Meanwhile, mounting scientific evidence links everyday exposure to devastating but less visible harms, including rising cancer rates, endocrine disruption, reduced fertility, and population-wide cognitive losses, such as declines in average IQ (see Chapter 2).

Exposure is linked to devastating but less visible harms, including rising cancer rates, endocrine disruption, reduced fertility, and population-wide cognitive losses

Unlike the dramatic birth defects that forced the reform of pharmaceutical regulation, the effects of chemical exposure are unfolding slowly, invisibly, across generations. And because regulation has remained permissive, society continues to bear the costs of both unmanaged hazards, where harm is well documented but insufficiently addressed, and unknown safety, where evidence is still emerging.

Momentum for change is building, but fragmented

The adoption of the Global Framework on Chemicals in 2023 reflected international recognition that chemical pollution poses systemic risks on par with climate change and biodiversity loss. The Framework establishes voluntary goals to minimize harmful impacts, phase out highly hazardous substances, and promote "safe and sustainable by design" innovation, establishing a possible basis for national and regional alignment. Yet global coordination remains fragile: geopolitical fragmentation has weakened multilateral environmental action, while inconsistent regulation risks creating "pollution havens," rather than spurring a virtuous "race to the top". This dynamic is underlined by the continued struggle to reach agreement in UN negotiations for a treaty to tackle plastic pollution, partially over disagreements on measures to regulate hazardous chemicals.[17]

The EU has been a pioneer in seeking to mitigate the inherent hazards of chemicals.[ii] Under its regulatory frameworks, the use of carcinogenic or endocrine-disrupting chemicals should be

i. Endocrine-disrupting chemicals interfere with the body's hormones, affecting growth, reproduction, and development.
ii. Such an approach is sometimes called the "hazard-based" or "generic risk" approach.

avoided, except for narrow essential uses (i.e., critical functions where no safe alternatives exist).[18] A crucial component of its Registration, Evaluation, Authorisation and Restriction of Chemicals Regulation (REACH) is the "no data, no market" principle, which makes access to markets conditional on the provision of hazard information. This aims to shift the burden of proof from regulators to producers and to prevent substances from being marketed before their safety is understood. Yet even under REACH, testing relies on data provided by the chemical industry, multiple exemptions are available, and a heavy burden is imposed on regulators to prove harm.[19]

The Montreal Protocol, adopted in 1987, serves as a powerful reminder that global coordination on chemical risks is both possible and potentially profitable. By coupling binding global timelines with funding for developing countries and clear market signals, it achieved the near-universal phaseout of ozone-depleting substances while stimulating innovation. A similar initiative—based on clarity, fairness, and collective action—could facilitate the global elimination of persistent and toxic chemicals.

The "no data, no market" principle makes access to markets conditional on the provision of hazard information - shifting the burden of proof from regulators to producers

However, industry influence on regulatory assessments and risk management policy constitutes a potent barrier to change. The prevailing permissive risk-based framework creates a systemic incentive problem: while businesses can realize profits today, the costs of harm are borne by the public and deferred over years or decades. Consequently, regulatory efforts often meet with significant pushback, with lobbying campaigns emphasizing economic costs (sometimes with limited evidence), while downplaying the long-term harms from the status quo and the potential benefits of change. The result is a cycle in which short-term interests outweigh systemic risks, frustrating the adoption of safer alternatives and precautionary approaches. Such resistance and delay are not without cost for firms: they exacerbate operational risk as the policy landscape becomes more unpredictable and regionally inconsistent, complicating long-term investment decisions.

Industry influence in practice

The Forever Lobbying Project—a group of academics, lawyers, and journalists—conducted an investigation into over 8,000 submissions and other documents related to the proposed "universal restriction" of PFAS proposed by the European Chemicals Agency (ECHA).[20] It found that many of these documents contained claims from industry that were "fearmongering, false, misleading, or potentially dishonest," aimed at securing deferrals and/or exemptions.[i,21,22] The influence of industry is particularly strong in regions with limited regulatory capacity, where chemicals banned elsewhere may continue to be used.

Focus and scope of this report

This report focuses on four groups of toxic chemicals of high relevance to food systems: phthalates, bisphenols, pesticides, and per- and polyfluoroalkyl substances (PFAS). These compounds were prioritized as they are among the most prevalent and best studied worldwide, with robust evidence of harm to human and ecological health. They enter the food chain directly through agricultural inputs, processing, and packaging (see Figure 1); as well as indirectly through air, soil, and water contamination. While many other synthetic chemicals are present in food systems, concentrating on these four allows us to combine depth of evidence with actionable insights, while illustrating systemic patterns relevant across the wider chemical economy.[ii]

i. For example, 997 documents argued that fluoropolymers, a subgroup of PFAS, should be exempted. These all cited two industry-funded papers which contended that fluoropolymers are "polymers of low concern" according to criteria established by the Organisation for Economic Co-operation and Development (OECD). However, the OECD has confirmed that "no agreed-upon set of criteria" was finalized and that it has not conducted an assessment of fluoropolymers. Claims of "safe fluoropolymers" are misleading: while they may pose limited risks during the use phase, the manufacturing and end-of-life phases release dozens of harmful PFAS and PFAS byproducts (ChemTrust, 2025). When the full lifecycle is considered, the case for inclusion of fluoropolymers is clear.

ii. Within these groups, only a subset of compounds has been scientifically investigated in detail. This has two important implications. First, harms identified in one compound are not necessarily shared by all others in that group. Second, widely used compounds within these groups have not been well studied, representing a risk of unknown safety that suggests estimates of harms are likely underestimated.

FIGURE 1 **Overview of primary food use cases across priority toxic chemicals (not exhaustive)**

✓ Confirmed usage (✓) Less common usage

		Bisphenols	Phthalates	PFAS	Pesticides
Crop Use	Herbicides			✓	✓
	Insecticides			✓	✓
	Fungicides			✓	✓
Food Processing/ Manufacturing	Conveyor Belts		✓	✓	
	Gasket and Seals		✓	✓	
	Vinyl Gloves		✓	✓	
	Farm / Milk Tubing		✓		
	Mixing Paddles	✓			
	Storage Tank[1]	✓			
Groceries	Microwave popcorn bags			✓	
	Ice cream cartons		✓	✓	
	Fresh food wrap		✓		
	Canned goods	✓			
Cookware	Non-stick pans	(✓)		✓	
	Non- stick Metal Baking Trays	(✓)		✓	
	Silicone baking trays	(✓)	(✓)		
	Plastic cooking utensils	✓	(✓)	✓	
	Elec. Non - stick cooking appliances			✓	
	Greaseproof paper			✓	
Storage	Glass jar lids	✓	✓		
	Food storage, e.g., Tupperware	✓	✓	✓	
	Water bottle	✓	✓		
	Baby Bottle	✓			
Takeaway	Plastic takeaway boxes	✓	✓	✓	
	Paper-based containers	(✓)	(✓)	✓	
	Deli / sandwich paper wrappers		✓	✓	
	Pizza box	✓	(✓)	(✓)	
	Foil lined pouches / cartons		✓	✓	
	Disposable hot drinks cups	✓	✓	✓	
	Popcorn tub			✓	

Notes: 1. For transport and storage purposes

Sources: Toxicity Eliminating the Threats to Planetary and Human Health Caused by Toxicity, DSV, January 2025; Plastic List. "The Plastic Scorecard." (2023); PFAS Insights. "PFAS Found in Pesticide Products." (2024); U.S. FDA. "Phthalates in Food Packaging and Contact Applications."; Ecology Center. "What's Cooking? Undisclosed PFAS in Cookware."; Ecology Center. "Phthalates in Farm Equipment."; Environmental Defense Fund. "EDF Testing Recommendations for Ortho-Phthalates."; MDPI – Materials. "Migration of Phthalates from Plastic Packaging."; The Guardian. "Paper Receipts Contain Bisphenol S." (2025); Toxic-Free Food Contact Alliance. "PFAS in Food Contact Materials." Minnesota Department of Agriculture "PFAS in Pesticides" (2024).

Each substance reflects a distinct dimension of the challenge: phthalates and bisphenols reveal both the power and the limitations of targeted regulation; pesticides show how dependency is reinforced by incentives in agricultural systems; and PFAS illustrate the cost of inaction on highly persistent pollutants. Together, they also capture the two sides of the problem: unmanaged hazards and unknown safety.

Micro- and nano-plastics and unknown safety

While micro- and nano-plastics (MNPs) are a subject of growing concern, the evidence on their human health impacts is less advanced. MNPs can be found in most human organ systems and biological samples, including the placenta, lungs, and liver, as well as in blood, urine, and breast milk.[23] Although they have been associated with harmful impacts across many species, links to adverse human health outcomes are only emerging.[24] Crucially, it is not yet clear whether the particles themselves are driving impacts, or whether the thousands of chemicals contained within plastics or other contaminants may be culpable. As such, MNPs were not evaluated within the scope of this report.

This report quantifies the combined health and environmental burden of these substances; identifies pathways for reduction; and proposes concrete measures for policymakers, businesses, and investors to realign incentives and accelerate the transition to a safer, more resilient food system.

The report is structured to guide readers from evidence to conclusions and solutions:

- **Chapter 2** synthesizes the evidence on the imperative for change, quantitatively estimating the harms to human health, fertility, and ecosystems.
- **Chapter 3** sets out feasible toxic chemical-specific solutions, drawing on findings from the successful regulation and phaseout of phthalates and bisphenols in the EU, and developing cost curves for the reduction of pesticides and PFAS, before comparing the costs of action with those of inaction, highlighting the economic case for ambitious regulation.
- **Chapter 4** concludes with recommendations, setting out cross-cutting enablers and toxic chemical-specific actions for policymakers, businesses, and investors.

Methodology

For a detailed outline of the methodology underlying our findings, please see the Technical Annex. The methodology combines multiple strands of evidence to ensure both breadth and robustness:

- **Selection of in-scope chemicals:** We prioritized four groups (phthalates, bisphenols, pesticides, and PFAS) based on their prevalence in the food system and documented hazards that are known, likely, or suspected.[25]
- **Health and fertility impacts:** We collated available evidence on health impacts and associated costs, including extrapolations across regions based on population, exposure[i], and relative health costs. In addition, where associations with health impacts have been established but impacts have not been quantified, we have extrapolated potential costs.

  On fertility impacts, UN population forecasts have been adjusted by a plausible range of impacts from the four groups of toxic chemicals based on academic literature to estimate the potential reduction in births between 2025 and 2100.
- **Ecological impacts:** We collected available evidence on the costs of remediating PFAS and pesticide contamination in water, and of agricultural losses linked to pesticide use. These were extrapolated based on human populations and toxic chemical volumes, respectively, while recognizing that they reflect just a small fraction of the actual losses to natural capital.

Continues overleaf

i. Technically, "attributable fraction" is the fraction of each health outcome attributable to the relevant pollutant.

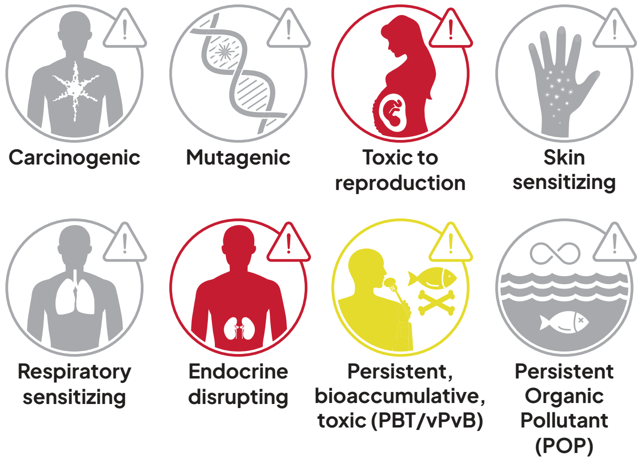
- **Solutions analysis:**
  - Case studies: For phthalates and bisphenols, we drew on evidence of the successes of EU regulation and phaseout to identify lessons for regions that have more permissive regulations in place.
  - Marginal abatement cost curves (MACCs): As reductions in pesticides and PFAS are less advanced, we assessed available levers to reduce the use of these toxic chemicals, including the likely volume and relative costs. MACCs are graphical tools, frequently used in relation to greenhouse gas emissions, that visualize the reduction potential of different measures and their associated costs or savings per unit of reduction (e.g., dollar per ton of greenhouse gases reduced).
- **Benefits:** To estimate the relative cost-benefit of phasing out these toxic chemicals, we applied the potential volume reductions identified in the solutions analysis to the cost estimates. This simple linear calculation does not reflect potential non-linearities but aims to provide an order of magnitude indication.
- **Limitations:** Current estimates understate total harms, as many chemicals and their ecological and long-term health impacts remain under-researched and/or unpriced. Similarly, the report's focus on single chemicals overlooks the effects of chemical mixtures, which can cause harm even if individual chemicals are below set exposure thresholds. Data availability on toxic chemicals, their use volumes, and associated disease and environmental impacts is insufficient. We acknowledge that our attempts to extrapolate missing impacts based on available evidence are imprecise, but they provide a transparent estimate of the potential extent of the costs of inaction compared to action. Absent better data, the default assumption for proven health and ecological impact associations that have not been quantified is that there is zero impact. This can be considered a lower bound by excluding the extrapolated costs. Further studies to complement and refine these estimates would be valuable.

FIGURE 2 Toxic chemical groups – high-level overview

- Strong evidence of hazard for subset of group, or entire group
- Evidence of hazard for subset of group, or suspected widely

Phthalates

Large group of chemicals generally used to soften materials (plasticiser), mainly PVC plastics.



Food system uses:

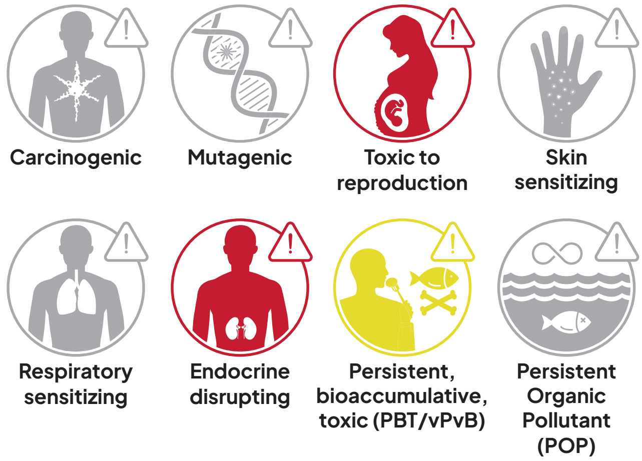
- Plasticizers in PVC food contact materials (films, tubing, gloves)
- Packaging (cling films, coatings)
- Processing equipment (hoses, seals)

Other uses:

- PVC flooring, cables, wires
- Toys, footwear, upholstery
- Medical devices
- Cosmetics & personal care (limited)

Bisphenols

Class of chemicals, best known being BPA, among the world's most widely-manufactured chemicals.



Food system uses:

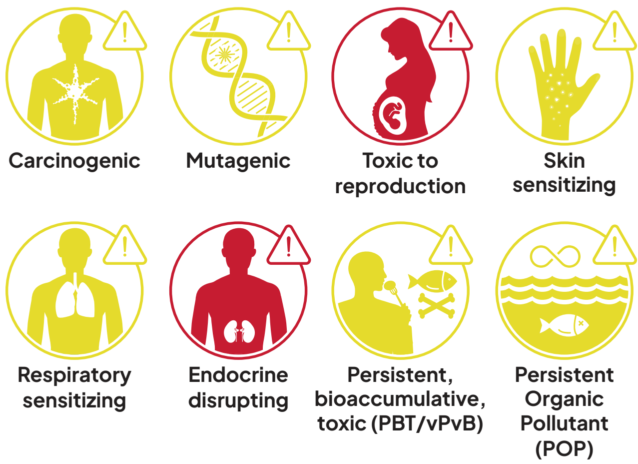
- Coatings in food & beverage cans, jar lids, bottle tops
- Epoxy resins in food packaging
- Plastic containers & reusable bottles, food storage, utensils

Other uses:

- Polycarbonate plastics (electronics, sports goods)
- Thermal paper (receipts)
- Coatings, adhesives
- Textile & leather finishing

Pesticides

Diverse range of chemicals, intended to kill living organisms (e.g., pests, weeds) but often strike beyond their intended targets.



Food system uses:

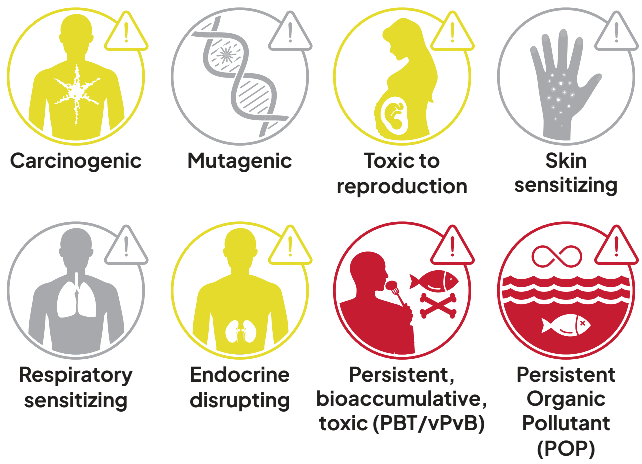
- Crop protection: herbicides, insecticides, fungicides
- Seed treatments
- Post-harvest treatments
- Water/soil fumigation

Other uses:

- Vector control (mosquitoes, public health)
- Non-agricultural pest/weed control (gardens, forestry)
- Biocides, disinfectants

PFAS

Large group of ~15.000 chemicals used for their resistance to heat, stains, oil, and water; known as "forever chemicals" due to their persistence.



Food system uses:

- Grease- and water-repellent coatings in food packaging
- Non-stick cookware
- Processing equipment with grease/water exposure
- Some pesticides

Other uses:

- Textiles & outdoor gear
- Firefighting foams
- Industrial coatings, lubricants
- Electronics, semiconductors
- Aerospace, automotive, medical devices

Source: Systemiq analysis. Simplified overview—see the Technical Annex for a full list of health impact references.

2 The cost of inaction: the imperative for change

The harms caused by toxic chemicals are too great to ignore. The combined health, ecological, and productivity losses caused by phthalates, bisphenols, pesticides, and PFAS amount to trillions of dollars each year. The evidence is clear: doing nothing is the most expensive option. This chapter quantifies the costs of this damage to human and ecological health.

In quantitatively estimating the human health and ecological costs of toxic chemical exposure, we faced substantial data limitations (see the “Methodology” box in Chapter 1). The estimates presented in this chapter are derived from available literature reviews and, where empirical evidence is lacking, from reasoned extrapolations to approximate impacts across regions and harms (see the Technical Annex).

Human health impacts

Toxic chemicals in the food system constitute a vast and under-recognized health burden. The proliferation of NCDs is often blamed on individual lifestyle choices, yet there is growing scientific evidence that chemical exposure in daily life is a major and preventable driver.[26] For example, over the past half-century, NCD rates in children have risen sharply: in the US, childhood cancer rates have risen by more than one-third, male reproductive birth defects have doubled, and one in six children now suffers from a neurodevelopmental disorder.[27] This chemical exposure is inescapable, beginning before birth and shaping lifelong health trajectories. Framing NCDs primarily as the outcome of personal behavior obscures the structural role of toxic chemical exposure. This narrative deflects responsibility from producers and regulators, perpetuating a system in which prevention is under-incentivized and illness becomes a downstream cost of doing business.

Globally, our analysis suggests that the combined food-related health costs of four major toxic chemical groups (phthalates, bisphenols, pesticides, and PFAS) endemic in the food system amount to between ~$700 billion and $2 trillion annually, with a central estimate of ~$1.4 trillion, based on outcomes with robust cost data. When extrapolations for impacts where cost estimates are not yet available are included, the total rises to between ~$800 billion and $2.8 trillion (central estimate of ~$2.2 trillion annually). To put this in perspective, it equates to roughly 1.8–2.9% of global GDP in the year of analysis—exceeding the combined annual profits of the world's 100 largest publicly listed companies (~$2 tillion in 2025).[28] Similarly, health costs of food-related exposure to these toxic chemicals are equivalent to around one-quarter of the global economic burden of air pollution, which is estimated at around $8.1 trillion per year.[29] But in contrast to air pollution, which declines as income levels rise and is set to drop further due to increased electrification, exposure to toxic chemicals remains unavoidable unless their use is effectively curbed.

Total estimated health costs of four major toxic chemical groups exceed the combined annual profits of the world’s 100 largest publicly listed companies

Figure 3 provides a mapping of toxic chemicals and associated health outcomes, as well as available and extrapolated cost estimates considered (for further details see the Technical Annex).

FIGURE 3 Overview of available cost estimates by toxic chemical–health outcome pairs

✓✓	✓	⚠	✗	
Evidenced and costed (direct **and** indirect cost)	**Evidenced and costed** (direct **or** indirect cost)	**Health outcome** Toxic chemical pair evidenced but not costed	**Health outcome** Toxic chemical pair is not evidenced	Extrapolated costs

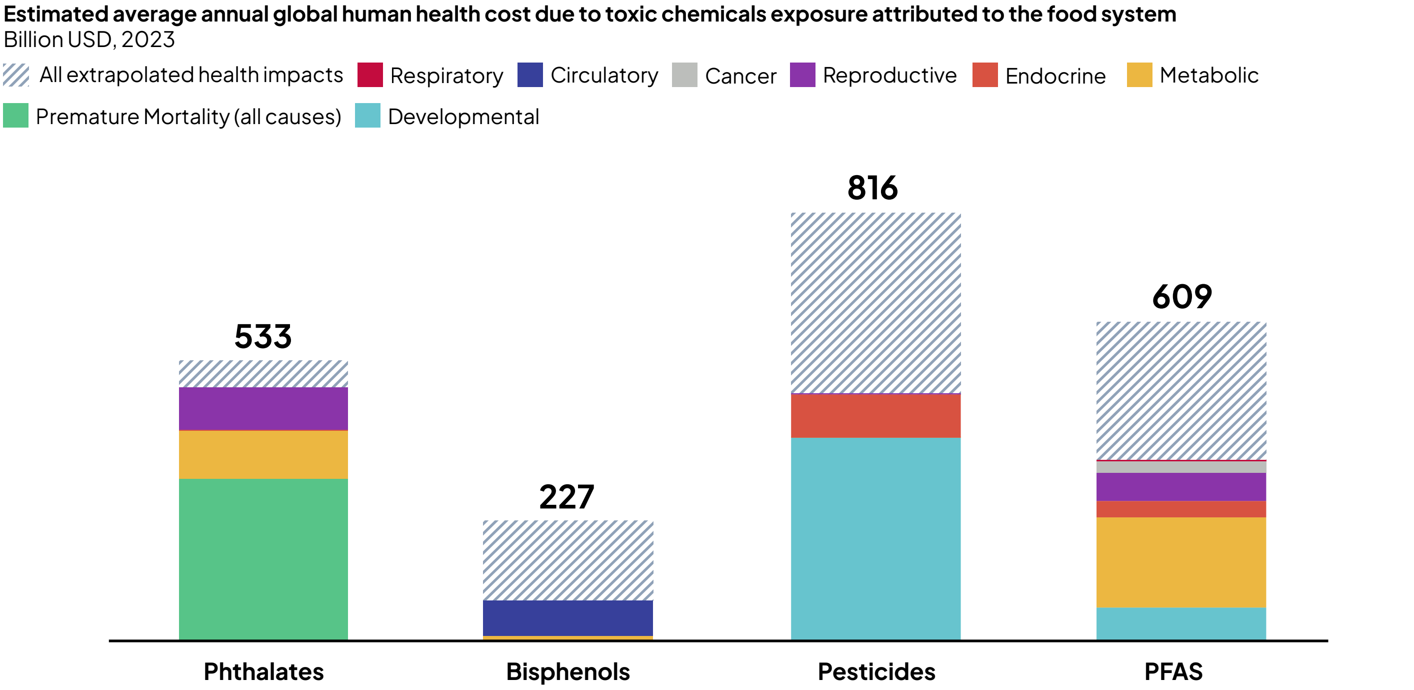
Health outcome categories[1]	Health outcome	Phthalate	Bisphenol	Pesticide	PFAS
Reproductive system	Infertility (male[2] / couple)	✓	⚠	⚠	✓
	Ovarian reserve[3]	⚠	⚠	⚠	⚠
	Uterus fibroid	✗	⚠	✓	⚠
	Endometriosis	✓	⚠	⚠	✓✓
Cancer	Kidney cancer	✗	⚠	⚠	✓✓
	Testicular cancer	✗	✗	⚠	✓✓
	Breast cancer	⚠	⚠	⚠	✓✓
	Prostate cancer	✗	⚠	⚠	⚠
	Liver cancer	✗	✗	⚠	⚠
Endocrine diseases	Hypothyroidism	✗	⚠	✗	✓✓
	PCOS	⚠	⚠	⚠	✓
	Diabetes	✓	⚠	✓	✓
	Gestational diabetes	✗	⚠	⚠	✓✓
Nutritional / metabolic Diseases	Adult obesity	✓✓	⚠	⚠	✓✓
	Childhood obesity	✗	✓	✓	✓
Cardiovascular diseases	Hypertension / cardiovascular	✓✓[4]	✓	⚠	⚠
Respiratory diseases	Pneumonia	✗	✗	⚠	✓✓
Genitourinary diseases	Renal dysfunction	⚠	⚠	⚠	⚠
Neurodevelopmental and developmental disorders	Intellectual disability	⚠	⚠	✓✓	⚠
	Birth defects	⚠	⚠	⚠	✓✓[5]
Immune system diseases	Immunotoxicity	✗	⚠	⚠	⚠
	Number of studies analysed	20+	10+	25+	30+

Sources: Trasande et al 2016, Trasande et al 2022, Trasande et al 2025, Attina et al 2016, Obsekov et al 2023, DSV 2025.
Notes: 1. Based on ICD-11 Mortality and Morbidity groupings. 2. Due to low sperm count 3. Growing evidence but no costing analysis 4. Costed as early mortality from all causes, e.g., cardiovascular and cancer. 5 Costed based on low-birth-weight attributed IQ loss not structural malformations.

Despite the significant scale of these estimated costs, our figures capture only a subset of known impacts. Many social costs—such as caregiving demands, reduced quality of life, and intergenerational effects—remain unaccounted for. The costs reported cover only a narrow range of health outcomes where the evidence is strongest; and within each toxic chemical group, just one or two subclasses were analyzed (e.g., organophosphates and organochlorines[i] for pesticides, BPA for bisphenols, DEHP for phthalates). The true burden of exposure to all toxic chemicals and their mixtures is therefore expected to be substantially higher.

i. While organochlorines have largely been phased out in high-income countries, they remain widely used in lower-income countries and continue to cause harms due to their persistence and bioaccumulation.

FIGURE 4 **Estimated average annual global human health costs due to toxic chemicals attributed to the food system**



Sources: Systemiq analysis based on Trasande et al. (2016); Attina et al. (2016); Trasande et al. (2022); Obsekov et al. (2023); and Landrigan et al. (2023). See the Technical Annex for details.

As shown in Figure 4, the harms cut across multiple dimensions, with the largest burdens arising from developmental disorders, all-cause premature mortality, metabolic diseases, and circulatory diseases. Pesticides account for about 32% of the total estimated costs of the four groups of compounds, largely through neurodevelopmental impacts that reduce cognitive potential and long-term productivity. PFAS account for roughly 29%, driven by metabolic disease, immune dysfunction, and certain cancers. Phthalates contribute another 29%—primarily through reproductive problems leading to the need for fertility treatment, metabolic diseases, and early mortality. Bisphenols account for around 15%, with cost estimates available only for circulatory diseases and childhood obesity. Together, these exposures affect multiple organs and biological pathways, creating systemic and unavoidable health burdens. Most of these chemicals act as endocrine disruptors, interfering with hormonal signaling in the body. Because the endocrine system is highly sensitive to low concentrations, even minute exposures can have measurable biological effects, particularly on fetuses and children. The relationship between dose and harm is often non-linear, meaning that prevailing testing methods—which assume higher doses cause proportionally greater harm—may underestimate the risks at low levels.

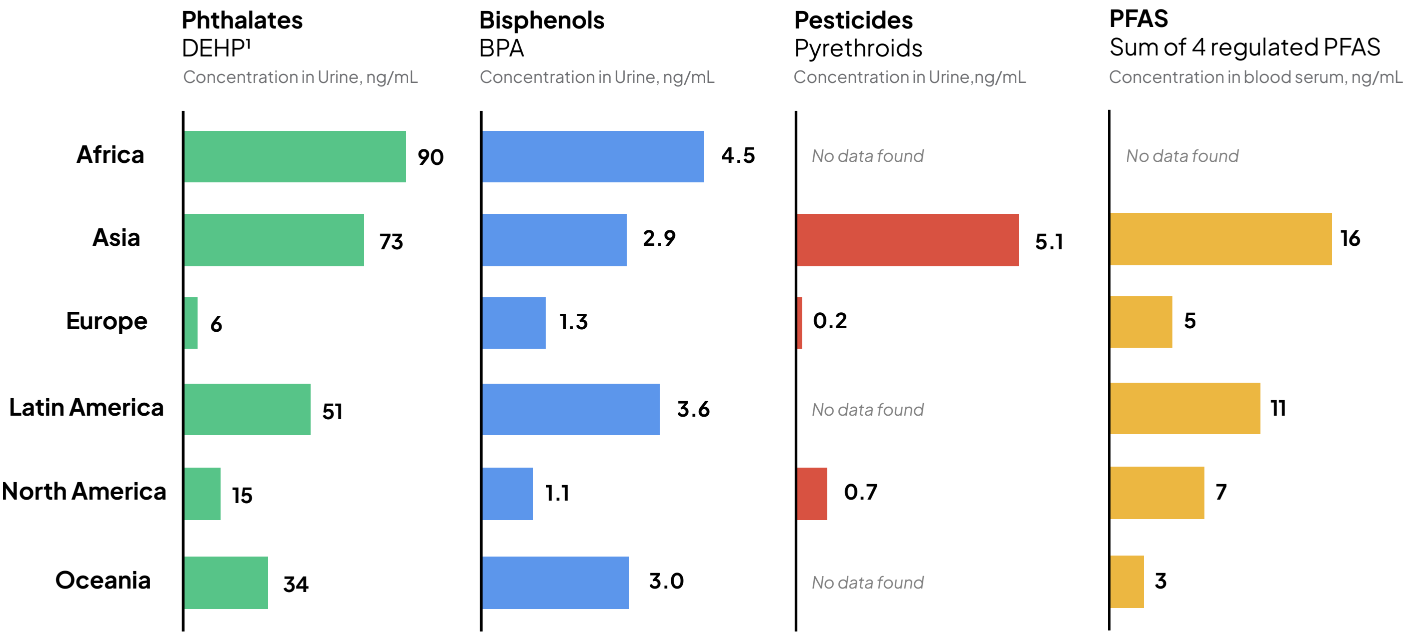
These figures should be interpreted as historical baselines, reflecting exposures and disease links documented mainly between 2010 and 2015. Because many health outcomes take years to emerge, recent exposure data cannot yet be translated into up-to-date cost estimates. As a result, the analysis may overstate burdens for chemicals with declining use (e.g., some pesticides and BPA) and understate them for chemicals with persistent or increasing exposures. The estimates are not directly comparable across the four chemical groups, as some include only direct medical costs while others also account for productivity losses or disability-adjusted life years, depending on available data and health outcomes.

Reported exposure levels vary substantially between regions (Figure 5), shaped by factors such as regulatory stringency, proximity to chemical production, use and consumption patterns, and the environmental persistence of different compounds. They are also affected by local practices. For example, elevated phthalate and bisphenol levels observed in parts of Africa may stem from the open burning and informal recycling of low-quality plastics, which release these compounds into the air and soil. Addressing such sources will require region-specific strategies, such as improving waste management infrastructure and promoting safe disposal and recycling systems to limit secondary exposure pathways. Biomonitoring coverage also differs widely, with some regions represented by robust datasets and others relying on limited or outdated studies, complicating direct comparison.

Despite these limitations, the available evidence suggests that Asia consistently exhibits the highest exposures across major toxic chemical groups; while Europe records the lowest levels, largely reflecting differences in regulation, production, and use. Although the data is not directly comparable, Figure 5 provides a valuable indication of relative exposure patterns across regions and highlights critical gaps in monitoring.

FIGURE 5 **Reported toxic chemical exposure across six regions**

Regional concentrations based on most recent data available

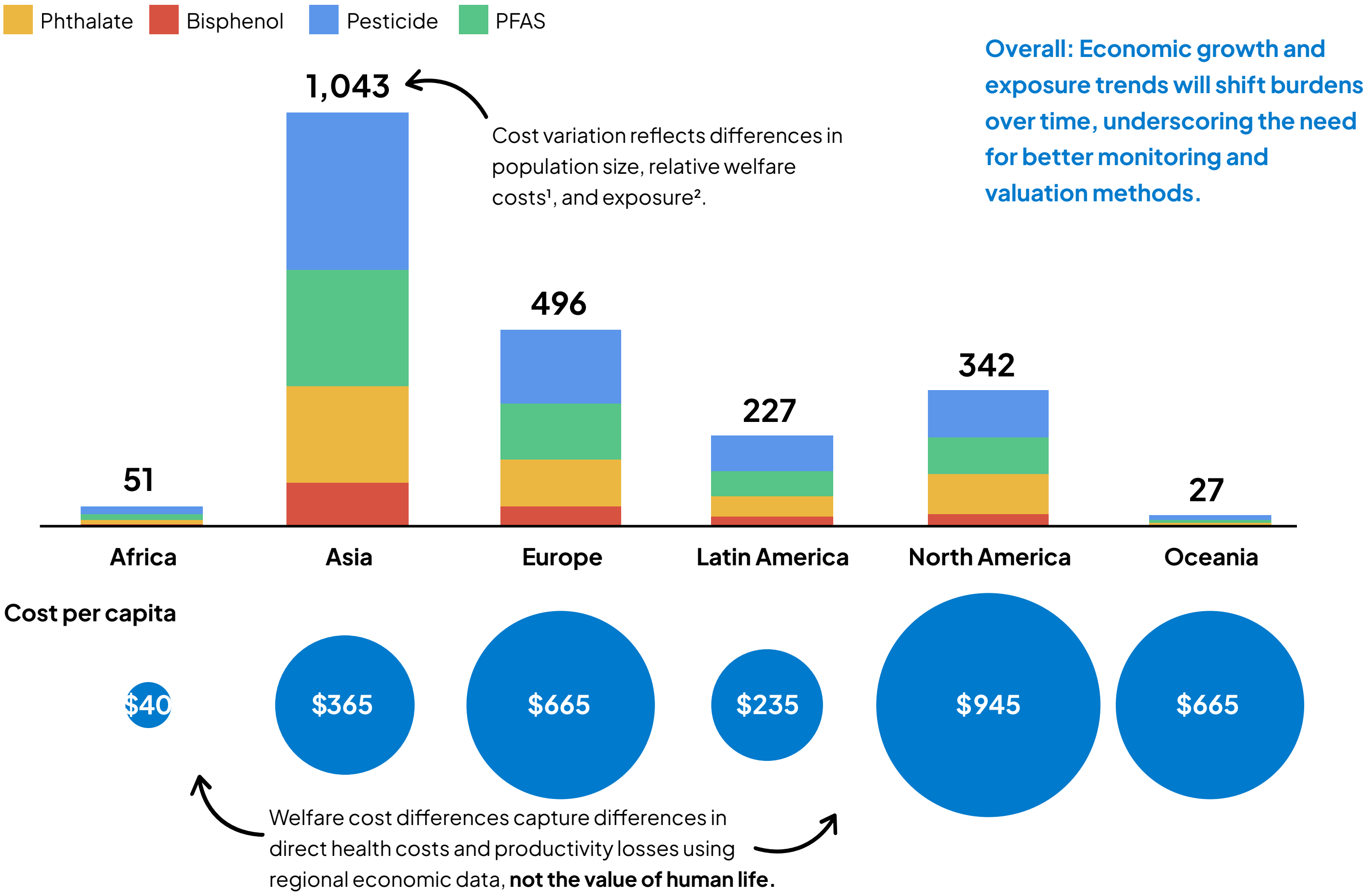


Sources: NHANES database; HBM4EU; Acevedo et al. (2025); Noren et al. (2020); Benson et al. (2021); Kasper-Sonnenberg et al. (2025); and Australian Bureau of Statistics. See the Technical Annex for details.
Notes: 1. DEHP equals to sum of MEHP + MEHHP + MEOHP + MECPP metabolites
Due to limited biomonitoring and toxicity data, only selected subclasses were included in the quantitative analysis. For instance, despite representing a small fraction of pesticide use, pyrethroids were used as a proxy, as these are available for use across regions.

FIGURE 6 **Estimated average human health costs across six regions based on varying attribution factors, population size, and welfare cost**

Estimated average annual human health cost due to toxic chemicals exposure attributed to the food system by region based on 2015 data

Billion USD, 2023



Sources: Systemiq analysis, based on 2015 data.

Notes: 1. Welfare cost is the monetary value of adverse health impacts, calculated using the Value per Statistical Life (VSL) for premature deaths (Cropper et al., 2025). 2. Technically "attributable fraction" is the share of cases attributed to specific toxic chemicals (affected by exposure, and other factors)

As shown in Figure 6, the estimated health costs from food-related toxic chemicals are highest in Asia and Europe in absolute terms, driven primarily by population size and welfare cost multipliers. Crucially, welfare costs do not represent a comparative value of human life across regions but capture relative price levels, such as differences in gross national income levels and willingness to pay for small reductions in mortality risk. However, costs per capita are greatest in North America, Europe, and Oceania, reflecting both higher baseline health expenditures and stronger valuation of welfare losses. The analysis is based on 2015 exposure data. Since then, levels have likely increased in parts of Asia, Latin America, Africa, and Oceania for some chemicals (e.g., BPA); while exposure in Europe and North America has generally declined, due to tighter regulation.[30] This implies that the relative burden in developing regions would now be considerably higher, amplified by population growth and rising economic productivity. Lower attribution factors applied outside the EU also reflect the scarcity of epidemiological and cost-of-illness data, requiring conservative estimates until region-specific evidence becomes available. The data in Figure 6 thus underscores both the unequal distribution of health costs and the likelihood that these figures understate the current and future burden in non-EU regions.

The associated health toll erodes productivity, increases healthcare costs, and compounds inequalities

The scale of these conservative estimates of health impacts from four sets of toxic chemicals is striking and warrants the elevation of these chemical externalities in policy and accounting agendas. The associated health toll erodes productivity, increases healthcare costs, and compounds inequalities. Without decisive intervention, these impacts will intensify—pushing societies further into hidden debt as they pay for harms that could and should have been prevented.

Fertility impacts

Fertility rates[i] worldwide have more than halved since 1970, driven by both socioeconomic shifts and declining reproductive health.[31] Historically, lifestyle and health factors have been most associated with this decline in reproductive health. However, in many regions smoking rates are now falling and obesity rates growing more gradually—trends that are not consistent with the accelerating deterioration in reproductive health. Scientific evidence has identified toxic chemicals in the food system (and beyond) that are risk factors for infertility and other reproductive harms, and could be a crucial but under-valued driver of dwindling fertility rates.

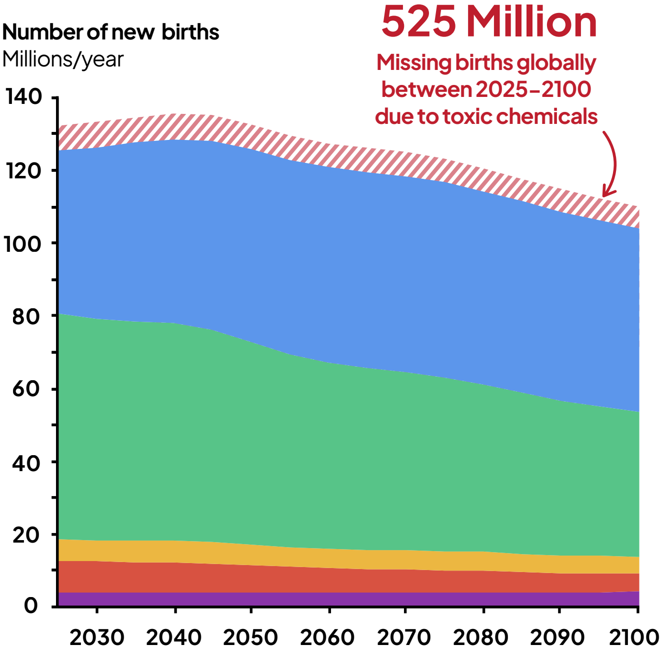
> **Toxic chemicals in the food system could be a crucial but under-valued driver of dwindling fertility rates.**

Food-linked toxic chemicals affect fertility in both men and women. Phthalates migrate into foods and can lower testosterone and semen quality.[32] Bisphenols mimic estrogen, disrupting hormonal balance, which can result in damage to ovaries and impaired egg and sperm quality.[33,34,35] Pesticides disrupt hormones and damage testicular cells, reducing sperm count and motility.[36] They also interfere with female hormonal function, which can lead to negative reproductive effects such as ovarian cycle irregularities and impaired fertility.[37] PFAS lengthen time to conception and harm babies through reduced birth weight and altered immune responses.[38] There is a risk that these effects are compounding, as endocrine disruptors impact the reproductive health of both women and men. For women, endocrine disruptors have been linked to heightened risk of menstrual irregularities,[39] endometriosis[40], and pregnancy complications.[41] Some scientists have warned of a looming "tipping point" at which sperm concentration falls below a critical threshold and the probability of pregnancy drops exponentially, approaching zero.[42,43] The ability to conceive is a function of both male and female reproductive capacity. When prospective parents both face clinically relevant fertility problems, it is expected that the chance of pregnancy will be lower than than in couples in which only one partner is affected.[44]

FIGURE 7 **Global "missing births" under a current-exposure scenario**

Africa | Asia | Europe | Latin America | North America | Total missing births across regions

Estimated number of missing births attributed to toxic chemicals exposure globally between 2025-2100



Estimated number of missing births 2025-2100
Share of projected births between the same period compared to baseline

	Central Estimate	Low Estimate	High Estimate
Africa	**200 Mn ↓5%**	85 Mn ↓2%	310 Mn ↓8%
Asia	**265 Mn ↓6%**	90 Mn ↓2%	330 Mn ↓8%
Europe	**15 Mn ↓4%**	10 Mn ↓2%	30 Mn ↓7%
Latin America	**30 Mn ↓5%**	10 Mn ↓2%	40 Mn ↓8%
North America	**15 Mn ↓5%**	5 Mn ↓2%	25 Mn ↓8%

Source: Systemiq analysis. See the Technical Annex for details.

i. Defined here as the average number of children a woman would have in her lifetime, based on current birth rates at different ages.

Demographic projections currently do not account for the influence of toxic chemicals on fertility trends. The UN's 2024 central forecasts[i] assume the global fall in fertility rates will begin to slow almost immediately, implying stabilization rather than continued decline.[45] However, a high-level assessment conducted for this report—combining projected fertility rates, exposure levels, and scientific estimates of toxic chemical-driven fertility impacts (see the Technical Annex)—reveals that the demographic implications of exposure could be stark: toxic chemicals could result in **200–700 million fewer births globally between 2025 and 2100** (see Figure 7). The high end of this estimate is equivalent to losing the entire population of Southeast Asia. The burden is broadly shared across regions but is largest in Asia; intermediate in North America, Latin America, and Africa; and lightest in Europe.[ii] Asia and Africa together account for over 450 million missing births; while the effect is lowest in Europe, reflecting stricter regulation of pesticides and phthalates and ongoing moves toward the phaseout of PFAS and bisphenols, as well as long-established trends of smaller families. Although fertility treatments such as IVF could help to mitigate these impacts to a considerable degree, they are less accessible in Africa and Asia, which account for most missing births. Should access become universal, the number of births lost could be more than halved at a cost of between $26-79 billion annually.

Moreover, while the scale of fertility impacts revealed by this analysis is significant, it may be an underestimate: most toxic chemicals remain poorly studied and exposure begins even before birth, as toxic chemicals are passed from mothers to fetuses and infants at vulnerable stages of development. Exposure in the womb shapes the fertility of both men and women for for life posing risks to subsequent generations. These intergenerational risks mean that today's children may carry impaired reproductive health into adulthood, compounding long-term fertility decline.

Most toxic chemicals remain poorly studied and exposure begins even before birth, as toxic chemicals are passed from mothers to fetuses and infants at vulnerable stages of development

Beyond the very real human cost to couples facing involuntary childlessness, the projected implications for fertility are sufficiently severe to alter global demographic and economic trajectories. Falling birth rates will have far-reaching economic consequences.[46] A shrinking workforce strains pension and healthcare systems; while aging populations are associated with reduced risk appetite, entrepreneurship, and company formation. A drop in the number of people contributing ideas may also slow innovation and weaken the division of labor—though extended and healthier lives and new technologies such as artificial intelligence (AI) could moderate these effects to some extent. The risk is that the persistent fertility declines which we are already witnessing across most of the world will be exacerbated by these reproductive impacts, worsening economic decline, eroding social resilience, and making adaptation more difficult and expensive.

While human reproductive outcomes are complicated by shifting choices and technologies, biology tells a simpler story in other species. Many animals, including fish, frogs, birds, alligators, and even household dogs, function as 'sentinel species' meaning they register exposure and early biological effects from hazards before comparable signals are evident in people. The evidence indicates that sentinel species face the same exposure to toxic chemicals, often through shared pathways, and are suffering resulting reproductive harms, largely via hormonal disruption.[47,48] These concordant signals strengthen the causal case and situate fertility loss within the wider triple planetary crisis of chemical pollution, climate change, and biodiversity decline.

i. While the UN baseline is widely used, other estimates consider this to be optimistic (i.e., overstating births).
ii. There are significant data gaps for Africa and Latin America, where regional estimates rely heavily on proxies from just one or two countries. Current evidence suggests that both regions have among the lowest PFAS exposures globally, reflecting limited historical PFAS production and remoteness from major contamination sources. Yet the strongest data comes from a handful of countries (e.g., Brazil and Tanzania), underscoring the need for further research to clarify exposure patterns and true average risk across these regions.

Ecological impacts

Toxic chemicals are undermining the ecological foundations of the global food system (see Figure 9); and existing cost estimates only capture the 'tip of the iceberg' (see Figure 8). Current analysis indicates that meeting EU water safety standards for pesticides and PFAS globally will require at least $600 billion in annual treatment costs,[49] with another $40 billion in global agricultural losses from contamination and reduced productivity.[50] Yet these figures reflect just a fraction of the true damage; most ecosystem impacts—including biodiversity loss, soil degradation, bioaccumulation effects, and cascading ecological harms—remain unpriced.

FIGURE 8 **Estimation of the environmental impact of toxic chemicals[51]**

COSTED METHODOLOGY

1 Ground and surface water contamination	~ $38 – 1,120 B	to make drinking water pesticide- & PFAS-safe
2 Agricultural productivity decline	~ $16 B	crop losses from excessive pesticide use
	~ $2.7 B	pollination value wiped out with bee losses
	~ $4.6 B	in natural pest-control services forfeited
	~ $17.7 B	extra spent battling resistant pests

QUANTIFIED METHODOLOGY

3 Soil contamination	~ 80%	global farmland soils carry pesticide residues
4 Seafood contamination	~ 74%	of seafood PFAS-tainted in recent FDA tests
5 Fresh fish stock decline	~ 90%	fish-harvest crash from pesticide-laden runoff
6 Wild life contamination	20%	red-listed species at risk from bio-accumulating toxic chemicals
	600 +	wildlife species confirmed with PFAS in their tissues
	~ 550 Mn	birds lost as pesticides drive crash in the food web

Sources: Ecological impact sources: 1. Bommelaer & Devaux 2011 (France), Goldenman et al. 2019 (EU & US), 2: Pimentel (2005), 3: FAO (2021), 4: FDA (2022), 5. Yamamuro, M. et al. (2019), 6: Rigal, S. et al. (2023), 6: ChemSec; Andrews, D.Q. et al. (2023)

Notes: 1) Based on findings from Bommelaer & Devaux 2011 (France), Pimental (2005) and Goldenman et al. 2019, 2) European Commission (2024), percentage based on median across member states of 50 m3 per person per year compared to Bommelaer & Devaux 2011 (France) 3) FAO (2022), 4) European Commission

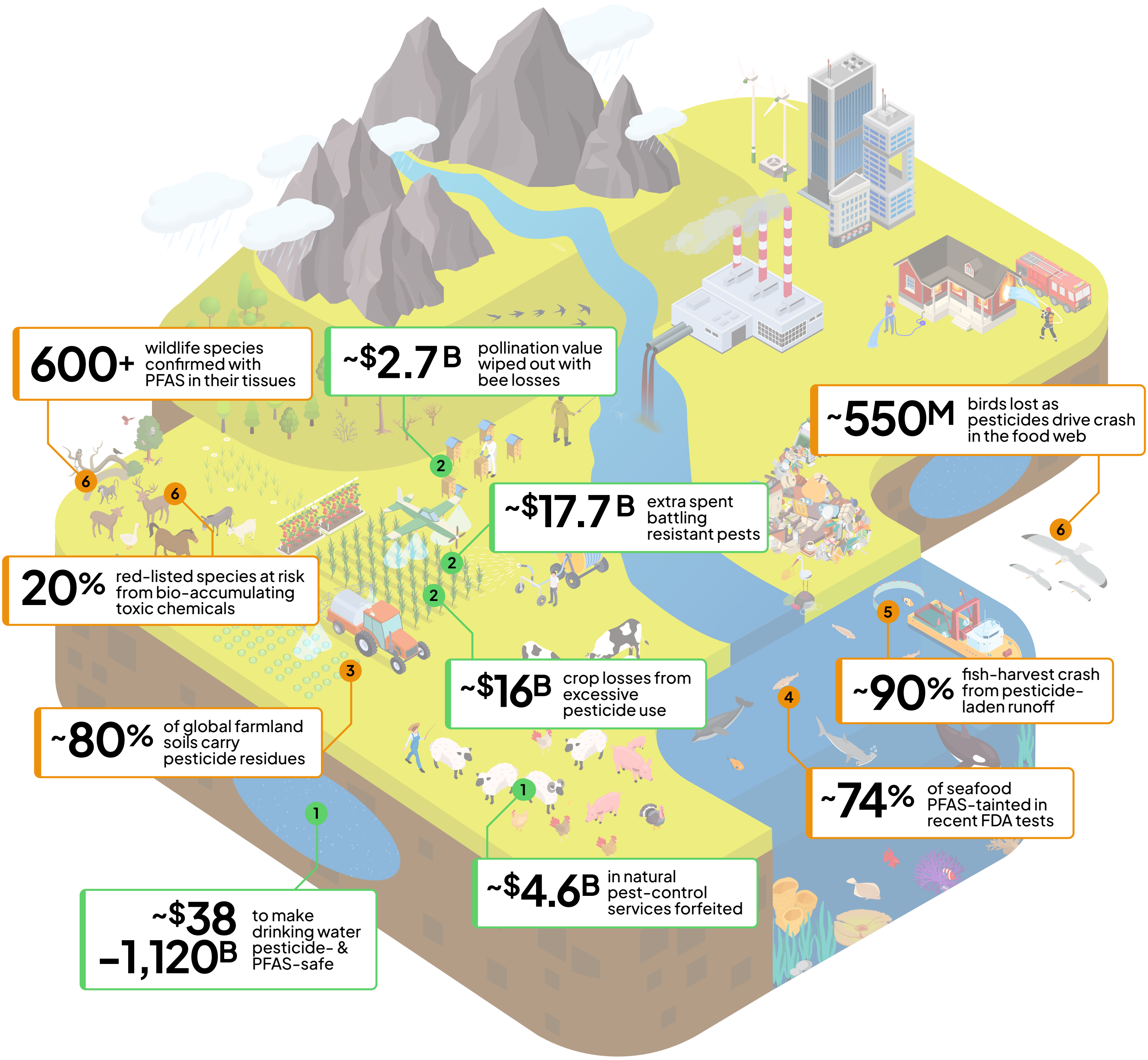
FIGURE 9A **Ecological impacts of toxic chemicals on major ecosystem services (non-exhaustive)**

Costed		Quantified			
1 Ground and surface water contamination	2 Agricultural productivity decline	3 Soil contamination	4 Seafood contamination	5 Fresh fish stock decline	6 Wild life contamination

Source: Adapted from Wee & Aris (2023).

FIGURE 9B **Ecological impacts of toxic chemicals on major ecosystem services (non-exhaustive)**

Costed		Quantified			
1 Ground and surface water contamination	2 Agricultural productivity decline	3 Soil contamination	4 Seafood contamination	5 Fresh fish stock decline	6 Wild life contamination



Source: Adapted from Wee & Aris (2023).

Toxic chemicals have permeated our ecosystems, including soil, water, air, and living organisms. Persistent substances such as PFAS are dispersed through the air, rain, rivers, and groundwater, accumulating in food webs and defying cleanup at any meaningful scale—theoretically, global remediation costs would exceed global GDP.[52] Pesticides, by design, kill living organisms, but they often strike beyond their intended targets. They decimate pollinators and natural predators of pests, undermining the ecosystem services on which agriculture itself depends. When pollinators decline, crop yields fall; and when natural pest predators are lost, farmers become more reliant on chemicals to control outbreaks.

This dynamic creates a "toxicity trap" of chemical dependence. As pests develop resistance, farmers are pushed to apply higher doses of pesticides or shift to other, often more hazardous, chemicals. As ecosystems degrade, farmers often respond by using more pesticides, which further weakens beneficial insect populations. The cycle can spiral: yields fall, costs rise, and producers turn to artificial substitutes such as hand or mechanical pollination to sustain output, further increasing economic burdens. Studies show that such collateral damage is not incidental but systemic, as toxic chemicals disrupt the self-regulating ecological processes that maintain agricultural resilience.[53] Because these ecological costs remain largely hidden, producers face little pressure to pivot—even as ecosystem degradation and supply chain instability expose the fragility of input-heavy systems.

Beyond agriculture, the ecological ripple effects are profound. Toxic chemicals disrupt soil microbiomes, reducing soil health and hindering carbon sequestration. They contaminate rivers and coastal zones, threatening fisheries and aquaculture. They fragment food webs, weakening biodiversity and amplifying economic losses at each trophic level.[54] Because many ecological harms remain invisible to markets, societies consistently underestimate the scale of these liabilities, treating natural capital as disposable even as it underpins food security and wider economic prosperity.

Ecological damage from toxic chemicals is both vast and compounding, and remediation of the most persistent chemicals is neither affordable nor feasible at scale. Drastically reducing their use is the only viable option. This would not only curb human exposure but also restore ecosystems that provide the irreplaceable services—from pollination to water purification—that are essential to long-term food system resilience.

Persistence and lock-in effects

Despite the overwhelming evidence of harm, toxic chemicals remain deeply entrenched in global food systems. Inertia and prevailing incentive structures perpetuate the problem—for instance, for decades, agricultural productivity gains have predominantly been measured by yields per hectare, rewarding input-intensive approaches. Agrochemical companies profit from selling more products, which are often bundled with proprietary pesticide-resistant seeds, discouraging efficiency and reduction. Farmers likewise have limited incentives to cut toxic chemical use: their yields and incomes are tied to input-heavy systems, while changing practices requires effort and is perceived as risky. Agronomic advisory services—often linked to pesticide sales—further reinforce the status quo.

These lock-in effects create a dependency that is both economic and ecological. The "toxicity trap" described above keeps farmers reliant on inputs. Breaking free requires systemic interventions: shifting incentives, reforming regulations, and rebalancing business models to prioritize and incentivize long-term health and ecological outcomes over short-term profits.

3 The cost of action: solutions to ensure a safer food system

Reducing toxic chemicals in the food system is both possible and cost effective. Past regulatory action has shown that when governments set clear rules, industries adapt rapidly—often at lower costs than anticipated. This chapter initially focuses on phthalates and bisphenols as proof-of-concept case studies of how regulation can work. The examples discussed below demonstrate that strong regulation can drive systemic change at limited cost and with measurable health benefits, while recognizing that exposure and substitutes continue to pose challenges. It then turns to pesticides and PFAS, where regulatory advances and phasedown are less mature. In this regard, we developed MACCs to map pathways, costs, and innovation needs.

Across the analyses, a solutions hierarchy applies (Figure 10), adapted from the waste hierarchy.[55] The principle is straightforward: prevention of unnecessary demand will deliver the greatest benefit at the lowest cost; while remediation of toxic chemicals already released is the least efficient and most expensive intervention, but an unavoidable complement if prevention has fallen short (e.g., in high-exposure pathways such as drinking water treatment and the management of sewage sludge applied as fertilizer, where ongoing contamination poses direct risks to human health and ecosystems). Between these extremes, redesigning systems (e.g., using different materials or business models that forgo the need for chemicals), substituting safer alternatives (e.g., other chemicals or natural compounds), and investing in innovation offer progressively more complex—but still feasible—pathways to cut toxic exposure. The hierarchy provides a lens through which each lever for reducing toxic chemical use can and should be assessed. It might be instinctive to default toward near-identical analogs, but this approach creates a risk of regrettable substitutions if the replacement chemicals lack robust assessment and leaves cost-effective, high-impact solutions under-explored. For firms, progressing up the hierarchy—toward redesign and elimination—also reduces exposure to litigation, reputational, and compliance risks, which escalate as jurisdictions tighten regulations unevenly.

FIGURE 10 **Our solutions follow a hierarchy for action on toxic chemicals – from reduction to remediation**

Costs of action hierarchy stages - definitions		Key tests applied:	
Eliminate	**Eliminate or shrink toxic chemical demand** before it enters the system, either by abandoning the underlying function or by radically lowering use-intensity	Does it stop demand before purchase?	**Eliminate**
Redesign	**Re-engineer the production or delivery system** so the function is still met but the toxic chemical becomes largely redundant or is needed in smaller doses	Does it change the process/system so the toxic chemical isn't needed?	**Redesign**
Substitute	**Swap the hazardous toxic chemical for a proven, safer alternative** that fits into the existing system with minimal process change	Is it mainly a chemical swap with the same process?	**Substitution**
Innovate	**Invest in research areas** where viable substitutes or redesign pathways don't yet exist or need robust evidence	Is it still at lab/pilot/research stage?	**Innovate**
Remediate	**Remediate and mitigate toxic chemicals** already released into people or the environment both by individuals and broader society	Is it cleaning up past use or treating/ mitigating harm?	**Remediate**

Source: Adapted from Ellen McArthur Foundation (2021).

Phthalates: Early proof of harm reduction

Toxic to reproduction

Endocrine disrupting

Persistent, bioaccumulative, toxic (PBT/vPvB)

Food system uses:

- **Plasticizers in PVC food contact materials** (films, tubing, gloves)
- **Packaging** (cling films, coatings)
- **Processing equipment** (hoses, seals)

Other uses:

- **PVC flooring, cables, wires**
- **Toys, footwear, upholstery**
- **Medical applications**
- **Cosmetics, personal care** (limited)

Why phthalates matter

Phthalates, more specifically ortho-phthalates,[i] are a family of industrial chemicals used as plasticizers: additives that increase the flexibility, transparency, and durability of materials. In Europe, over 90% of all plasticizer consumption is used in flexible PVC,[56] which appears in various guises throughout the food system—examples include conveyor belts, dairy tubing, gloves, and flexible packaging such as cling film. Migration into food is especially pronounced when products are fatty or heated, making diet a major pathway of human exposure. Phthalates can also migrate from recycled PET beverage bottles, even though they are not intentionally used in PET production.[57]

Phthalates migration into food is especially pronounced when products are fatty or heated, making diet a major pathway of human exposure

DEHP remains the most widely used phthalate globally—and one of the most hazardous. Several phthalates (e.g., DEHP, DBP, BBP, DIBP) have been shown to be antiandrogenic (e.g., inhibiting testosterone production in the developing male fetus); and systematic reviews have yielded moderate evidence that a subset of these chemicals has adverse effects on male and female reproduction (e.g., infertility, reduced sperm count, and decreased ovarian reserve) and increases the risk of metabolic disorders (e.g., insulin resistance and diabetes).[ii,58] Suspected health impacts include spontaneous abortion and neurodevelopmental harms.

Regulatory and industry response

Regulation on phthalates is fragmented globally. Restrictions have advanced the furthest in the EU, under multiple frameworks—including REACH, the Food Contact Materials Regulation, the Toy Safety Directive, the Waste Framework Directive, and the Restriction of Hazardous Substances Directive.[59] Eight phthalates are now on the REACH Authorisation List, meaning they cannot be produced or imported without specific authorization. Some EU member states have gone further—for example, Denmark has restricted all phthalates in toys for children under three and the Netherlands recently tightened its specific migration limits[iii] for several phthalates, going beyond REACH.

These rules gave industry clear timelines and certainty of enforcement. In response, the PVC industry transitioned away from low molecular weight (LMW) ortho-phthalates—specifically DEHP,[iv] DBP, BBP, and DIBP, which are subject to restriction.[60] In many instances, this initially involved replacing them with higher molecular weight (HMW) ortho-phthalates like DINP, DIDP, and DPHP. However, this shift posed a risk of regrettable substitutions, as these HMW phthalates are themselves categorized in the medium or low concern banding (as detailed in Figure 11), and are currently subject to further evaluation by ECHA to assess the risk of endocrine disruption and their persistent, bioaccumulative, and toxic potential.[61]

Consequently, the industry has increasingly shifted toward non-phthalate alternative plasticizers. Historical evidence shows that the EU's regulatory signals drove a substantial redirection of innovation. According to patent records, nearly 100 companies developed "phthalate-free" or "non-phthalate" alternatives between 1972–2011, with marked increases in patenting following the introduction of the 1999 restrictions and, more sharply, the adoption of REACH in 2006.[59] Notably, the three most active patent filers were ExxonMobil, Dow Chemical, and Eastman Chemical—among the world's largest phthalate manufacturers—demonstrating that clear regulatory timelines can shift R&D priorities even for incumbents.[63]

i. Esters made of ortho-phthalic acid and alcohols.

ii. To ensure consistent language in evaluating the strength of evidence for the four groups of toxic chemicals, we used a single paper that provides a consistent framework (Woodruff, 2025). Known or likely health effects are those for which associations have been classified in a robust or systematic review as known, causal, sufficient, presumed, likely, robust, or moderate. Suspected health effects are those supported by a lower level of evidence. The list of reported health effects is not comprehensive. For a full list of the academic literature used for each chemical, see the Technical Annex.

iii. The specific migration limit is the maximum permitted amount of a substance that may transfer from food contact materials into food, set to ensure consumer safety. Producers are responsible for testing or otherwise demonstrating that their products comply with this limit under standard conditions.

iv. DEHP is generally regulated alongside these compounds due to its similar toxicity profile and widespread use in flexible PVC, although sometimes it is also classed as transitional in molecular weight.

FIGURE 11 Overview of phthalates and common substitutes by level of concern as per ECHA[64]

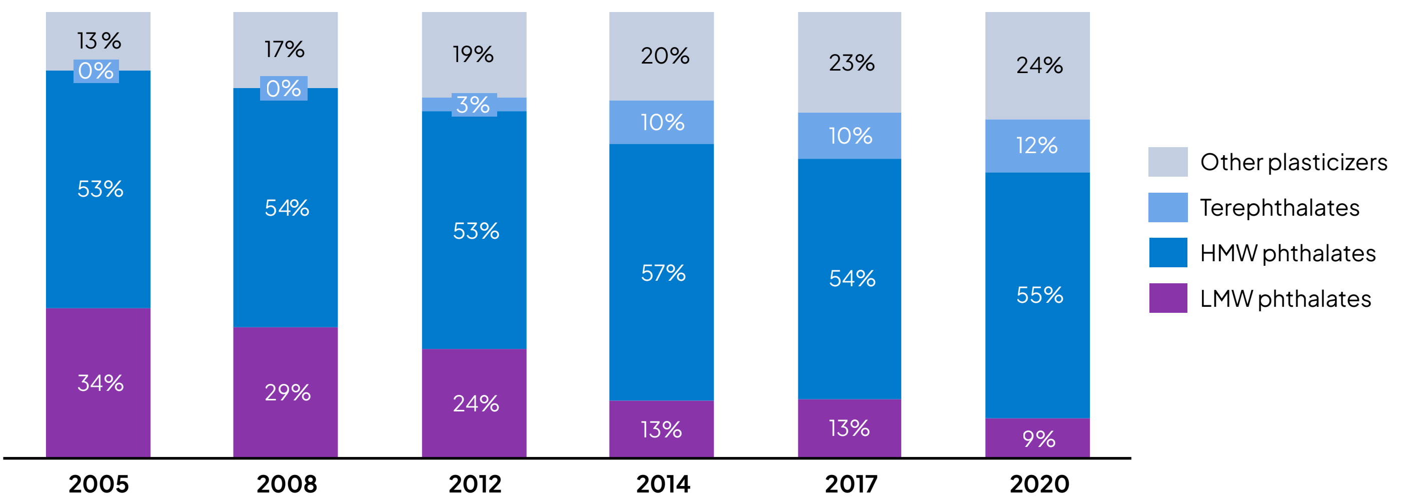
	High concern	Medium concern	Low concern	Currently no identified regulatory concern
Specific substances Top leading examples	• **DEHP, DBP, BBP** (C4-C6 Ortho-phthalates)	• **DINP, DPHP, DBTP** (Phthalate/Terephthalate groups) • **DINCH, TOTM, ESBO, ATBC** (Key substitutes)	• **DIDP, DUP** (Long C9-C18 Ortho-phthalates)	• **DOTP** (or **DEHT**)
Reasoning	• Classification based **on confirmed threshold or non-threshold severe toxicity.** • Substances are listed as Repr. 1B, often possessing endocrine disruptive and PBT[1] properties. Use is subject to Authorization List (Annex XIV).	• This band covers substances where **concerns regarding reprotoxicity, endocrine disruptive, or PBT properties are likely or possible** (e.g., C7-C8 ortho-phthalates, Trimellitates, and Benzoates). • Substitutes in this category are assessed as not preferred alternatives but are subjects for ongoing evaluation.	• Experimental data do not show clear severe toxicity shared with shorter chains. • No firm conclusion can be drawn due to data gaps and potential constituents similar to medium-chain phthalates, thus they are subject to further evaluation in ECHA.	• **No hazards or potential hazards were identified.** • It is recognized as the main alternative plasticizer.

Source: ECHA (2023).
Note: 1. PBT classifies substance or mixture that is Persistent (P), Bioaccumulative (B), and Toxic (T).

The availability of these viable, safer alternatives to LMW phthalates is deemed the most important prerequisite for successful substitution. Key replacements include terephthalates such as DOTP—the main alternative plasticizer, which is currently categorized as of no identified regulatory concern; and DINCH, one of the most popular non-phthalate plasticizers.

FIGURE 12 Overview of phthalates market shift from 2005–2020

EU phthalate market share, %

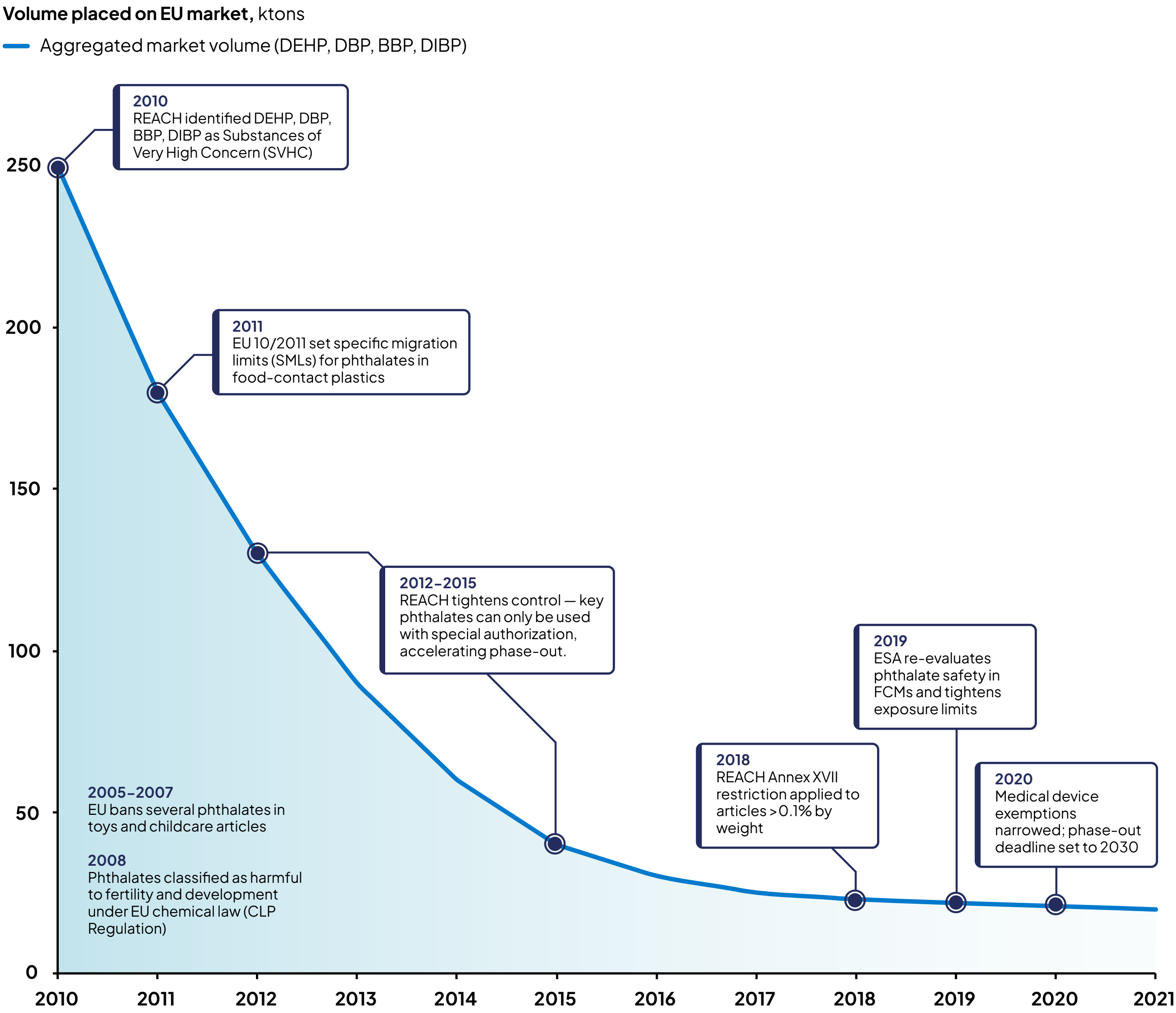


Source: Adapted from European Plasticizers Factsheet (2020).

What was achieved?

The results of this transition were dramatic. The volumes of phthalates subject to REACH authorization placed on the EU market were slashed by nearly 90% between 2010 and 2021.[65] Human exposure has fallen in parallel—biomonitoring data from Germany revealed a sharp decrease in urinary metabolites of DEHP, DBP, BBP, and DIBP between 2010 and 2021. Importantly, this shift was achieved without major commercial disruption: products remained available; no significant additional costs to end users were reported; and producer and user industries adapted well before the regulations formally required them to do so. Patent trends from the early 2000s support this picture: innovation in alternative plasticizers continued to accelerate after regulation was announced, supporting the hypothesis that industry will invest in substitutes when the direction of travel is clear.[66]

FIGURE 13 **Volumes of high-concern phthalates placed on the EU market were cut by ~90% within a decade, driven by regulation and corporate substitution**



Sources: European Chemicals Agency (ECHA) (2023).
Notes: The ~91% decline refers only to the five Annex XIV SVHC phthalates (DEHP, DBP, BBP, DIBP, diisopentyl phthalates), with DEHP comprising 96% of total tonnage in 2010. 2. Estimates based on ECHA + industry reports. Precise sectoral share data not publicly disclosed; these are approximations.

Remaining challenges

Outside the EU, however, regulation remains patchy. DEHP still accounted for around one-third of global plasticizer production in 2017, with much output concentrated in Asia.[67] Variations in regulatory approaches across regions present ongoing risks via imported goods and dilute the impact of regulation (e.g., in the EU).[68]

Moreover, substitution has not solved all concerns: HMW phthalates and newer alternatives like DINCH are now widely used, with some categorized as of medium concern as per ECHA's assessment.[69] Regular biomonitoring and toxicological investigations are advisable to monitor the risk of regrettable substitutions.[70] In general, assessments of the risks posed by different compounds simply reflect the extent to which clear evidence of severe toxicity has been confirmed in research—not that potential harm has been ruled out. Scientific understanding continues to evolve, and ongoing evaluations are essential. For example, emerging research has raised concerns that DIDP and similar HMW phthalates may pose greater risks to human health than previously recognized.[71,72] Classifications should thus be treated as provisional and should be regularly updated as new evidence becomes available. While these regulatory frameworks are helpful in providing clear guidance and timelines for phasing out the highest-risk substances, approaches that consider substances with shared structural and chemical characteristics (group-based restrictions) should also be considered.

In the EU, the use of DEHP is still permitted for sensitive applications—for example, medical devices like IV bags and blood tubes. However, ECHA's assessments indicate that cost- and performance-effective alternatives for medical uses are available today, so phaseout should be possible without disruption. In fact, in all medical applications, DEHP can be—and in some cases, has already been—successfully replaced by non-regulated alternatives.[73]

The phthalate case illustrates how strict regulatory deadlines can drive rapid substitution at manageable cost by providing investable certainty

Implications

The phthalates case demonstrates the effectiveness of the "redesign" and "substitute" tiers of the solutions hierarchy. Clear regulations and firm timelines in the EU have eliminated unnecessary uses of these substances (e.g., in toys and consumer products) and have forced cost-effective substitution in remaining uses. Furthermore, this experience illustrates how strict regulatory deadlines can drive rapid substitution at manageable cost by providing investable certainty. The surge in non-phthalate patenting by major global producers following EU action, as regulatory clarity mobilized investment in safer chemistries, underscores how regulation can stimulate innovation. Similar initiatives in other regions would bring major gains (see Chapter 4), cutting exposure to reproductive and metabolic toxic chemicals where they remain prevalent.

BISPHENOLS

Bisphenols: The next frontier

Toxic to reproduction

Endocrine disrupting

Persistent, bioaccumulative, toxic (PBT/vPvB)

Food system uses:

- **Coatings in food & beverage cans, jar lids, bottle tops**
- **Epoxy resins in food packaging**
- **Plastic containers, reusable bottles, food storage, utensils**

Other uses:

- **Polycarbonate plastics** (electronics, sports goods)
- **Thermal paper** (receipts)
- **Textile & leather finishing**

Why bisphenols matter

Bisphenols are a group of chemicals used primarily as building blocks for plastics and resins. The most prominent, BPA, is polymerized to produce polycarbonate plastics (used in bottles and food ware, including those intended for reuse, as well as equipment parts) and epoxy resins (used as protective linings for metal food cans, closures, and food-processing equipment). Although food contact uses represent less than 5% of total BPA production, they are the most critical to human health, as they account for 90% of infant and 66% of adult BPA exposure (see Figure 14).[74]

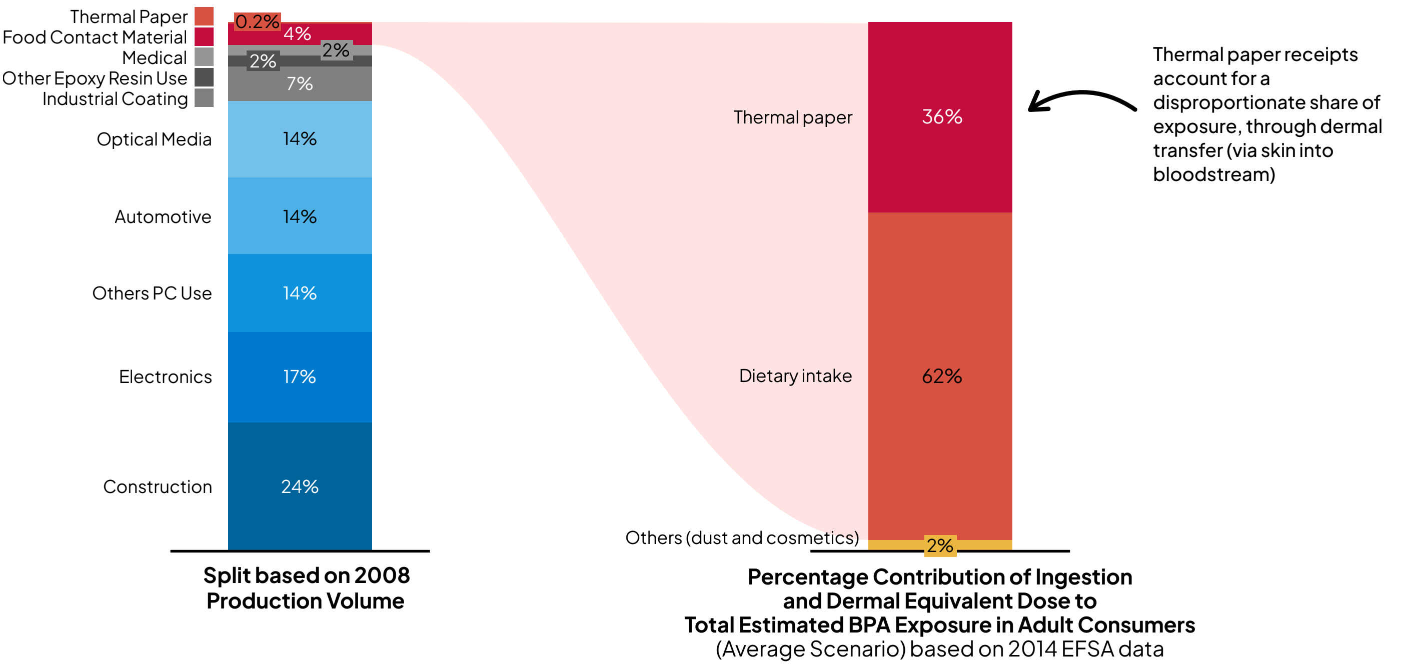
BPA and its common substitutes, such as bisphenol S (BPS) and bisphenol F (BPF), are endocrine disruptors, known to mimic estrogen. They have been found to increase the risk of immunotoxic responses (e.g., asthma and allergies), developmental neurotoxic effects, and female reproductive issues (e.g., abnormal ovarian development) later in life, even at extremely low levels of exposure.[75]

Although food contact uses represent less than 5% of total BPA production, they are most critical to human health

Regulatory and industry response

The EU has progressively restricted bisphenols, banning BPA in baby bottles in 2011, BPA in thermal paper in 2020, and both BPA "and other hazardous bisphenols or hazardous bisphenol derivatives" in all food contact materials in 2024.[76] Crucially, this latest regulation was preceded by a major shift in evidence evaluation: the European Food Safety Authority applied systematic review methods to reassess BPA, integrating the full body of available studies with transparent, bias-reducing protocols. This led to the tolerable daily intake of BPA being slashed by a factor of 20,000—a dramatic example of how systematic review can transform regulatory outcomes.[77]

FIGURE 14 **EU overview of bisphenol applications and drivers of average ingestion and dermal exposure in adults**[i]



Source: van Es (2014).

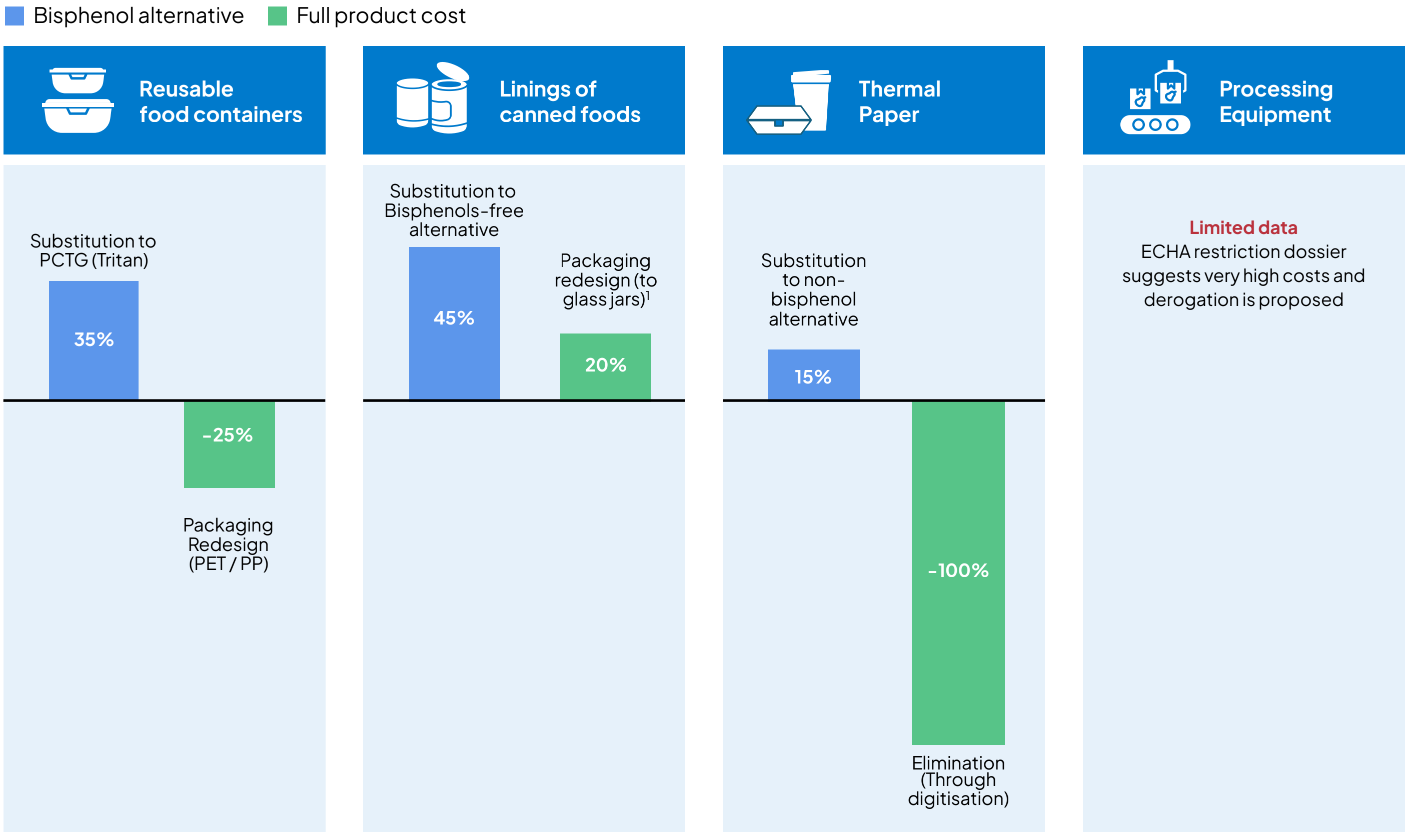
i. Figure 14 provides a high-level overview of BPA use in food-related applications and its contribution to overall adult exposure. The right-hand chart presents the estimated total equivalent oral dose for adult consumers (women and men aged 18–45) under an average exposure scenario. Estimates are derived from aggregated data in the Technical Annex. Total exposure is calculated by combining ingestion and dermal pathways, with dermal exposure converted to oral dose equivalents using physiologically based pharmacokinetic modelling.

Other regions have generally limited the regulation of bisphenols to uses in products for infants, most commonly banning BPA in baby bottles. Japan was an early mover, eliminating BPA in can linings through voluntary industry action in the early 2000s.[78] Industry has also responded: Campbell Soup Company, Nestlé, and Coca-Cola have transitioned to BPA-free linings; and retailers like Walmart and Tesco have pushed suppliers to do the same. Packaging leaders such as Crown Holdings and Ball Corporation have also adopted bisphenol-non-intent coatings, demonstrating that safe substitutes can reach commercial scale.

What was achieved?

Biomonitoring has confirmed that BPA exposure in the EU has fallen: German data reveals that levels of BPA metabolites have declined since 2005, even as production volumes have remained stable.[79] Market transitions also show that safer alternatives are commercially viable. In many cases, redesigns such as shifting from polycarbonate to PET bottles have even reduced costs (see Figure 15).

FIGURE 15 **Estimated material cost implications of the phaseout of bisphenols from the food system**



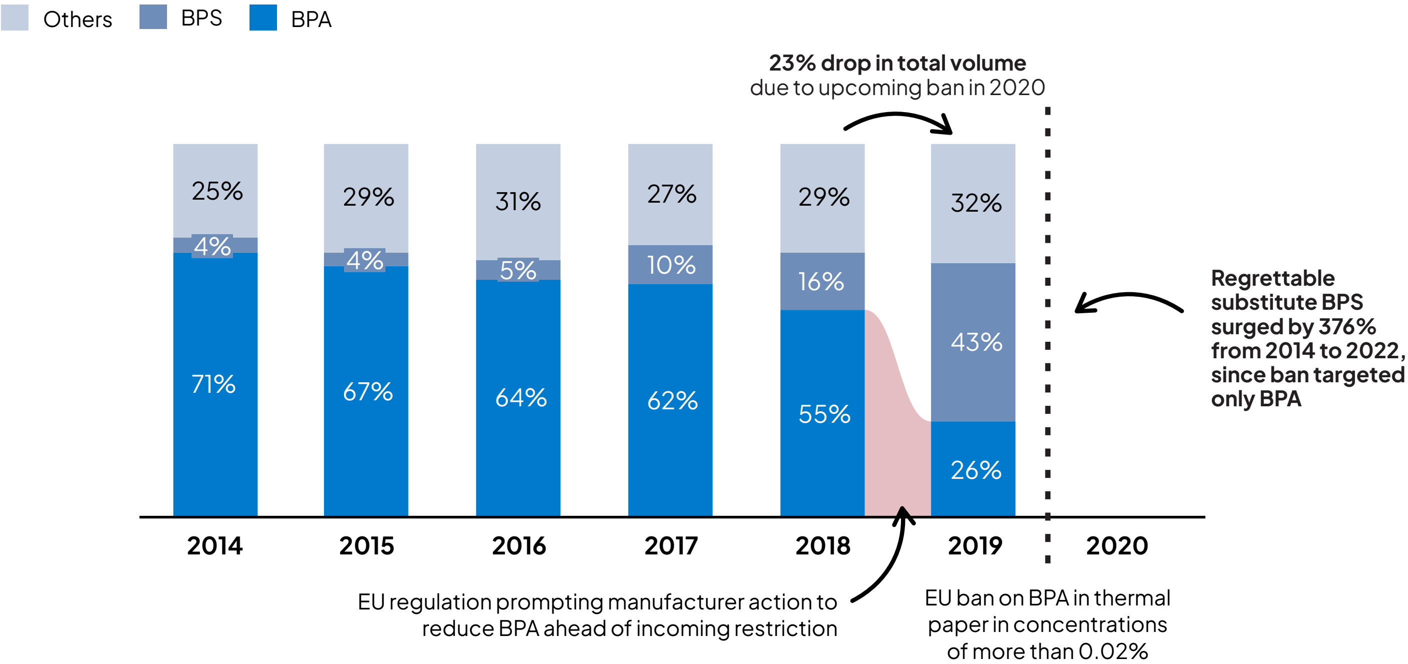
Source: Systemiq analysis based on Rulyda Plastic (2018);[80] Plasticker (2025);[81] PW Consulting Chemical & Energy Research Center (2025);[82] Packaging Digest (2015);[83] and van Es (2014).[84]
Notes: The costs of substitutes and redesign are not directly comparable. Substitutes are like-for-like replacements of bisphenols, whereas redesign options are relative to full container/receipt.
1. Based on beverage container cost for aluminum cans (which typically use BPA linings for coating) compared to glass container in the US and western Europe. Cost data taken from International Aluminium (2022).

Remaining challenges

The greatest risk is that of regrettable substitutions. As seen in Figure 16, many "BPA-free" products initially replaced BPA with BPS, which exhibits similar endocrine-disrupting effects. Technical challenges persist in certain high-performance uses, such as heavy-duty corrosion protection and large-scale processing equipment, where alternatives carry higher costs or involve performance tradeoffs. Some specialist applications, like polysulfide filtration membranes in dairy production, still lack viable substitutes and have been granted derogations (time-limited exceptions).

FIGURE 16 **Evidence of regrettable substitution from BPA to BPS in thermal paper**

Share of thermal paper manufactured in and placed on the EU market[i] in 2014–2019, %



Source: National Institute for Public Health and the Environment (2014); ECHA (2020).
Note: Placed on EU market by European Thermal Paper Association members.

Implications

The BPA case highlights the power of the "reduce," "redesign," and "substitute" tiers of the solutions hierarchy. Regulation has already eliminated the use of BPA in infant products around much of the globe, while the EU has gone furthest to restrict broader use in food contact materials. Redesign has shifted packaging formats away from bisphenols altogether (e.g., from polycarbonate to PET); and substitution has enabled BPA-free can linings to scale.

The EU's Food Contact Material Regulation, introduced in 2024, is a landmark instrument that will accelerate scaleup and drive innovation for further reductions, and that may catalyze similar restrictions globally. Importantly, the BPA case underscores the value of moving up the hierarchy to prioritize elimination at source, to avoid the risk of regrettable substitutions (e.g., the replacement of BPA with BPS and BPF). The slashing of the tolerable daily intake recommendation also demonstrates the importance of employing the best available methods to evaluate the full range of scientific evidence.

Together, these lessons point to the need for regulation that not only addresses individual substances but prioritizes source reductions and bans at the chemical group level, to secure lasting public health gains. Recognizing hazard at the group level also changes the risk calculus for firms and investors: laggards face potential stranded assets and brand damage, while innovators stand to capture expanding demand for safer solutions.

These lessons point to the need for regulation that prioritizes source reductions and bans at the chemical group level, to secure lasting public health gains

PESTICIDES

Pesticides: Moving to a low-toxicity system

Carcinogenic | Mutagenic | Toxic to reproduction | Skin sensitizing | Respiratory sensitizing | Endocrine disrupting | Persistent, bioaccumulative, toxic (PBT/vPvB) | Persistent Organic Pollutant (POP)

Food system uses:

- Crop protection: herbicides, insecticides, fungicides
- Seed treatments
- Post-harvest treatments
- Water/soil fumigation

Other uses:

- Vector control (mosquitoes, public health)
- Non-agricultural pest/weed control (gardens, forestry)
- Biocides, disinfectants

Why pesticides matter

Pesticides remain the most visible and widely used group of toxic chemicals in the food system. In 2023, nearly 4 million tons of active ingredients[i] were used in agricultural applications globally.[85] These inputs underpin modern agricultural systems but carry heavy health, ecological, and economic costs. Established health impacts of these diverse substances include impaired neurodevelopment (e.g., lowered IQ) and reduced sperm quality.[86] Suspected health impacts include increased susceptibility to childhood cancers, testicular cancer, and impaired fetal growth. Additional harms are linked to declining biodiversity and widespread contamination of soil and water.

Beyond volumes: the importance of toxicity

Measuring pesticide use in terms of volume alone gives only a partial picture of the consequent risks. Applying one liter of a highly hazardous substance has a far greater impact than applying an equal amount of a lower-risk product. To capture this, new assessment methodologies are emerging. The EU uses a simplified indicator framework that tracks active ingredient volumes across four categories— ranging from "low concern" to "banned"—to monitor progress toward non-binding targets, including a 50% reduction in the use of "more hazardous" pesticides by 2030.[87]

Globally, the Aggregate Total Applied Toxicity (ATAT) methodology has been developed as part of the Kunming-Montreal Global Biodiversity Framework. The aim is to halve the overall risk from pesticides and highly hazardous chemicals by 2030. By aggregating active ingredient volumes weighted according to a continuous scale of toxicity to eight key species, the ATAT methodology provides a more granular assessment of overall toxicity.[88] Both frameworks reveal that reductions in *toxicity* can be at least as important as reductions in *volume*. This is especially true in agricultural markets where pesticide intensity is relatively low, but the use of toxic pesticides banned elsewhere is widespread. It is also important to recognize that pesticide toxicity extends beyond target species. Off-target toxicity can affect a wide range of non-target organisms, with impacts varying considerably across species and ecosystems. This highlights the need for toxicity metrics and reduction strategies that integrate risks across trophic levels and ecosystems. For example, neonicotinoids were designed to target insects but have nonetheless been shown to have ecological and vertebrate impacts beyond their intended targets.[89]

While relative toxicity is critical, significant volume reductions are also needed. Using the simplified EU framework, we estimate an 80% risk reduction compared to 2022 would require a reduction in volume of between 54–75% (see the Technical Annex).[90] The uncertainty stems from the fact that not all EU member states are systematically reporting the volumes of banned active ingredients that have been granted approval for emergency use.[91]

Our MACC analysis (see "Assessing the potential scale of reduction and costs" below) focuses on volumes as a practical and comparable lens, while recognizing that this does not capture the full picture. Regulators, industry, and farmers should prioritize the phaseout of the most hazardous pesticides, while simultaneously supporting the development of less harmful, more targeted compounds. Importantly, toxicity concerns extend beyond active ingredients: in some cases, other substances such as adjuvants or formulants may be more hazardous than the active ingredients themselves.[92]

i. "Pesticide volume" in the following discussion always refers to volume (tons) of active ingredients.

Greater visibility on the relative toxicity of different active ingredients and compounds will strengthen incentives for companies to act. Comparable metrics could enable civil society, investors, and policymakers to scrutinize corporate practices, rewarding companies that proactively eliminate the most hazardous compounds from their portfolios. A first step for producers is to understand exposure across their product lines—requiring transparency from suppliers and additional testing where necessary. Frameworks such as the World Business Council for Sustainable Development's (WBCSD) Portfolio Sustainability Assessment provide practical tools for this purpose, helping chemical producers identify and prioritize high-risk products for phaseout.[93] Chemical producers in particular should assess their entire product ranges, including both actives and additives, to identify candidates for phaseout.

This dual focus—reducing both overall volumes and toxicity—points toward a transition to fewer, safer, more targeted pesticides, aligned with a broader shift toward yield-optimized, service-based farming models. Combining toxicity and volume considerations is essential to reduce pesticide use in a way that delivers better environmental and health outcomes without compromising food security.

Combining toxicity and volume considerations is essential to reduce pesticide use in a way that delivers better environmental and health outcomes without compromising food security

Available reduction pathways

Practical solutions that can deliver large-scale pesticide reductions are available today. Precision agriculture enables farmers to apply pesticides only where needed, replacing blanket spraying with targeted spot application. Conventional precision tools—such as GPS-guided sprayers and variable-rate technology—are already helping to optimize pesticide use. Meanwhile, emerging systems that combine AI, machine vision, and advanced application hardware—from camera-guided boom sprayers to drones—can achieve reductions of up to 80-90%.[94] When supported by equipment-sharing schemes and advisory services, these approaches can substantially lower spraying volumes, stabilize yields, and reduce operating costs for farmers. IPM focuses on redesigning farming practices, combining crop rotation, cover crops, biological controls, threshold spraying and more to suppress pest cycles before they take hold. Evidence shows that IPM can substantially reduce pesticide dependence with relatively modest changes to farming practices and costs; and although some measures (e.g., crop rotation) may cause short-term yield declines, these are often offset over time by yield stabilization, quality gains, and reduced input costs. Substitution also plays a role. Among other types of safe alternatives, biopesticides—made from microbes, fungi, or plants such as neem—are increasingly competitive with synthetics. They are often effective against specific pests and as production is scaled up, their costs will fall. Finally, organic farming demonstrates that production without synthetic pesticides—relying instead on natural or biological alternatives—is technically possible. However, while organic farming can be profitable for individual farmers where markets offer a premium, it typically entails lower yields and other system costs (e.g., increased tillage) which must be considered alongside the reduction in toxicity—particularly if the lower yields put pressure on land elsewhere.

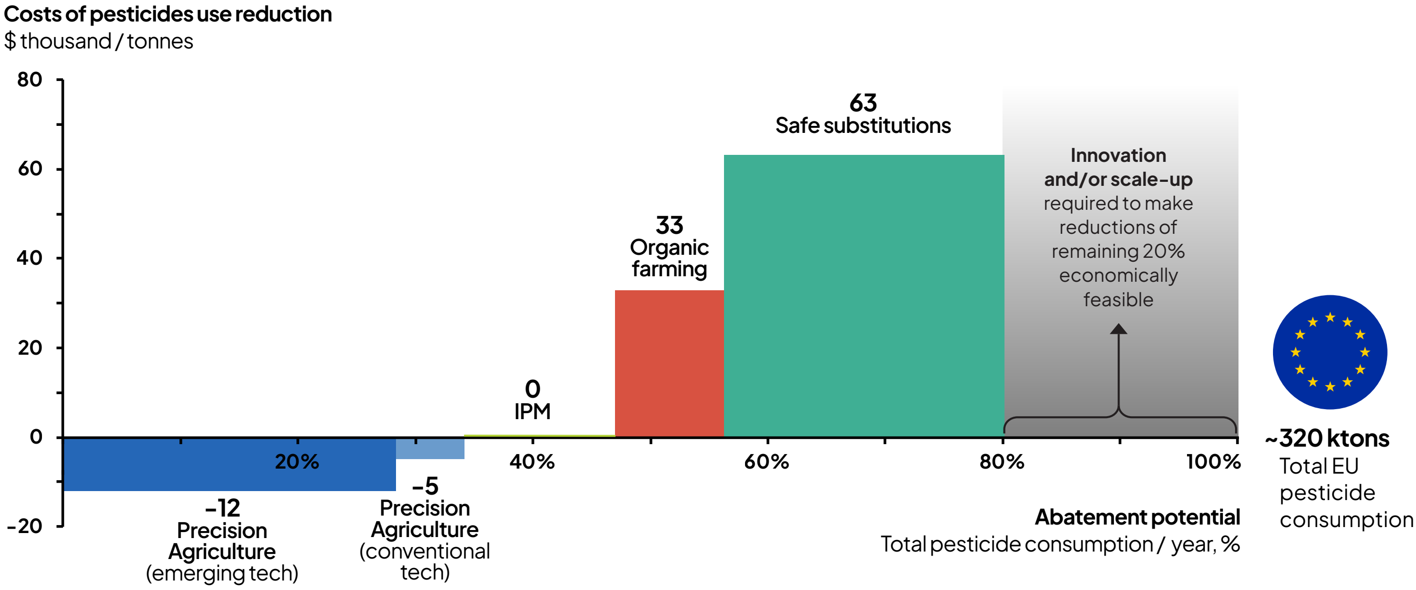
Assessing the potential scale of reduction and costs

The scope for reducing pesticide use—and the associated costs—depend on local agronomic, ecological, and economic conditions, as well as the scale and maturity of available technologies. The types of pesticides applied (herbicides, insecticides, or fungicides), the extent of current precision agriculture and IPM use, and adoption rates of organic farming or safe substitutes all determine what is currently feasible. Factors such as crop mix, farm size, economics, and farmer behavior strongly influence the speed and scale at which these solutions can be implemented. Each solution also delivers a specific reduction potential, depending on its technical efficacy and the conditions under which it is applied. To reflect this, we analyzed distinct reduction pathways for the EU, Brazil, and India, each based on region-specific data and assumptions on pesticide intensity, technological efficacy, and adoption rates (see the Technical Annex).

In the EU, synthetic pesticide use could feasibly decline by up to 80%. Note that this is distinct from the existing non-binding EU target of a 50% reduction in the use and risk of chemical pesticides, which weights active ingredient volumes according to their estimated risks[95] (see "Beyond volumes: the importance of toxicity" above). The MACC (Figure 17) shows nearly half of this reduction is achievable with net savings through precision agriculture and IPM. Adding organic farmland delivers a further ~10% reduction by expanding current adoption from 10% to the EU target of 25%,[96] though at a higher system cost due to yield gaps. Safe substitutions could replace another ~25%, with any further reductions dependent on market growth, the wider adoption of existing measures, and innovation in next-generation technologies (see below).

FIGURE 17 **MACC for pesticide reduction in the EU**

Volume reduction of up to 80% is feasible—about half achievable with net savings through precision application and IPM

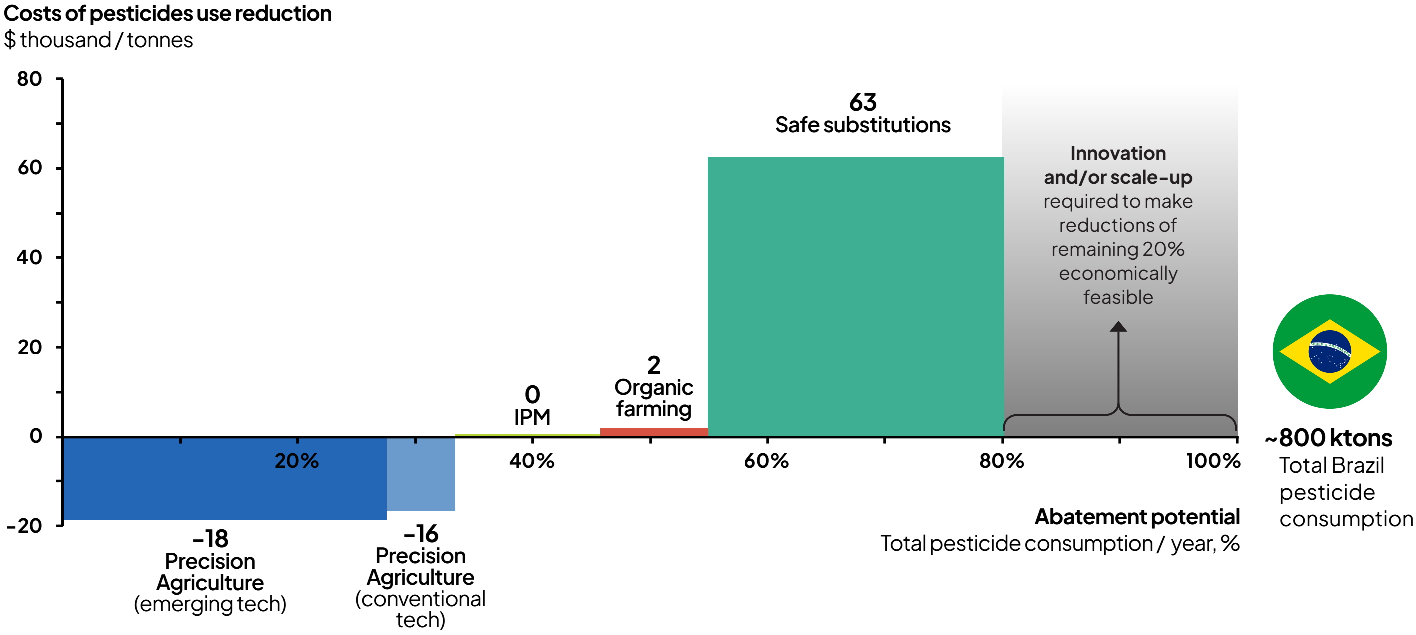


Source: Systemiq analysis (see the Technical Annex for details).
Note: IPM costs are set to zero to ensure the analysis remains generalisable across diverse farming contexts. In practice, IPM performance is highly context-dependent (crop type, regional conditions, specific measures used, implementation quality), yet evidence shows that holistic IPM programmes often become cost-neutral or cost-saving over time.

In Brazil, our analysis suggests a different picture. Pesticide-focused precision agriculture is starting from a much lower base, which will slow near-term reductions from this technological option. However, pesticide intensity is higher per hectare and farms are generally larger, making precision tools, organic farming, and IPM comparatively more effective and cost competitive compared to the EU once adoption has been scaled up. Organic farming can also play a role, though the target is lower than in the EU given the crop mix and the smaller domestic market for organic produce. A more realistic pathway may be to focus organic expansion on cash crops for export, where premiums can offset yield gaps. As precision agriculture, IPM, and organic farming combined account for a smaller share of reductions than in the EU, Brazil must rely more heavily on safe substitutions to approach an 80% reduction—making the overall pathway costlier but also aligning with Brazil's leading position in the adoption of biopesticides (see further below).[97]

FIGURE 18 **MACC for pesticide reduction in Brazil**

Volume reduction of up to 80% through large-scale precision technology and bio-based substitutes



Source: Systemiq analysis (see the Technical Annex).
Note: Rather than calling out via arrow, would instead add a Note: Costs for IPM are set to zero. Reported IPM costs and benefits are highly context-dependent (crop, region, bundle of measures, implementation quality), but can generally be cost effective / saving.

For India, a volume-based MACC is not considered meaningful because overall pesticide intensity is already very low—around 20 times lower than Brazil;[98] instead, the key risks stem from pesticides that are hazardous, persistent, or banned elsewhere but are still in widespread use. With small and fragmented landholdings (averaging ~1 hectare)[99] and a high share of agricultural labor,[100] precision technologies are both economically and technically unfeasible in the near term; equipment-sharing models are hard to establish; and dominant crops like rice do not lend themselves to spot-spraying systems designed for large row crops. Given this structural context, the most practical pathway for India focuses on reducing toxicity rather than volume, primarily through IPM adoption and the gradual uptake of safer chemical and biological substitutes. Yet despite decades of promotion, IPM is applied on just 3–5% of cultivated land, indicating substantial scope for toxicity reduction.[101] In this setting, the transition will be labor intensive and knowledge driven, and the levers that will drive large volume reductions in the EU or Brazil will play a far smaller role.

The above examples illustrate how reduction potential and costs are shaped by local circumstances and dynamics. In Europe, deep reductions can be achieved with net savings, with challenges concentrated on the remaining 20% share of pesticide use for which scalable alternatives are lacking. In Brazil, a lower adoption rate of precision agriculture combined with higher pesticide intensity and larger farms shifts the balance: here emerging technologies, IPM, and organic farming are relatively more cost effective, but safe substitutions more important and costly. India, by contrast, points to a labor-intensive and toxicity-focused pathway, where IPM and safe substitutions play the central role—a trajectory likely mirrored in other smallholder-dominant regions.

Across all regions, the final share of pesticide use remains the hardest to replace. Precision agriculture can reduce blanket spraying but cannot eliminate pre-emergence herbicide use;[i] and while biopesticides could in theory substitute further, technologies are still maturing and production must be scaled. A complete phaseout is therefore unlikely in the near term, although gradual substitution with bio-based alternatives will continue as innovation accelerates (see "Unlocking change" below). Overall, significant reductions in pesticide-related toxicity and exposure are technically feasible worldwide, but the balance of solutions—and the underlying economics—will vary. This underscores the importance of tailoring approaches to national contexts while investing in innovation, regulation, and market development to close the gap where conventional tools cannot yet deliver.

Significant reductions are technically feasible worldwide, but the balance of solutions—and the underlying economics—will vary

i. Pre-emergence herbicides are applied to the soil before weeds sprout, stopping seeds from germinating and young shoots from growing. They act preventively to control weeds before they appear.

Why solutions have not yet been widely adopted

The main obstacles are not technical but systemic. Farmers operate under tight economic conditions and thus have less scope and appetite to test out unfamiliar practices that could affect yields and income. Many view new approaches as complex or risky—an understandable response given limited time, resources, and support to manage additional uncertainty. Moreover, agronomic advisory services often remain tied to input sales, reinforcing reliance on conventional practices. For example, while IPM has been a proven and profitable approach for decades, agrochemical companies have little incentive to promote alternatives that would cut into their core business. Yet even in places where IPM is well understood, adoption is often modest due to perceived yield risks, uncertainties about pest control effectiveness, and the greater management effort required.[102] Precision agriculture faces multiple barriers, such as high upfront investment, uncertain returns, connectivity issues, data and skills gaps, and a lack of interoperability across equipment and platforms.[103,104,105] These all constrain uptake, especially for small- and medium-sized farms. For safe substitutions, market volumes remain too low to achieve economies of scale, keeping prices high; moreover, many biological alternatives are more targeted or less durable than synthetic pesticides, and thus not like-for-like replacements.[106] Organic farming, while technically feasible, continues to face adoption challenges due to lower yields and associated opportunity costs, which can be offset only where consumer demand supports price premiums—a pattern that differs sharply by region.[107]

Public policies often exacerbate these problems. Subsidies tend to reward production volumes or areas (e.g., the Common Agricultural Policy in Europe), rather than the provision of societally desirable farming practices or outcomes; and the rollout of financial instruments such as taxes or EPR schemes for pesticides or quantitative caps on production and use has been slow. The same misalignment is evident in financing and crop insurance systems—particularly in the US, where the broader agricultural policy and data infrastructure perpetuate conventional production models. Commodity price data, yield metrics, futures markets, and crop insurance form a self-reinforcing network that privileges high-input, short-term yield maximization over long-term resilience.[108] Within this system, coverage and credit access are often tied to standardized management practices and conventional input use. Farmers who adopt alternative approaches—such as reduced spraying, crop diversification, or precision application—risk losing insurance eligibility or favorable financing terms, especially when insurance and credit services are bundled with agrochemical inputs and offtake agreements controlled by the same actors. Without a shift in incentives and business models, the adoption of existing solutions will remain patchy. For instance, by integrating precision application or proven IPM strategies into "good farming practice" criteria, crop insurance could instead become an enabler of transition toward more sustainable systems.

Picture credit: Carbon Robotics

Unlocking change

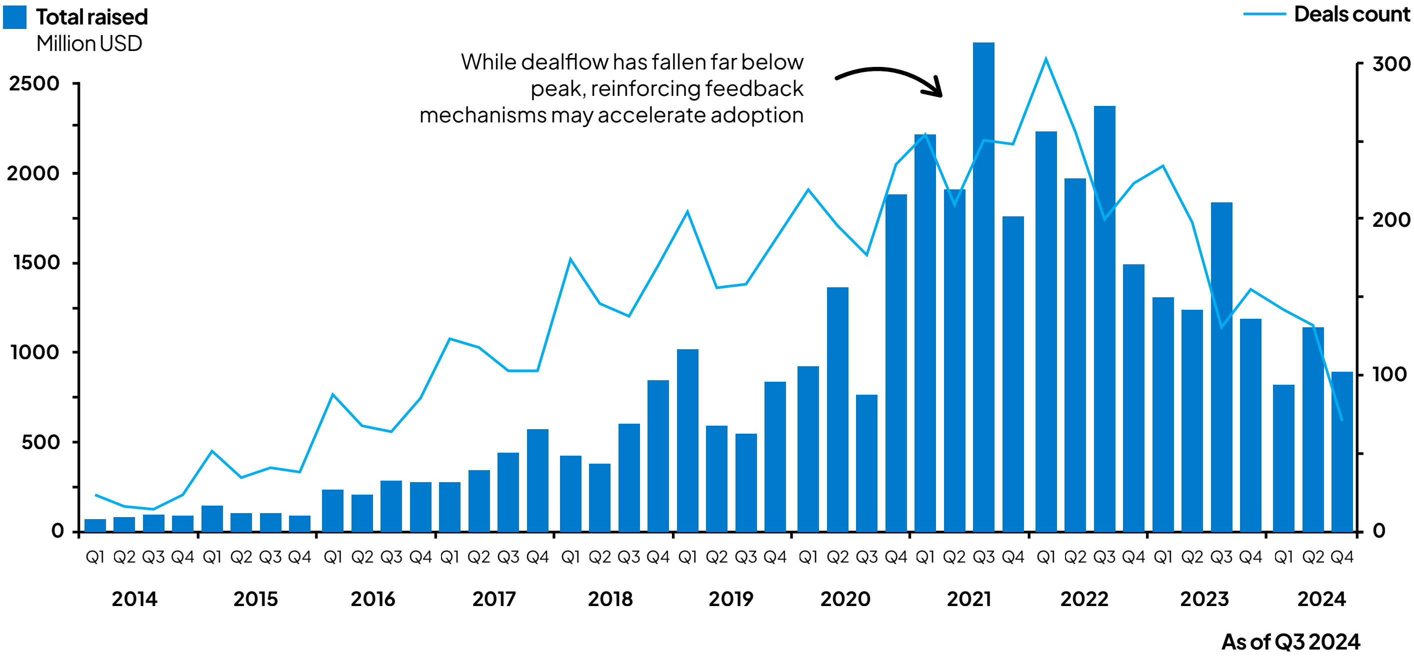
However, many of these barriers can be overcome as innovation accelerates and markets mature. Substitution technologies, in particular, are advancing rapidly: biopesticides have been growing at double-digit rates (~14% annually) and now represent around 10% of the global pesticide market by value, with Brazil leading the way.[109] This trend is being driven by improved returns on investment, tighter restrictions on chemical pesticides, and a growing need to tackle pesticide resistance and residue management.[110] Combined with AI and machine learning, new omics technologies—high-throughput methods used to analyze biological molecules on a large scale—are further accelerating innovation in this space, increasing discovery hit rates by an order of magnitude and shortening development cycles for next-generation bio-based products. In the

EU, the substitution share modelled in the MACC (see Figure 17) could be achieved by the mid-2030s if the growth rate seen between 2011 and 2022 is maintained.[111]

Aware that precision agriculture could dramatically change their business model, agrochemical firms have made significant investments in startups and joint ventures in this field. However, this enthusiasm has waned in recent years, alongside a wider dip in funding for agricultural technologies (see Figure 19), as the prospects for large-scale commercialization remain uncertain—even though adoption on farms is steadily increasing. This is consistent with a broader pattern seen in other transitions: new solutions often encounter dampeners that slow momentum after an initial surge of interest, even as reinforcing feedback mechanisms quietly build in the background. Transitions rarely follow a straight line, and temporary slowdowns can precede rapid acceleration once solutions become sufficiently affordable, attractive, and accessible to promote rapid adoption and diffusion.[112] In the case of precision agriculture, advances in AI and greater standardization and integration across tools and platforms may create the feedback loops needed to unlock this next wave of adoption and shift the sector onto a steeper S-curve.

Advances in AI, greater standardization and integration may create the feedback loops needed to unlock this next wave of adoption and shift the sector onto a steeper S-curve

FIGURE 19 **Agricultural technology venture capital deal count and total raised by quarter, 2014–2024[113]**



Source: Adapted from THRIVE Agrifood (2024).

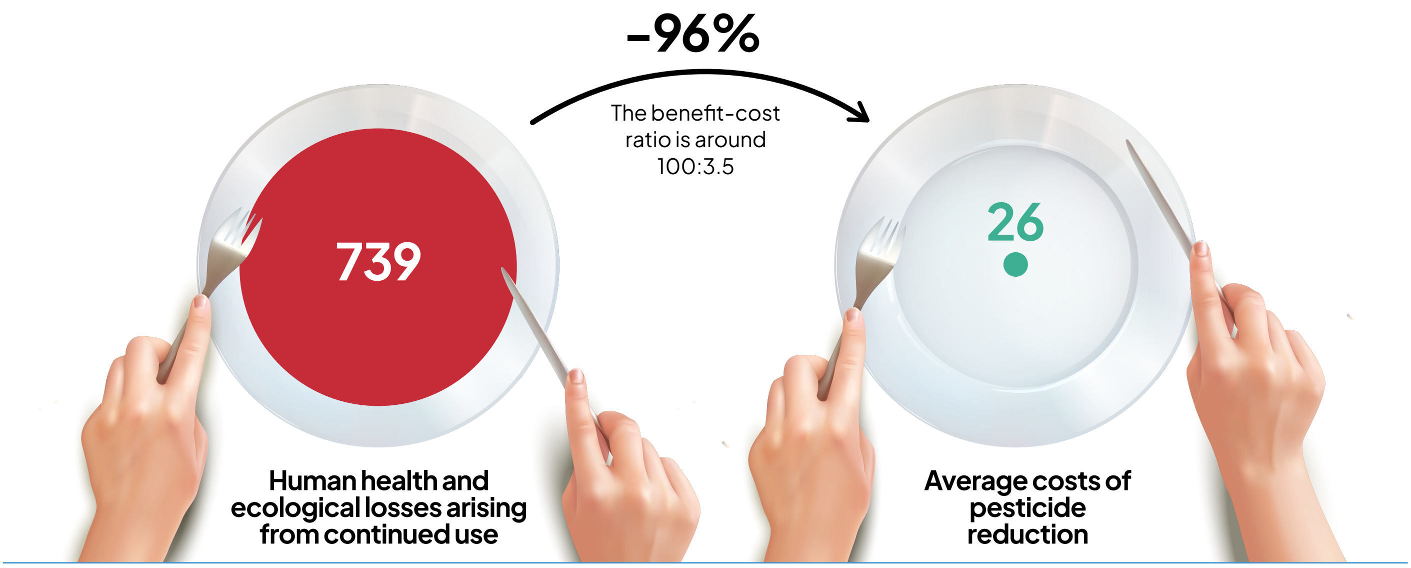
One path forward is to shift from selling inputs to providing services, aligning revenues with farmer outcomes rather than input volumes. A "clean field" (i.e., pest free) or "yield optimization" model could integrate precision tools, IPM practices, and agronomic advice into bundled offerings for farmers. Agrochemical firms and intermediaries such as agricultural retailers are already selling packages that combine commoditized inputs (e.g., pesticides, fertilizers) with value-added services (e.g., advice, digital agronomy). While financial statements do not routinely distinguish revenues and margins from novel digital service activities, the accompanying narratives suggest digital-enabled services are enhancing margins—albeit accounting only for a small share of current revenues.[114,115,116,117,118] Turning the traditional logic on its head, agricultural solutions providers could deepen their collaboration with farmers to maximize yields under a fixed-price or performance-based subscription model. This would incentivize them to deliver "clean fields" or maximize yields while minimizing costly inputs. If major agrochemical players pivot toward such outcome-oriented services, these packages could reach mainstream producers at scale. Independent advisory systems, targeted public funding to expand precision agriculture to underserved farm and crop types, and reforms to agricultural support schemes could further accelerate this transition.

Benefits of reduction

Our analysis reveals that significant reductions in synthetic pesticide use are technically feasible in regions such as the EU and Brazil, though with distinct cost profiles and transition pathways. In total, the sums needed to fund the transition are estimated at around $5 billion per year for the EU and $17 billion per year for Brazil. Although these headline costs appear high, they are largely driven by the early-stage market prices of bio-based substitutes (see Figures 17 and 18), which are expected to fall sharply as production scales, regulations streamline, and markets mature. When viewed against the costs of inaction, the picture changes dramatically: in the EU, current human health and ecological losses from pesticide use are estimated to exceed $700,000 per ton of pesticide applied, compared to an average reduction cost of just $26,000 per ton (Figure 20). This makes the transition not only technically viable but economically justified when externalities are accounted for. The regional analysis did not allow us to compute the costs of inaction for Brazil specifically, but the same rationale applies: what appears costly today represents the early phase of a cost curve that will bend sharply downward as safer alternatives reach scale and is a mere fraction of the cost of inaction.

FIGURE 20 **Comparison of harms from inaction and pesticide reduction costs in the EU**

Costs per volume of pesticide, thousand $ / tonne



Moreover, reducing pesticide dependence will deliver benefits well beyond avoided harms. A decline in cancers, metabolic diseases, and neurodevelopmental disorders will alleviate human health burdens. Ecological resilience will strengthen as pollinators and natural pest predators recover, reducing long-term pest pressure. Soil health will improve, enhancing carbon sequestration and delivering climate and biodiversity co-benefits through regenerative practices. Economically, farmers will be less vulnerable to price volatility and resistance spirals, bolstering the security of the food system.

Implications

The pesticides case demonstrates the feasibility of deep reductions at net economic benefit. In the EU, an 80% cut in synthetic pesticide use by 2040 is realistic with today's tools, provided the right incentives, advisory systems, and regulatory frameworks are in place. The pesticides case encompasses the full solutions hierarchy: reductions and redesign deliver the lion's share of gains; substitution and organic farming add depth; and innovation will be essential to reach the hardest final 20%. By realigning incentives and reshaping the business model of farming, countries can break free of the toxicity trap and deliver safer, more resilient food systems.

PFAS

PFAS: An intergenerational challenge

Carcinogenic

Toxic to reproduction

Endocrine disrupting

Persistent, bioaccumulative, toxic (PBT/vPvB)

Persistent Organic Pollutant (POP)

Food system uses:

- Grease- and water-repellent coatings in food packaging
- Non-stick cookware
- Processing equipment with grease/water exposure
- Some pesticides

Other uses:

- Textiles & outdoor gear
- Firefighting foams
- Industrial coatings, lubricants
- Electronics, semi-conductors
- Aerospace, automotive, medical devices

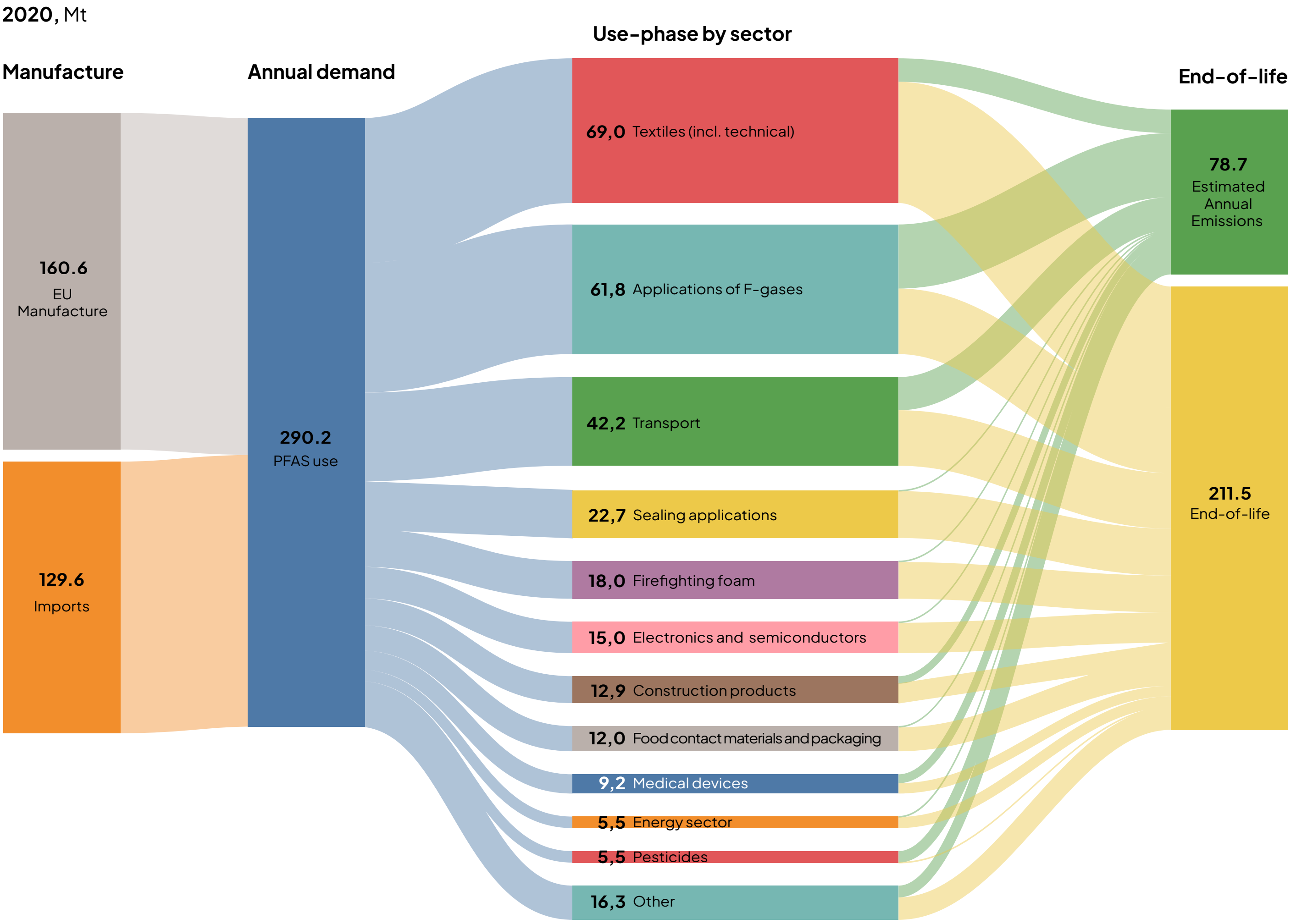
Why PFAS matter

PFAS are a family of nearly 15,000 synthetic chemicals[119] with properties including water and oil repellence, chemical resistance, thermal stability, and friction reduction. These qualities explain their widespread use in applications ranging from food contact materials and textiles to aerospace, electronics, and medical devices (see Figure 21 for an illustration of 2020 EU use volumes and emissions across industries). But they come at the cost of extreme persistence and toxicity. PFAS do not degrade significantly in the environment or the human body.[i] As a result, they accumulate in the environment, and many biomagnify in the food chain, creating a mounting exposure legacy. Studies around the globe have revealed that PFAS concentration in rainwater exceeds levels considered safe for drinking water.[120] Even if all PFAS use stopped tomorrow, concentrations in ecosystems and people would remain high for decades or centuries. Regulatory cost-benefit assessments risk systematically undervaluing the harms of such extremely long-lived substances, as they typically use a 30-year horizon for comparability.[121]

Around the globe PFAS concentration in rainwater exceeds levels considered safe for drinking water

Because PFAS are so persistent, eliminating their use is the only viable strategy. At end of life, PFAS embedded in products almost inevitably turn into emissions—for example, municipal waste incinerators in the EU typically operate at ~850°C, below the 1.050-1.400°C range needed for complete breakdown. Studies show that at lower temperatures, PFAS can transform into other fluorinated PFAS compounds, including fluorinated gases and acids such as trifluoroacetic acid, which is widely detected in rainwater globally.[122] Given our current understanding, there is no realistic prospect of large-scale cleanup (e.g., of river systems or fields) and the estimated remediation costs exceed global GDP.[123]

FIGURE 21 **PFAS manufacture and major PFAS use sectors in the EU[124]**



Source: Systemiq analysis based on ECHA (2025).
Notes: Mid estimates. Emissions include estimated annual use phase emissions, including from technical stock for F-gases and transport. End-of-life fate likely represents emissions due to persistence and stability.

i. Technically, the carbon-fluorine bond characteristic of PFAS does not break down at all. However, some PFAS can break down into shorter PFAS in the environment over time. Persistence in organisms (including humans) can vary significantly across different types of PFAS.

PFAS are deeply embedded in the food system. Direct exposure occurs through food contact materials such as greaseproof packaging, non-stick coatings, and processing equipment. However, we estimate that only ~20% of PFAS exposure comes directly from food contact applications, with indirect dietary exposure accounting for the vast majority (~80%) via contaminated air, soil, and water (see the Technical Annex for details).

FIGURE 22 **Estimated PFAS dietary exposure pathways**

Estimated PFAS dietary exposure pathways, %

of PFAS dietary exposure comes from **contaminated water and soil leading to bioaccumulation in raw food**

of PFAS dietary exposure comes from **contamination through food contact materials**

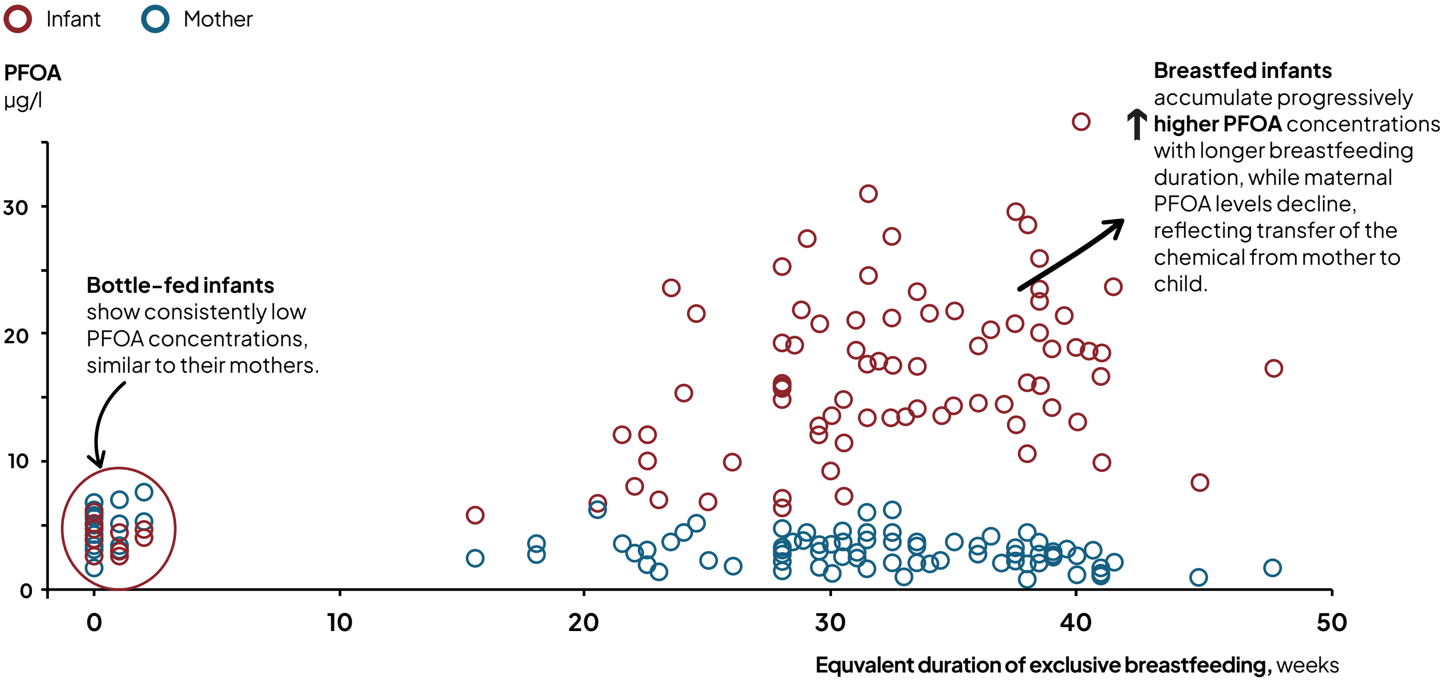
Source: Systemiq analysis (see the Technical Annex for details).

The health impacts are serious and cross-generational. Systematic reviews and authoritative bodies have found sufficient evidence linking multiple chemicals of this group with an increased risk of adverse health outcomes, including reduced fetal growth, dyslipidemia, a decreased antibody response to vaccines, and an increased risk of kidney cancer.cxxiii In addition, there is limited suggestive evidence of heightened risks of breast and testicular cancer, and thyroid disease and dysfunction. Of particular concern is intergenerational transfer: PFAS such as PFOA pass from mothers to fetuses and infants, with infant blood levels rising sharply during breastfeeding as maternal levels decline (Figure 23).[126] High levels of PFOA reduce the immune response to vaccines in children. This means new generations begin life with elevated chemical loads, entrenching exposure over time and leading to material health effects.

New generations begin life with elevated chemical loads, entrenching exposure over time and leading to material health effects

FIGURE 23 **Levels of PFOA in one-year-olds and mothers in relation to duration of exclusive breastfeeding**

Levels of PFOA in 101 healthy 1-year-old children and mothers in relation to duration of exclusive breastfeeding



Note: While these findings are concerning, the overall health benefits of breastfeeding are still considered to outweigh the risks of PFAS exposure.

Source: Adapted from Wee et al (2023).

Regulatory and industry response

Regulation is advancing but remains fragmented. Many countries and US states, as well as the UN Stockholm and Rotterdam Conventions, have imposed bans or limits on specific PFAS compounds, often in consumer goods or packaging. Yet this chemical-by-chemical approach is easily outpaced by industry substitutions: as individual PFAS are restricted, other variants enter the market. Regrettable substitutions have been the norm—for example, there was a shift in the 2000s from the original long-chain PFAS to short-chain PFAS, which have been found to pose similar hazards.[127]

The EU has been taking steps to introduce the world's first universal PFAS restriction, covering the entire group and all major uses, with entry into force expected before 2030. ECHA recently announced that the restriction will exclude eight use sectors that were not considered within the original proposal, due to time and resource constraints.[128] The remaining uses still account for 90% of PFAS emissions and volume in Europe. At present, the timeline for the other sectors is unclear. Nonetheless, this landmark measure marks a systemic break from the piecemeal regulation that has hitherto prevailed. The draft restriction includes time-limited exceptions of up to 13.5 years for certain applications.[i] Such clear regulatory timelines are critical to provide market signals that will lower costs by driving adoption, scaleup, and innovation in areas where solutions are not yet available. However, given the persistence of PFAS, decade-long delays in some phaseouts and the initial exclusion of eight sectors will still translate into prolonged harm.

The levels of industry progress in phasing out PFAS are as diverse as their uses across the economy. Food packaging and consumer goods firms have successfully eliminated PFAS in response to regulation in selected markets or to protect brand reputation and avoid litigation. In contrast,

i. This applies to main uses. Minor exemptions for some spare parts and recycled plastics (outside of food contact applications and toys) are proposed for 20 and 23.5 years after entry into force, respectively.

sectors with more complex performance demands—such as transport, electronics, and medical devices—have been slower to respond, citing technical barriers and uncertainty. Supply chain opacity compounds the problem: many downstream users are unaware that PFAS are present in components, making substitution difficult without stricter disclosure requirements.

Reduction pathways available today

The following discussion presents a high-level assessment of the reduction potential and associated costs, largely based on evidence gathered as part of the ECHA restriction proposal. To provide a more detailed assessment of the economic case for phaseout across industries and specific uses, we plan to conduct a follow-on project with ChemSec and its PFAS Movement—a cross-industry coalition of over 120 companies committed to phaseout. This will assess credible and practical pathways, sector by sector, and quantify the costs of substitution. If you would like to contribute to this effort, please reach out via toxics@systemiq.earth.

Ultimately, the EU restriction aims to cover all major PFAS uses, despite the initial exclusion of eight sectors due to time and resource constraints. Therefore, we assessed the PFAS reduction potential and associated costs across 10 major use sectors, including two that fall within the initially excluded sectors: textiles, fluorinated gases, transport, sealing applications, electronics and semiconductors, construction, food contact materials, medical devices, energy, and technical textiles (in order of estimated use volume). Together, these accounted for 92% of EU consumption in 2020.[i] As data on PFAS use outside Europe is limited, we assume broadly similar use patterns globally, though practices and dynamics may differ across regions.

Assessing the potential scale of reduction and costs

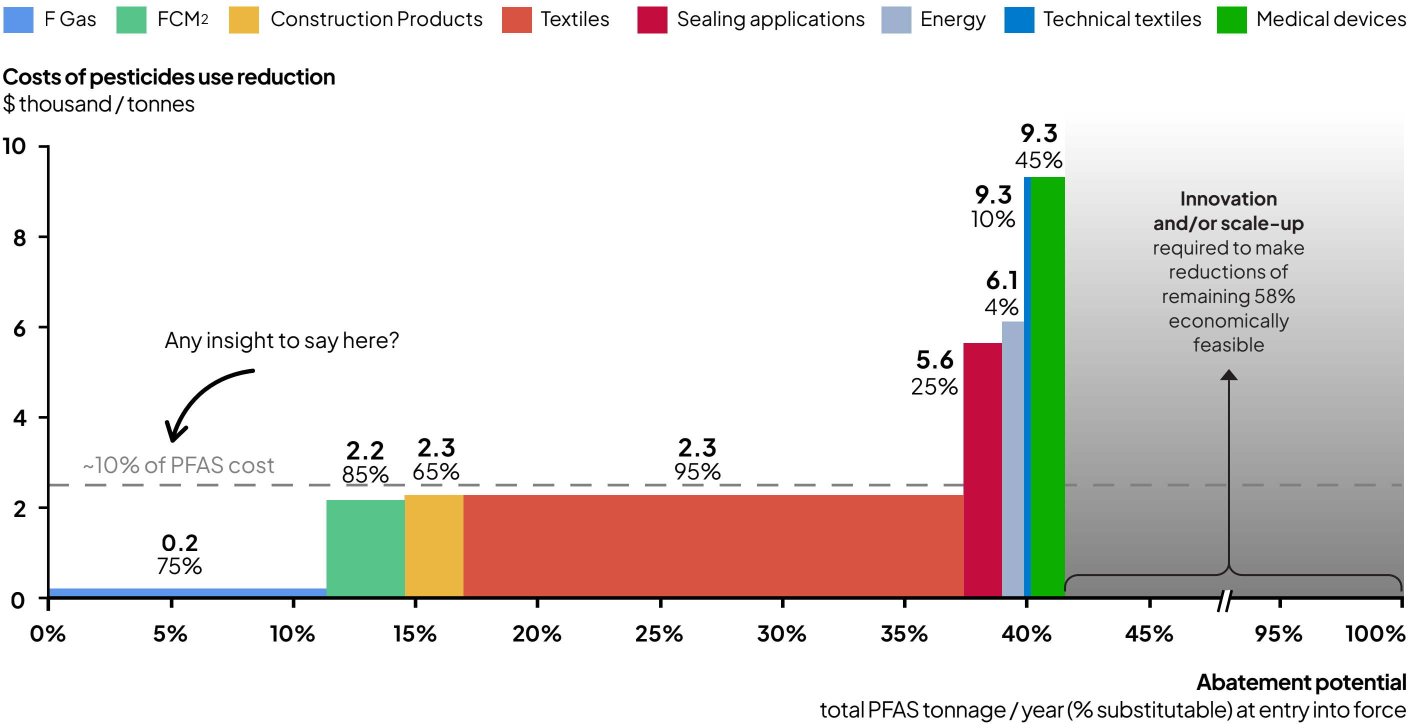
PFAS reduction potential by 2030 differs widely across the 10 sectors (see Figure 24). Overall, in uses accounting for 42% of volume, substitution is already feasible. Specific uses in fluorinated gases, textiles, food packaging, and construction products all have cost-effective alternatives that can replace PFAS without major performance or cost tradeoffs. In these sectors, rapid phasedown is possible with clear regulatory timelines.

In the remaining 58%, however, solutions for reducing PFAS use are currently less proven. Materials used in critical sectors such as transport, electronics, energy, and medical devices demand high performance across a combination of properties. For these applications, PFAS remain difficult to replace at scale without compromising safety or performance. Crucially, this is even more reason to enact clear, time-bound phaseouts to catalyze innovation. Experts within these sectors are increasingly calling for action, not delay. For instance, over 150 medical professionals sent a letter to the European Commission rejecting the justification of continued PFAS use on the grounds of “patient safety,” stating “the only effective way to protect EU citizens from PFAS exposure is to stop all PFAS use”.[129]

i. This figure includes volumes for firefighting foams, which are covered under a separate ECHA restriction but were excluded from the MACC due to a lack of comparable data. Unfortunately, the ECHA proposal excluded pesticide-related uses, so an assessment as part of the MACC analysis was not possible. See the Technical Annex for further details.

FIGURE 24 **PFAS MACC at the level of 10 major use sectors**

MACC for PFAS phase-out in the EU; 42% reduction at $464M total cost[1,3]
$1000/year, based on EU annual tonnages from major PFAS use sectors[4] in 2020 under the mid estimate and growth to 2030

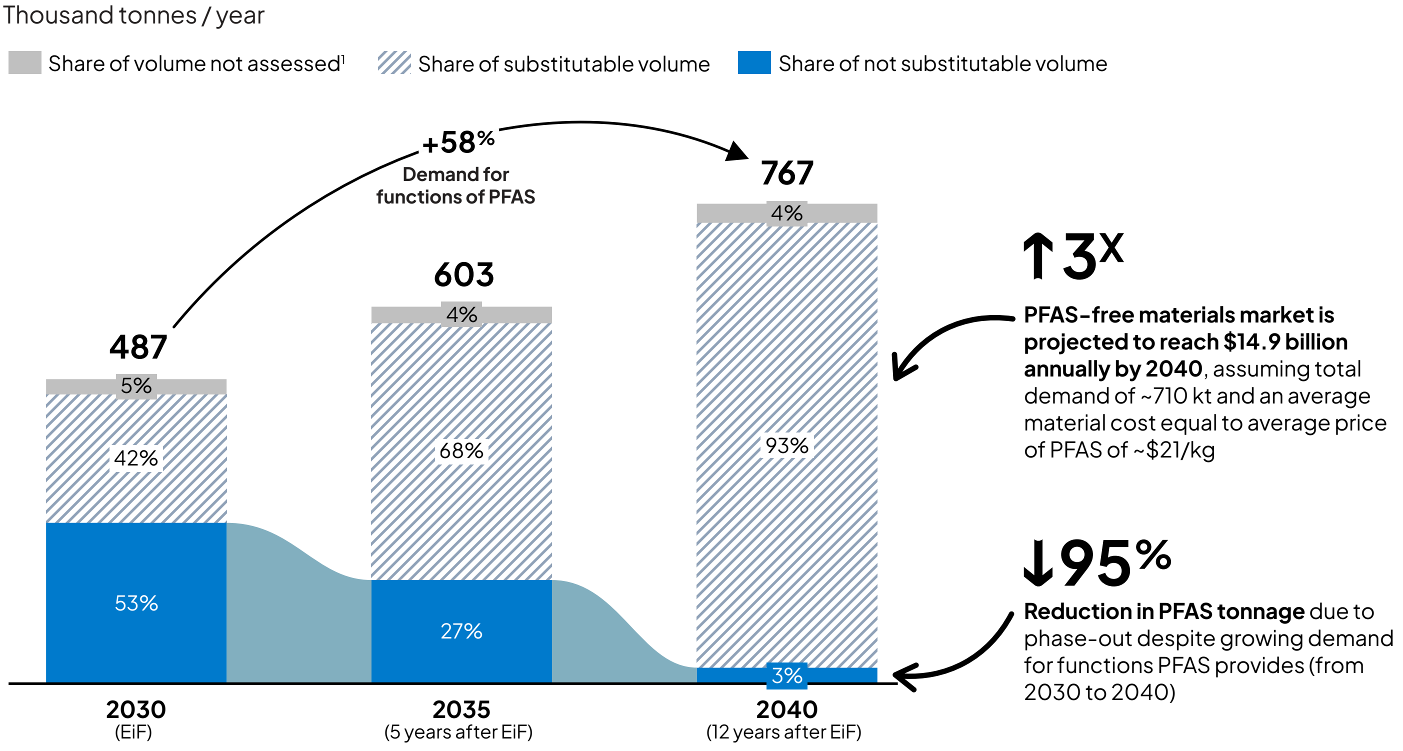


Source: Systemiq analysis based on ECHA (2022a);[134] ECHA (2025b);[135] and ECHA (2025a).[136]
Notes: 1. Cost covers incremental capex and opex only, excluding broader economic impact such as business closures or revenue loss due to transition. 2. Uses economic cost impact from RO3 scenario as proposed by ECHA. 3. Assumes available substitution by entry into force (estimated to take place before 2030). 4. Electronics and semiconductors and transport are not depicted, as they have been conservatively assessed as having no substitutable volume by 2030.

Beyond direct substitution, redesigning systems can help eliminate PFAS altogether. Food packaging provides a clear example: where PFAS serve an aesthetic function—that is, avoiding grease stains—some players have simply phased them out in response to regulation.[133] Likewise, moving away from single-use paper packaging to reusable containers could remove the need for PFAS coatings entirely. Similar redesigns in textiles and consumer products show that innovation in business models and product design can cut PFAS dependence at the source. While these opportunities higher up the solutions hierarchy are not quantified in our MACC, given the diversity of PFAS uses across industries, such systemic solutions could deliver even greater benefits and accelerate comprehensive phaseouts.

For the hardest-to-replace uses, sustained investment in innovation and scaleup will be indispensable. Without regulatory pressure and in some cases targeted public support, industry has little incentive to develop long-term alternatives to high-performance PFAS. Yet with coordinated action—combining regulation, targeted research funding, and cross-industry coalitions—the transition is both possible and affordable.

FIGURE 25 **Estimated PFAS substitutable volume between 2030–2040**



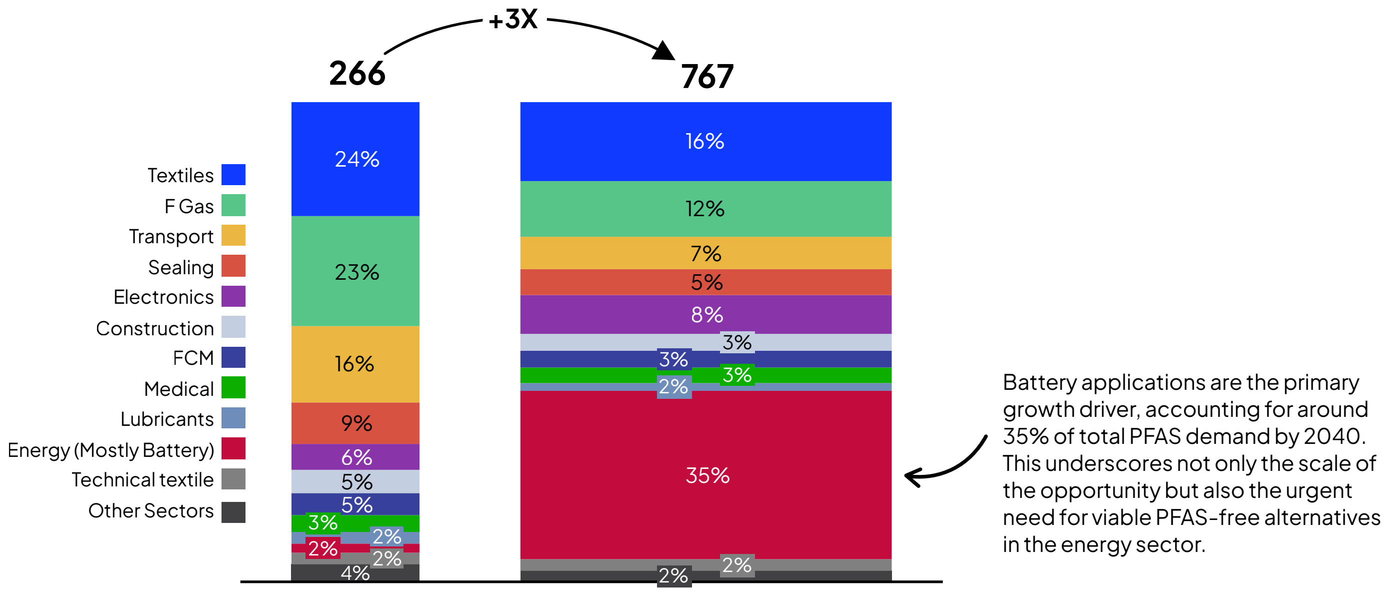
Source: Systemiq analysis based on ECHA (2022a);[134] ECHA (2025b);[135] and ECHA (2025a).[136]
Notes: 1. Industries not assessed include lubricants, other medical applications, military applications, broader industrial uses, metal plating and manufacture, machinery applications, cosmetics, explosives, printing applications, consumer mixtures, petroleum and mining, and ski wax.

By 2040, clear phaseout timelines for most uses could translate into a $14.9 billion market for alternatives to PFAS in the EU alone, conservatively assuming the same average cost per ton as current PFAS. Applying ECHA growth rate estimates by use sector, Figure 25 illustrates that the market for the functions PFAS fulfill in the EU economy is expected to grow by almost 60% to 2040. The volumes due to be phased out as part of the latest ECHA proposal will rise to more than two-thirds by 2035 and over 90% by 2040. The volume of PFAS alternatives in the EU is forecast to amount to around 650,000 tons annually by 2040.

PFAS use is not increasing evenly across sectors (see Figure 26). Energy stands out, with ECHA assuming ~35% growth to 2030 and ~10% thereafter, driven by battery demand as electrification accelerates. Because substitution is harder and costlier in many high-growth areas—also including medical devices, electronics, and semiconductors—innovation is the main lever to decouple growth from exposure. The ECHA restriction's clear phaseout targets can catalyze this innovation and investment. Signals are already positive: patent mapping shows a surge in non-fluorinated substitutes—including for photovoltaic modules and secondary batteries—and PFAS-free options are emerging across hydrogen, heat pumps, solar, wind, and key battery components.[137,138] Given the longer derogations under current proposals, near-term strategies that accelerate phaseout and curb exposures, while allowing time to scale viable alternatives, are in the public interest.

FIGURE 26 **Estimated PFAS volume growth and composition between 2020–2040**

PFAS tonnage split by industries in 2020 and projected tonnage split in 2040
Thousand tonnes / year[1], % of total volume in the respective year
Volume excludes firefighting foam as it has been assessed separately



Source: Systemiq analysis based on ECHA (2025).
Note: 1. Based on mid estimate scenario

Why solutions have not yet been widely adopted

The slow pace of PFAS reduction is due not only to a lack of awareness of the risks, but to systemic barriers that make change difficult. Regulation is fragmented, with some countries and US states banning specific PFAS while thousands of unregulated variants remain in use. This patchwork of rules creates uncertainty and sends weak market signals, leaving companies with little incentive to make proactive changes.

The functions PFAS provide are also unusually diverse. This breadth of uses means that no single substitute can replace PFAS as a group, complicating transition strategies. In sectors with demanding safety or performance requirements, such as aerospace and medical devices, alternatives that meet all required properties either are unavailable or fail to meet current durability and reliability standards.

Economic and organizational factors compound these technical barriers. Larger firms may have PFAS expertise, but this is often siloed and can lack visibility in companies not focused on chemicals. However, as regulations are introduced in key markets, PFAS can quickly become a board-level issue. Many downstream users are also unaware that PFAS are present in the inputs or components they buy. Without mandatory disclosure, supply chain opacity makes substitution a slow and uncertain process. Shifting to PFAS-free alternatives often requires upfront investments in new processes and equipment—costs which are difficult to justify without supportive policies or clear regulatory deadlines, particularly for companies operating on thin margins.

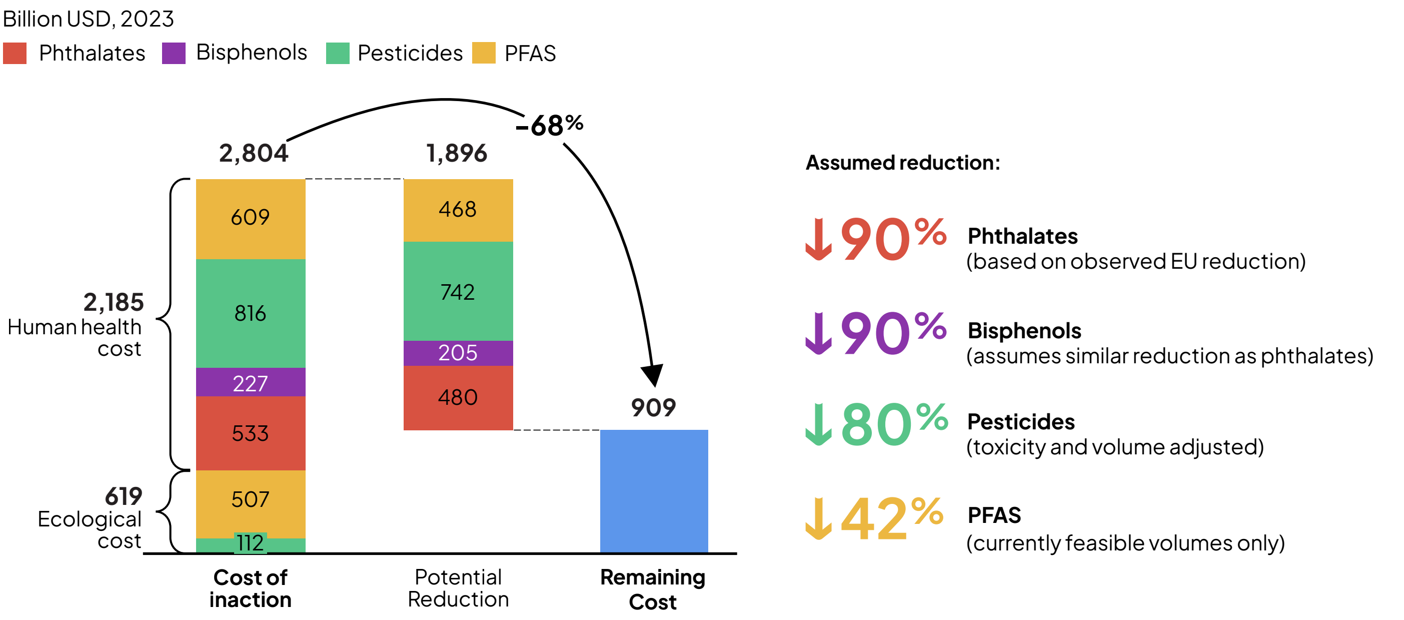
Shifting to PFAS-free alternatives often requires upfront investments which are difficult to justify without supportive policies or clear regulatory deadlines

Taken together, these barriers explain why solutions that are technically feasible in many sectors have not yet been adopted at scale. Stronger regulation, targeted incentives, and greater transparency will be needed to overcome inertia and accelerate the transition away from PFAS.

Summary case for action: a safer future pays for itself

While a comprehensive cost-benefit analysis is beyond the scope of this report, high-level estimates suggest that the reductions outlined above could cut global human health and ecological costs by around 70%—equivalent to $1.9 trillion annually, or roughly 3% of global GDP. This calculation is indicative, translating reductions in chemical volumes into proportional reductions in harm. In academic studies using more complex methods in similar contexts, the figures remain within the same order of magnitude. The overall reduction potential assumes immediate global implementation; continued exposure in the absence of action will increase costs over time.

FIGURE 27 **Estimated health and ecological benefits from toxic chemical reduction globally**



Source: Systemiq analysis.

This is an indicative exercise intended to provide relative orders of magnitude. Limitations include that exposure does not always correlate linearly with harm: endocrine disruptors can have disproportionate effects at low doses, while other substances cause escalating damage beyond certain thresholds. In some cases, this approach might overstate benefits; in others, it may underestimate them. Legacy harms, such as chronic diseases already triggered by past exposure, will endure even if current volumes fall. And highly persistent chemicals like PFAS will continue to contaminate ecosystems for decades or even centuries. Intergenerational impacts—where effects accumulate across multiple lifetimes—are not captured here.

A detailed assessment of the costs of phaseout across the four chemical groups and all regions was beyond the scope of this report. However, looking at specific examples paints a picture of the relative order of magnitude. The costs of phasing out 42% of PFAS volumes in the EU in 2030 are estimated at $500 million per year. In contrast, the estimated annual health impacts of PFAS in the region stand at between $46 billion without extrapolated health impacts and $83 billion including extrapolated health impacts. That means the costs of phaseout amount to between 0.5–1% of the health impacts. Similarly, for pesticides in the EU, the average reduction costs of $26,000 per ton of pesticide use avoided are just 3.5% of the human health and ecological losses resulting from pesticide use, estimated to exceed $700,000 per ton of pesticide applied (Figure 27). Significant reductions in the use of phthalates and bisphenols in the EU with minimal disruption are similarly encouraging.

The evidence is clear: across the four groups of toxic chemicals, the benefits of action vastly outweigh the costs of acting. Transitioning to toxic chemical-free systems will deliver broad economic gains through greater workforce productivity, lower health expenditures, reduced legal liabilities, and avoided remediation costs. It will also open up fresh opportunities for innovation and growth. While chemical producers fear losses to their current businesses, their expertise and scale should allow them to pioneer safe and sustainable alternatives if they choose to seize the initiative.

4 Recommendations

Achieving drastic reductions in toxic exposure across our food system and beyond requires more than incremental measures. The challenge is twofold. On the one hand are **unmanaged hazards**: substances whose health and environmental harms are already well documented, but where action lags behind the available evidence. On the other hand are **unknown hazards**: the thousands of substances in circulation that have not been adequately assessed for safety. Here the problem is not “unknown harm” but “unknown safety,” leaving a systemic blind spot that perpetuates risk.

These failures are rooted in misaligned incentives. Chemical production and use currently generate private profits while imposing public costs. As long as health and environmental harms are externalized, firms face little financial motivation to act, and change depends on the slow machinery of regulation or litigation. Realignment requires not only stronger laws, but also clear signals from finance, consumers, and liability frameworks that make safety and sustainability the more profitable path.

Binding phaseout timelines are the cornerstone of progress. Strict deadlines provide certainty for industry, accelerate cost reductions by scaling existing solutions, and create predictable markets that stimulate private R&D. Around this foundation, action is required across concrete roles for industry, investors, and civil society.

The good news is that the path forward is clear. Many safer substitutes and process innovations are already available and increasingly affordable. Experience from other transitions shows that when policies align with market incentives, progress accelerates. The Montreal Protocol’s CFC phaseout and the dramatic reduction in phthalates in the EU prove that regulation can unlock profitable new markets for safer solutions; in the same way, the transition away from toxic chemicals can serve as a catalyst for green chemistry, materials safety, and transparent supply chains.

Experience from other transitions shows that when policies align with market incentives, progress accelerates

Realigning incentives is essential. Chemical production and use currently generate private profits for companies while imposing public costs on health and ecosystems. Correcting this imbalance requires clear, predictable signals from governments, finance, and consumers that incentivize industry to embrace safety and sustainability.

The evolution of the electric vehicle (EV) industry is both a cautionary and inspiring parallel. In China, early recognition of the EV shift as an industrial opportunity enabled rapid innovation and global leadership. In contrast, many established automakers in Europe, the US, and beyond sought to protect legacy combustion technologies, delaying investment and lobbying to postpone the deadlines by which all new vehicles must be zero emission in the face of lost market share. The same dynamic could play out in chemical-intensive sectors: **early movers that adopt safer solutions as growth strategies will define the markets of the future.**

Policymakers hold the most powerful levers to shape the transition. Their interventions must combine decisive action to eliminate unmanaged hazards with systemic reforms to close the safety gap on unknown hazards and cross-cutting enablers that realign incentives for safer chemical systems.

STOP using toxic chemicals we already know are harmful
ELIMINATE UNMANAGED HAZARDS

A decisive shift is needed to eliminate substances with well-documented risks. **Binding phaseout timelines** must become standard practice, creating both certainty for industry and stronger signals for innovation. Some uses of toxic chemicals—for example, PFAS uses in aerospace, medical devices, and batteries—are harder to replace. However, the current lack of viable alternatives should not result in deferred regulatory action, as the need for a strong signal here is even more critical. Group bans, such as those now proposed for PFAS in the EU, are essential to prevent regrettable substitutions.

Binding phaseout timelines provide certainty for industry, accelerate cost reductions, and stimulate private R&D

Enforcement must be strengthened through **biomonitoring, monitoring of chemicals in food and other exposure pathways, and supply chain transparency.** Exports of substances banned or severely restricted domestically should be prohibited. Producing toxics for export causes concentrated harm to workers and local environments, and knowingly exporting substances deemed unsafe for use is ethically indefensible. In 2022, for example, EU companies planned to export 122,000 tons of 75 pesticides already banned in Europe—a 50% increase on the figure for 2018.[139]

Liability frameworks are another critical tool. Progress has too often been delayed by entrenched opposition from incumbent industries, particularly in jurisdictions where regulatory processes are heavily influenced by producer interests. More robust liability and disclosure frameworks can counterbalance industry pushback by establishing tangible financial and reputational costs of inaction.

Litigation has historically been a driver of change, alongside regulation and innovation. As an example, glyphosate lawsuits have resulted in at least $10 billion in settlements, with manufacturer Bayer setting aside another $6 billion in provisions.[140] Payouts by PFAS manufacturers in the US are of a similar order of magnitude.[141] Stricter liability rules would ensure compensation and remediation, while also realigning incentives: firms that identify and phase out hazards early on can reduce the risk of costly litigation, reputational damage, and supply chain disruption.

While **multilateral cooperation** is challenging, global coordination is critical to prevent toxic chemicals from contaminating the environment and ensure a level playing field across markets. Countries or regions can and should act independently, while pursuing international alignment to tackle toxic chemicals in the long term. Voluntary agreements, such as the Global Framework on Chemicals, offer clear signals of such convergence. Translating these into binding national and regional measures—from group-based restrictions to transparency requirements—would accelerate change and prevent leakage between jurisdictions.

The Montreal Protocol provides a tested blueprint for this kind of global coordination. Its success in phasing out ozone-depleting substances rested on three key design features that remain highly relevant today: clear and binding **phaseout timelines; differentiated responsibilities** supported by financial and technical assistance for developing economies; and **incentives** that aligned industry participation with innovation rather than resistance. Crucially, many of the same companies that produced CFCs also developed their replacements, demonstrating how regulation can catalyze profitable transitions when expectations are clear. A global approach to toxic chemicals could apply the same model, establishing binding international goals backed by predictable funding for capacity building. This would ensure fairness across markets while accelerating the worldwide phaseout of the most hazardous chemicals.

PREVENT toxic chemicals reaching people and ecosystems
CLOSE THE SAFETY GAP ON UNKNOWN HAZARDS

Most chemicals in use today entered the market without robust toxicity testing and may remain unexamined for decades. To close this gap, chemical regulation should ensure that substances are allowed to enter and remain on markets only if rigorous, independent scientific assessments demonstrate safety at anticipated exposure levels.[142] This mirrors the principle long applied to pharmaceuticals: proof of safety before market entry. Such assessment should include robust conflict of interest policies. Post-market surveillance should be required to detect unforeseen harms early on.

Regulators must also adopt systematic review methodologies—transparent and reproducible frameworks for weighing all relevant evidence streams (e.g., epidemiology, animal studies, mechanistic data).[143] Systematic review methods reduce bias and reflect best practices in environmental health science. As noted above, when Europe applied such methods to BPA, the tolerable daily intake was slashed by a factor of 20,000, demonstrating how transformative this shift can be. Studies on mixtures, transgenerational impacts, and epigenetic effects must also be considered. Only then can regulatory science reflect the full reality of chemical risks.

REALIGN incentives and redesign systems
Transform to a safer, more innovative chemical economy

Certain interventions can address both unmanaged hazards and unknown hazards. **Incentives and regulations that reward chemical intensity should be reformed** (e.g., see the subsection on pesticides in "Toxic chemical-specific recommendations" below). In a strained fiscal environment, the aim is not to introduce new subsidies, but to correct distorted market signals. When the costs of pollution are priced in and safer alternatives become visible investment opportunities, capital will naturally shift. In addition to predictable phaseout timelines, EPR schemes should be imposed on remaining essential uses, to achieve this rebalancing through enforcement of the "polluter pays" principle.

Meanwhile, **public money should be used strategically to ensure support is targeted and short term**—such as public-private innovation missions, backed by procurement and offtake guarantees, to derisk the commercialization of safer alternatives. Developing scalable solutions for common exposure pathways—for example, toxic residues in drinking water or sewage sludge applied as fertilizer—should be a public research and deployment priority.

Finally, **education is a long-term enabler.** Tomorrow's chemists, clinicians, engineers, and material scientists currently receive little training on hazard evaluation. Embedding hazard literacy and safe-by-design principles in curricula will help ensure future innovations do not perpetuate today's mistakes.

A systematic approach to safer chemicals

The EU's Chemicals Strategy for Sustainability[144] is a prime example of a plan for a fundamental shift toward hazard-based, precautionary regulation. It presents a coherent strategy for the systematic improvement of the safety and sustainability of chemicals by not only calling for the phaseout of hazardous chemicals (including PFAS), but promoting the development of chemicals that are safe and sustainable by design; setting a zero-pollution ambition; and aligning with other environmental strategies, such as the Circular Economy Action Plan, to enable safe recycling and reuse and prevent tradeoffs with other solutions.

Industry and firms

Industry must move beyond compliance to actively lead the transition. Across the four groups of toxic chemicals assessed in this report, attractive alternatives with low or even negative costs exist, representing promising investment opportunities on these terms alone. Misaligned incentives have long rewarded volume and cost reduction over safety and sustainability, even as litigation, reputational, and operational risks grow. Firms that proactively manage these risks—by identifying hazards across their supply chains and investing in safer alternatives—will capture the benefits of clearer regulation and rising demand for toxic chemical-free materials and food systems.

Firms that proactively manage these risks will capture the benefits of clearer regulation and rising demand for toxic chemical-free materials and food systems

For unmanaged hazards, **voluntary commitments or internal strategies** to phase out toxic chemicals enable firms to reduce litigation and regulatory risks while managing transitions on their own terms. A first step is to understand exposure, demanding transparency from suppliers and conducting additional testing where necessary. The WBCSD has developed the Portfolio Sustainability Assessment as a helpful framework applicable to all chemical-intensive sectors, which has been used successfully by leading chemical producers.[145] Once risks have been identified and prioritized, firms can evaluate and pilot solutions in collaboration with suppliers and new providers. Disruption and operational performance issues are often a significant cost driver, especially when transitions are rushed due to regulatory timelines. Proactive phaseout allows firms to mitigate these risks and carefully consider complex tradeoffs.

For unknown hazards, true R&D leaders can play a vital role. However, all firms should **invest in transparency and testing** to close gaps in safety data and **join collective efforts to develop safe-by-design alternatives.**

Across both categories, industry can use its **purchasing power** to drive demand for safer substitutes, join coalitions committed to phaseouts, and pilot innovative business models that reduce reliance on chemical inputs (e.g., outcome-oriented services in agriculture).

While firms can and should proactively adopt these measures, the track record of voluntary initiatives demonstrates that regulation is a prerequisite for the market at large to move. Voluntary efforts can show what is possible, but regulation unlocks a virtuous circle of increasing adoption, driving down costs and innovation to enable a faster and cheaper transition.

Investors and funders

Capital allocation will determine the speed of transition. At present, toxic chemicals and pollution remain an under-recognized financial risk which is severely underfunded compared to climate solutions. In 2021, European philanthropy dedicated just €7 million to this issue; and only one venture capital firm globally focuses on toxic chemicals.[146] Litigation, liability, and brand damage are rising, while demand for safer products is growing. Integrating these realities into investment analysis is both prudent risk management and an opportunity for superior long-term returns.

For unmanaged hazards, investors should **divest from firms without credible phaseout strategies** and anticipate financial risks from litigation and stranded assets. For unknown hazards, investors and funders should seize the opportunity to fund **toxic-free innovation, independent safety science, and safe-by-design platforms. Mandatory disclosure of toxicity-weighted metrics**—such as those under development for pesticides—would enable investors to quantify these risks and reward leadership. As capital markets increasingly price chemical risk alongside climate and biodiversity risk, first movers could unlock outsized opportunities in high-growth, low-risk markets.

Philanthropic and public funders can catalyze the transition by **supporting initiatives aimed at enhancing awareness and transparency** as well as procurement mechanisms and early deployment of alternatives, helping derisk investments and crowd in private capital.

Citizens, nongovernmental organizations and media

Evidence and regulation alone are rarely sufficient to overcome institutional inertia. Civil society mobilization is essential to build the public and political momentum needed for systemic change. Public scrutiny can also counterbalance entrenched industry influence, exposing the economic externalities that have long remained hidden. Sustained media attention and monitoring by NGOs help ensure that chemical hazards are not treated as technical health issues alone, but as questions of justice, accountability, and prosperity.

Civil society mobilization is essential to build the public and political momentum needed for systemic change

On unmanaged hazards, NGOs can campaign against the continued production and export of toxic chemicals, demand enforcement of bans, and expose greenwashing or inaction. On unknown hazards, advocacy can raise awareness of the sheer number of substances on the market without adequate testing, pressing for precautionary reform.

Media outlets play a critical role in keeping toxic chemicals high on the public agenda, while philanthropy and grassroots networks can amplify momentum. Together, civil society actors provide the visibility, accountability, and urgency that compel governments, firms, and investors to act.

Toxic chemical-specific recommendations

While the general measures outlined above establish the foundation, the following recommendations highlight the targeted action required for each of the four groups of toxic chemicals discussed in this report.

Phthalates

Phthalates exemplify the dual challenge of unmanaged hazards and unknown safety. Four high-risk compounds (DEHP, DBP, BBP, DIBP) remain in widespread use globally, despite well-established reproductive and endocrine harms. **Extending EU-style group bans, removing remaining derogations, and enforcing import traceability** would rapidly cut exposure at limited cost. At the same time, many substitutes—such as HMW phthalates and terephthalates—entered markets with incomplete safety data, highlighting the need for **consistent application of the "no data, no market" principle** across jurisdictions and stringent assessment of substitutes by their shared characteristics. Procurement standards for phthalate-free medical devices and packaging, disclosure of plasticizer content, and continued biomonitoring can accelerate safer innovation while closing both regulatory and information gaps.

Bisphenols

In the case of bisphenols, attempts to address unmanaged hazards have similarly resulted in unknown safety issues. While bans on BPA in food contact materials and thermal paper have drastically reduced exposure in Europe, global use remains high and substitution with near-identical analogs such as BPS and BPF risks repeating the same harms. Extending group-based restrictions internationally, harmonizing exposure limits, and employing systematic reviews in regulation are critical to break this cycle. Public procurement of bisphenol-free packaging and thermal paper, mandatory disclosure of bisphenol content in consumer goods, and targeted support for innovation in bisphenol-free linings and coatings can lock in lasting reductions and foster safer materials globally. The monitoring of bisphenol discharges from any remaining uses should be expanded.

Pesticides

Pesticides encompass both unmanaged hazards—continued use and trade of highly hazardous pesticides such as organophosphates and paraquat—and unknown safety, as inert ingredients (e.g., adjuvants), mixtures, and newer actives remain under-tested. Regulators should **set binding, staged phaseout timelines that prioritize the most toxic substances first, shift metrics from volume to toxicity** (e.g., ATAT or equivalent toxicity-weighted indicators), and **ban the production and export of pesticides prohibited domestically.** Where full phaseout is not feasible with current technology, setting a deadline can drive R&D and innovation toward safer substitutions and other technological and practice alternatives. To accelerate adoption, incentives should be realigned toward outcome-based models (integrating IPM, precision application, and biocontrols) and fast-track regulatory processes for lower-hazard biopesticides; and full formulation disclosure (active ingredients plus co-formulants) and portfolio reviews by firms should be required. Region-specific barriers—such as restrictive crop insurance in the US, which discourages the adoption of practices like precision agriculture or IPM—should also be addressed. Public procurement (e.g., school meals, hospitals) should favor toxicity-reduced supply.

Businesses have a critical role to play by reviewing their full portfolios (see "Cross-cutting enablers" above), including potentially toxic inert ingredients. Furthermore, shifting to outcome-oriented service models that integrate precision agriculture and IPM rather than relying on input sales presents significant opportunities. Investors should condition capital on credible phaseout plans and performance against toxicity-weighted indicators.

PFAS

As persistent, bioaccumulative, and toxic chemicals that remain in use across thousands of applications, PFAS epitomize unmanaged hazards. We recommend **setting a target for the rapid, group-wide phaseout of PFAS**, with time-limited exceptions granted only for essential uses where no viable alternatives are currently available. Targeted public R&D support should prioritize substitution in critical applications where the need for PFAS will be most enduring, such as batteries and medical devices. End-of-life solutions may also warrant public investment—for example, to facilitate safe recycling (e.g., via routine testing) or affordable technologies to remediate the most harmful exposure pathways at scale. Remaining PFAS uses could be made subject to EPR schemes, to raise funds for innovation and deployment of remediation technologies, for example. These measures would not only cut ongoing emissions but also reduce the long-term costs of health impacts and the cleanup costs of PFAS pollution.

Traffic light for safer chemicals in the food system

Three essential levers to reduce toxic exposure and build a safe-by-design future.

STOP using toxic chemicals we already know are harmful

ELIMINATE UNMANAGED HAZARDS

- Ban and phase out highly hazardous chemical groups with clear deadlines
- Strengthen enforcement through biomonitoring, food & water testing, and supply chain transparency
- Prohibit production and exports of chemicals restricted domestically
- Strengthen liability frameworks so producers are incentivized to identify and phase out hazards

PREVENT toxic chemicals reaching people and ecosystems

CLOSE THE SAFETY GAP ON UNKNOWN HAZARDS

- Adopt precautionary, hazard-based regulation
- Require pre-market proof of safety based on independent scientific assessment ("no data, no market" principle)
- Monitor unforeseen harms through post-market surveillance
- Apply systematic review methods to weigh all scientific evidence transparently

REALIGN incentives and redesign systems

Transform to a safer, more innovative chemical economy

- Reform fiscal and regulatory incentives to reward lower toxicity
- Fund time-bound innovation missions to accelerate solutions in hard-to-replace uses or critical exposure pathways
- Drive product & system redesign to eliminate unnecessary chemical use
- Embed hazard literacy and safe-by-design principles in STEM education and industry training

When governments and industry act across all three levers, toxic exposure can fall dramatically — improving health, fertility, and ecosystem resilience.

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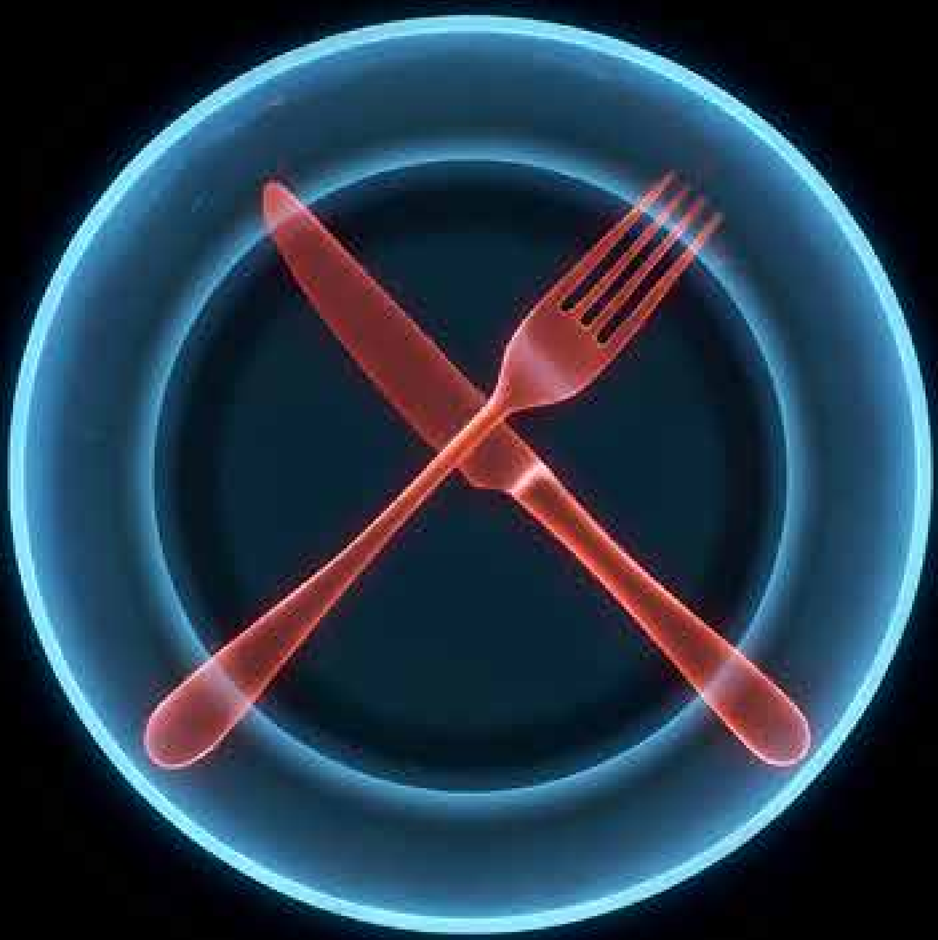

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