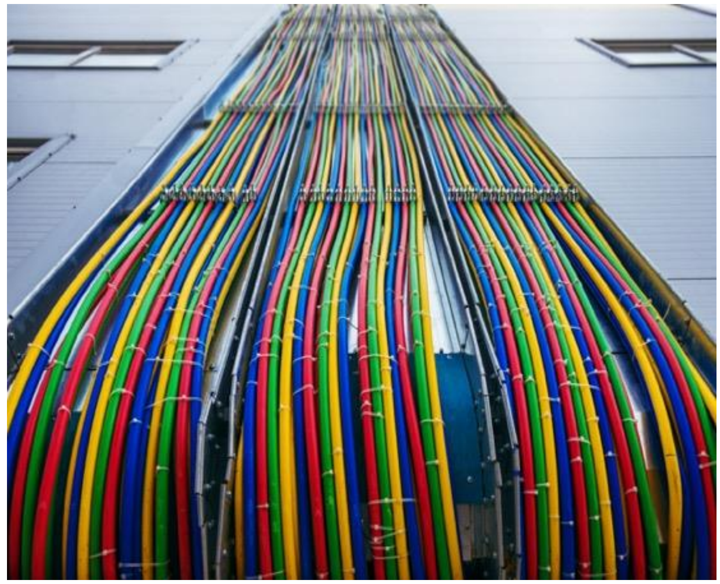
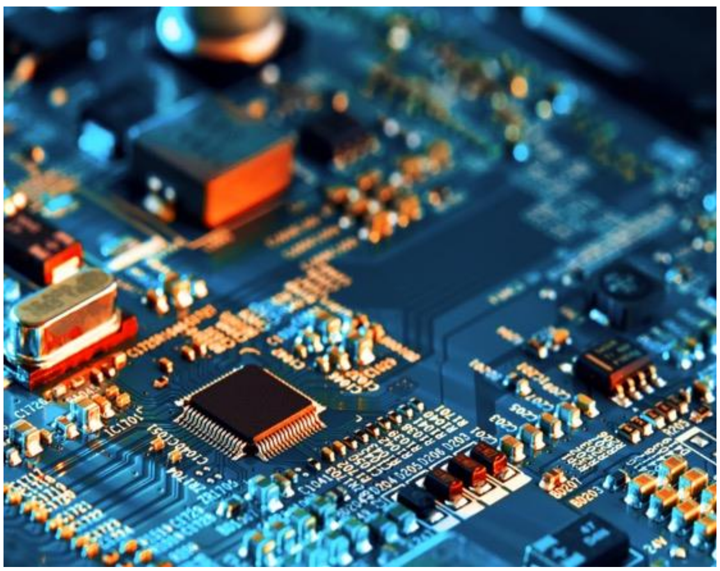
ASSOCIATION FOR THE ADVANCEMENT OF ALTERNATIVES ASSESSMENT





Using Alternatives Assessment to Support Informed Substitution of PFAS in the Electronics Industry

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ABOUT A4

The Association for the Advancement of Alternatives Assessment (A4) is a professional association solely dedicated to advancing the science, practice, and policy of alternatives assessment and informed substitution. A4 is an interdisciplinary community of researchers and practitioners from government agencies, academia, industry, and non-profits, working collaboratively to accelerate the transition to the use of safer chemicals, materials, processes, and products.

The A4 includes professionals representing the broad range of scientific disciplines involved in alternatives assessment and informed substitution – toxicology, exposure science, engineering, chemistry, lifecycle assessment, law and policy, and economics, among others – who are working to advance the methodological underpinnings, best practices, and professional capacity for the field.

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INTRODUCTION

There is increasing scrutiny on the use of per- and polyfluoroalkyl substances (PFAS), a class of over 10,000[1,2] manufactured chemicals with more than 200 uses across a wide range of industries, including aerospace, food production, energy, and electronics[3]. PFAS can be classified into two main categories, polymeric and non-polymeric, both of which are used in a variety of applications in electronics[4,5,6]. Some of the uses for PFAS in electronics are summarized in **TABLE 1**, though these uses of PFAS do not necessarily include PFAS used in upstream manufacturing processes or in the manufacturing of product components.

TABLE 1. A sample of uses of PFAS in various electronics products and processes[4,5,6]

Product or Process	PFAS Use or Function in Electronics Products
Smartphone surfaces	• Anti-smudge on touch panel • Smoothness
Liquid crystal displays	• Provides the liquid crystal with a dipole moment • Moisture sensitive coating for displays
Printed circuit boards	• Solder resistance • Low water absorption
Electric wire and cables	• Electric insulation • Dielectric properties
Lithium-ion batteries	• Binder • Separator material
Electronic industry	• Heat-transfer fluids • Solvent systems and cleaning
Semiconductor industry	• Non-stick coating on carrier wafer • Increase stress tolerance (fiber-reinforced fluoropolymer layer)
Glass surface treatment & finishing	• Etching and polishing • Improving fire or weather resistance
Metallic and ceramic surfaces	• Making surfaces hydrophobic and oleophobic • Ease of cleaning
Wires and cables	• High temperature endurance • High stress crack resistance

[1] National Institute of Environmental Health Sciences. Perfluoroalkyl and polyfluoroalkyl substances (PFAS). Available at: https://www.niehs.nih.gov/health/topics/agents/pfc/index.cfm#:~:text=PFAS%20are%20used%20in%20hundreds,9%2C000%20PFAS%20have%20been%20identified
[2] ECHA PFAS restriction proposal defines PFAS as >10,000 substances. [7 February 2023, Press Release] https://echa.europa.eu/-/echa-publishes-pfas-restriction-proposal
[3] Glüge J., Scheringer M., Cousins I.A., DeWitt J.C, Goldenman G., Herzke D., Lohmann R., Ng C.A., Trier X., Wang Z. An overview of the uses of per- and polyfluoroalkyl substances (PFAS). (2020). *Environmental Science: Processes & Impacts*, 12(22), 2345-2373. https://doi.org/10.1039/D0EM00291G
[4] ChemSec. Check Your Tech, A guide to PFAS in electronics. Available at: https://chemsec.org/app/uploads/2023/04/Check-your-Tech_230420.pdf
[5] Tansel, B. (2022). PFAS use in electronic products and exposure risks during handling and processing of e-waste: A review. Journal of Environmental Management, 316: 115291. https://doi.org/10.1016/j.jenvman.2022.115291
[6] IPC. Preliminary Findings: PFAS Use in the Electronics Industry. (2020). Available at: https://www.ipc.org/media/2438/download

PFAS are increasingly the focus of government and market-based restriction efforts because they are persistent in the environment, can bioaccumulate in human bodies, and are associated with several health impacts, including liver disease, kidney disease, adverse reproductive and developmental outcomes, cancer, and reduced immunological function[7]. The recently published European Chemicals Agency (ECHA) proposal to restrict nearly 10,000 PFAS as a class with minimal exemptions[2], along with 3M's recent announcement of its intention to stop its manufacturing and use of PFAS across its product portfolio by 2025[8] provide a strong motivation for PFAS substitution in a range of applications across product types.

In anticipation of pending policies, some electronics companies have been proactive in phasing out PFAS. For example, Apple has taken significant steps, banning perfluorooctanoic acid (PFOA) in 2010, perfluorooctanesulfonic acid (PFOS) in 2013, and restricting perfluorocarboxylic acids C9-C14 (PFCA and perfluorohexanoic acid, PFHxS) in 2021. Recently, Apple made a commitment in November 2022 to phase out the use of all PFAS compounds, acknowledging that this will be no small task and requires: 1) Compiling a comprehensive catalog of PFAS use in electronics, 2) Identifying and developing non-PFAS alternatives that can meet the performance needs for critical applications, and 3) Ensuring that non-PFAS alternatives do not result in regrettable substitutions[9]. Despite these phase-out efforts, alternative solutions are needed that are safer and fulfill performance needs.

PFAS ALONG THE SUPPLY CHAIN: HUMAN HEALTH AND ENVIRONMENTAL IMPACTS

PFAS exposures can happen during electronics product manufacturing, use, reuse, and disposal. Even when PFAS is not part of a finished electronic product, PFAS may have been used in upstream stages of product and material manufacturing, posing an exposure risk to workers and communities. Consumers, including sensitive populations such as children, pregnant women, the elderly, and the immunocompromised, may also be exposed to PFAS if it is intentionally added to the product or remains in the product as residuals of a manufacturing step. Exposures may be particularly problematic at a product's end-of-life stage, introducing important circularity and environmental justice concerns. Global e-waste was projected to be 52 million metric tons in 2021[a] and it is estimated that up to 41% of the EU's annual e-waste by volume is either improperly treated or ends up in uncontrolled e-waste facilities in developing countries, where for the U.S., this ranges from 5-50%[b]. The health and economic burdens related to PFAS exposures in developing countries may be enormous and unaccounted for, but the societal costs of PFAS exposure in the 31 European Economic Area countries ranges from €52-84 billion per year for health-related effects and up to €170 billion for environmental remediation costs[c].

[7] Fenton, S. E., Ducatman, A., Boobis, A., DeWitt, J. C., Lau, C., Ng, C., Smith, J. S., & Roberts, S. M. (2021). Per- and Polyfluoroalkyl Substance Toxicity and Human Health Review: Current State of Knowledge and Strategies for Informing Future Research. Environmental Toxicology and Chemistry, 40(3), 606–630. https://doi.org/10.1002/etc.4890
[8] 3M. 3M to Exit PFAS Manufacturing by the End of 2025. 3M News Center. https://news.3m.com/2022-12-20-3M-to-Exit-PFAS-Manufacturing-by-the-End-of-2025
[9] Apple's commitment to phasing per- and polyfluoroalkyl substances (PFAS). November 2022. https://www.apple.com/environment/pdf/Apple_PFAS_Commitment_November-2022.pdf

INCORPORATING ALTERNATIVES ASSESSMENT INTO SUBSTITUTION EFFORTS

Phaseout or restriction of chemicals of concern, without careful consideration of alternatives, can lead to sub-optimal or regrettable substitutes, where the alternatives are either only minimally improved, are equivalent, or are more problematic in terms of their performance and/or their environmental or health impacts. Alternatives assessment is a tool that can help companies in identifying, assessing, and adopting safer chemical, material, and product redesign options to a chemical of concern based on their hazards, exposure potential, technical feasibility, cost, performance, lifecycle impacts, and/or other factors, guiding the transition to safer, more sustainable solutions. The alternatives assessment process also considers the final decision-making process, adoption of a solution, and potential re-evaluation of that decision as updated information or new alternatives arise. An alternative assessment rarely reveals a "perfect" solution. Rather, with the help of stakeholder input, it outlines the key tradeoffs and competing priorities to consider for each potential alternative solution during the decision-making process, leading to a more *informed substitution* process that supports a transition to safer alternatives[10].

AVOIDING REGRETTABLE SUBSTITUTIONS

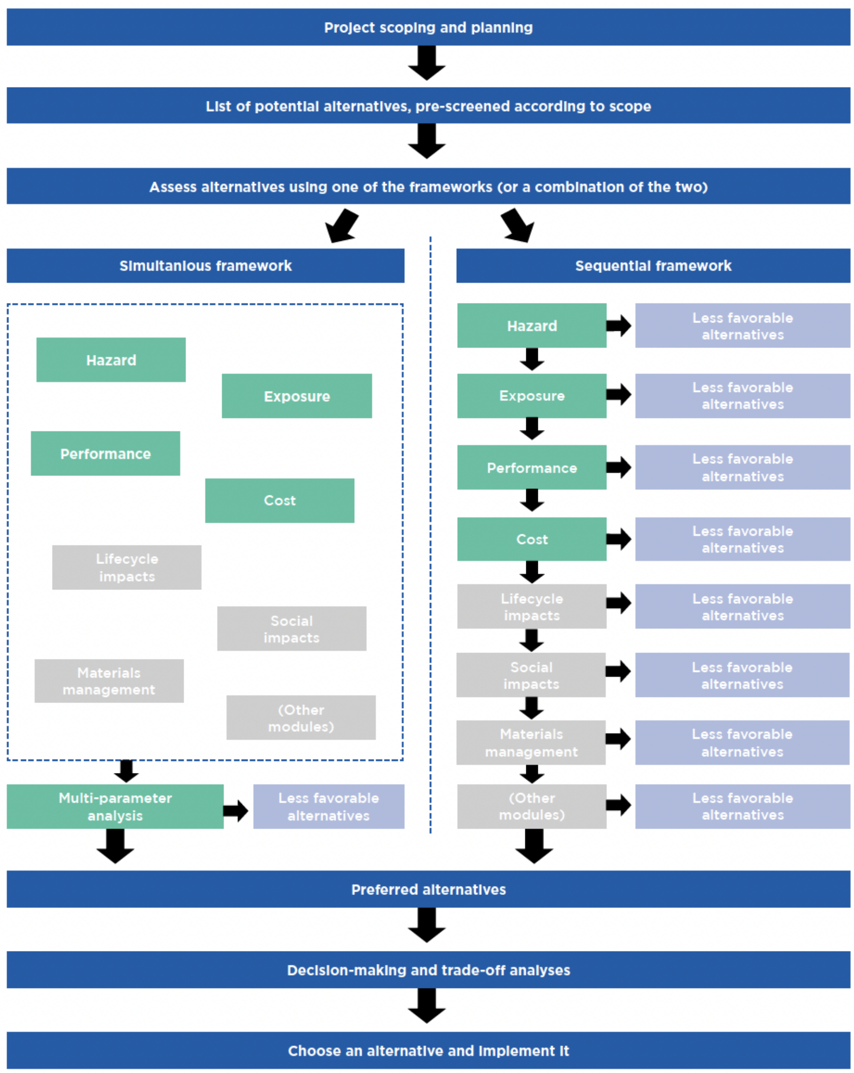
Regrettable substitutions occur when elimination of a chemical of concern results in new or different harmful exposures to humans and the environment or inadequate performance, which can result in increased time and resources needed to identify a new alternative solution. The purpose of alternatives assessment is to avoid these scenarios by more comprehensively assessing possible solutions and taking informed action to implement them. The lessons learned from examples of regrettable substitutions, such as the replacement of the hormone-disrupting chemical bisphenol A (BPA) with the similarly hazardous substance bisphenol S (BPS), provide motivation to ensure that substitutes to PFAS are carefully considered and driven by an approach to evaluating functional alternatives that prioritizes the reduction of hazard while being transparent on potential trade-offs.

The overall approach to an alternatives assessment has been refined over the years but generally follows a stepwise set of assessment components and can incorporate gate-checks to determine if candidate alternatives are sufficient or whether additional research is needed. The Interstate Chemicals Clearinghouse (IC2) Alternatives Assessment Guide (v1.1)[11] illustrates the general process, which begins with a scoping process for the assessment followed by recommended and optional modules by which to evaluate each of the identified alternatives. In some cases, preferred alternatives may not be available and must be developed using green chemistry principles and criteria[12].

[10] National Research Council. (2014). *A Framework to Guide Selection of Chemical Alternatives*. Washington, DC: The National Academies Press. https://doi.org/10.17226/18872. Available at: https://nap.nationalacademies.org/catalog/18872/a-framework-to-guide-selection-of-chemical-alternatives
[11] Interstate Chemicals Clearinghouse (IC2). Alternatives Assessment Guide v1.1. (2017). Available at: http://theic2.org/article/download-pdf/file_name/IC2_AA_Guide_Version_1.1.pdf
[12] United States Environmental Protection Agency. (n.d.). Basics of Green Chemistry. https://www.epa.gov/greenchemistry/basics-green-chemistry

This approach can be adjusted depending on the goals and needs of the assessment. **FIGURE 1** highlights different options for the organization of the assessment. The left side illustrates an approach where information about each alternative is collected and assessed against all modules at once. The right side illustrates another approach that screens out unacceptable alternatives as they progress through each module, resulting in a smaller number of final solutions to compare. A combination of the two approaches can also be used, where alternatives are screened through an initial one or more modules and then information is collected for all remaining alternatives for the rest of the modules. The alternatives assessment approach can become more complex when comparing a chemical alternative to a material or technology change, where lifecycle attributes may play an important role in comparing alternatives.

FIGURE 1. A sample alternatives assessment framework (Grey boxes indicate optional component evaluations)[13]



[13] Society of Environmental Toxicology and Chemistry (SETAC). (2023). Technical Issue Paper. Chemical Alternatives Assessment. Pensacola (FL): 4 pp. https://www.setac.org/resource/setac-tip-alternative-assessments-pdf.html

Alternatives assessment is flexible and can be adapted to meet specific needs and contexts. For example, the Swedish non-profit ChemSec, in partnership with Apple and other corporate leaders, created a 4-step process called ChemCoach[14], which companies can use to identify and replace endocrine disrupting chemicals (EDCs). **FIGURE 2** shows how this tool can be adapted to address PFAS. Like the IC2 framework, this approach outlines the process in a simplified manner beginning with identifying the problem, evaluating available solutions, identifying when innovation is needed, and phasing out the chemical of concern when safer alternatives exist.

For the hazard assessment portion of an alternatives assessment – a key element in every assessment – several organizations have established criteria and minimum tests for identifying a "safer" option, including ChemFORWARD, Clean Production Action's GreenScreen®, and the Organization for Economic Cooperation and Development (OECD)[15]. These generally rely on both an initial review of authoritative government restrictions lists (which helps to screen out potentially problematic alternatives) and a more detailed assessment utilizing criteria from the Globally Harmonized System of Classification and Labeling of Chemicals (GHS). These hazard assessment approaches also include an evaluation of data gaps.

Functional Substitution – A starting point for thinking about potential alternatives

As a first step, highlighted in Figure 2 and noted in Apple's phaseout commitment, PFAS uses must be identified, which is an enormous challenge as many uses of PFAS may not be known or disclosed. After identifying PFAS uses, it is critical to understand the function of PFAS in the particular application. The concept of functional substitution[16] begins with an understanding of the function of the chemical of concern (PFAS in this case) in an application and asking whether the function is necessary to achieve or maintain the performance of the product. If not – and this is rare – PFAS could potentially be removed without changes in product performance, potentially reducing reformulation costs, potential liability, and reputational risk. However, for most situations where the function of PFAS is necessary, functional substitution requires going beyond the idea of just a drop-in chemical substitute as a solution, to considering how the function could be fulfilled in other ways, including material changes or upstream process changes that eliminate the functional need of PFAS. Solutions could also include more systemic changes such as product redesign to achieve performance in different ways, which is what Best Buy did to eliminate flame retardants from its own brand models of televisions[17]. However, this strategy could require significantly more resources, financial investment, and research into whether the change would be successful in the market.

Difficulties in data on chemical uses across global supply chains (data transparency) are common and are not unique to PFAS. but these pose a unique challenge in the case of PFAS as a result of the sheer number of chemicals in the class wide range of uses that may not yet be fully understood. The disclosures necessary to support informed substitution go beyond those included in legally required SDS's. BizNGO's Principles for Chemical Ingredient Disclosure[18] outline the

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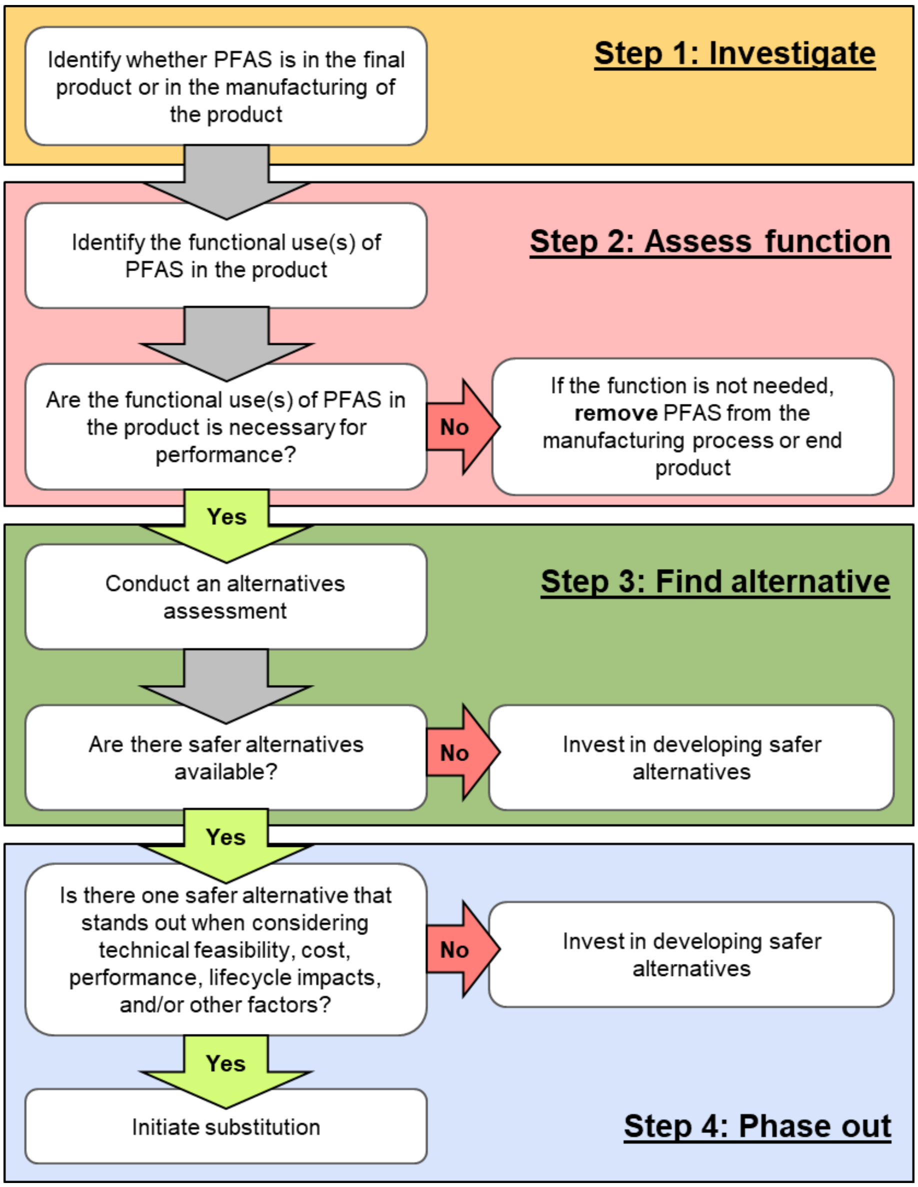
[14] ChemSec. ChemCoach. https://chemsec.org/chemcoach/
[15] OECD. (2021). Guidance on Key Considerations for the Identification and Selection of Safer Chemical Alternative, OECD Series on Risk Management, No. 60, Environment, Health and Safety, Environment Directorate, OECD.
[16] Tickner JA, Schifano JN, Blake, A, Rudisill C, Mulvihill MJ. (2015). Advancing Safer Alternatives Through Functional Substitution. *Environmental Science & Technology*, 49: 742−749. https://doi.org/10.1021/es503328m
[17] Best Buy. (2022). Best Buy commits to eco-friendly television displays. https://corporate.bestbuy.com/best-buy-commits-to-eco-friendly-television-displays/
[18] BizNGO. Principles for Chemical Ingredient Disclosure. Available at: https://www.bizngo.org/public-policies/principles-for-chemical-ingredient-disclosure

needs for more extensive disclosure of information to consumers and across supply chains, including the disclosure of known chemicals of concern while balancing this with Confidential business information protections only when necessary. Given the concerns surrounding PFAS as a class and number of uses, enhanced chemical information disclosure across the electronics supply chain will be needed to support informed substitution.

FIGURE 2. An alternatives assessment approach for substituting PFAS, adapted from ChemCoach's 4-Step Approach to Identifying and Replacing EDCs



MOVING TOWARDS SAFER ELECTRONICS PRODUCTS – SUPPORT, CERTIFICATION, AND COLLABORATION

Substitution is a complex process where multiple competing priorities need to be considered and where adoption in global supply chains may be challenging. Extensive resources exist to support companies in identifying, evaluating, and transitioning to safer chemicals, as well as in recognizing better options. Supply chain and research collaborations can help address some of the barriers inherent in the substitution process.

Tools for the Trade: Resources and Services

An extensive suite of resources is already available to help identify and support the transition to safer alternatives. These resources are also applicable to other chemicals of concern and can help underpin more extensive corporate sustainability initiatives. For instance, ecolabels and certifications can be powerful tools for verifying the safety and sustainability of products across the supply chain, and many institutional buyers such as the U.S. federal government rely on these ecolabels to guide their responsible purchasing decisions. U.S. federal purchasers must ensure 95% of their electronics acquisitions are EPEAT certified where an established product standard exists[19]. The EPEAT standard uses a rating system to reward and motivate manufacturers to use less hazardous substances that do not result in additional impacts across the product's life cycle[20]. In addition, these certifications are helpful or even required in certain Environmental, Social and Governance (ESG) disclosure frameworks. The reporting of standards or verifications speaks directly to the link between safer chemicals and business performance, particularly as ESG disclosures are increasingly scrutinized by investors. Engaging with such programs or substitution efforts, particularly as they begin to incorporate safer criteria, helps with stakeholder transparency, and gives businesses incentives to invest in and maintain critical chemical management and data systems that will be needed to ensure successful substitution of PFAS within their supply chains. A sample of useful tools, some which have associated costs and some that are available for free, is featured in **TABLE 2.** Other tools or approaches may be used, these should align with the basic principles of alternatives assessment: reduction of chemical hazards, thoughtful and open assessment of trade-offs, avoidance of regrettable substitutes, and movement towards safer substitutes.

[19] Meyer, D. A., & Katz, J. (2016). Analyzing the environmental impacts of laptop enclosures using screening-level life cycle assessment to support sustainable consumer electronics. Journal of Cleaner Production, 112, 369–383. https://doi.org/10.1016/j.jclepro.2015.05.143
[20] J. Katz, W. Rifer and A. R. Wilson, "EPEAT: Electronic Product Environmental Tool - development of an environmental rating system of electronic products for governmental/institutional procurement," Proceedings of the 2005 IEEE International Symposium on Electronics and the Environment, 2005., New Orleans, LA, USA, 2005, pp. 1-6, https://doi:10.1109/ISEE.2005.1436980.

TABLE 2. A sample list of resources and tools that could be used to assist in PFAS alternatives selection

Alternatives Assessment Frameworks and Guidance	
National Research Council (NRC)	A Framework to Guide Selection of Safer Alternatives
Interstate Chemicals Clearinghouse (IC2)	Alternatives Assessment Guide v1.1 (as well as a library of completed alternatives assessments)
Organization for Economic Cooperation and Development (OECD)	Guidance on Key Considerations for the Identification and Selection of Safer Chemical Alternatives
Free Alternatives Assessment Tools	
Organization for Economic Cooperation and Development (OECD)	Substitution and alternatives assessment tools and data sources
Toxics Use Reduction Institute (TURI)	Pollution Prevention Options Analysis System (P2OASYS)
Occupational Safety and Health Administration (OSHA)	Transitioning to Safer Chemicals: A Toolkit for Employers and Workers
Fee-Based Chemical Assessment & Management Tools and Services	
ChemFORWARD	Cloud-based safer ingredient repository with third-party verified assessments and certified SAFER® products across several sectors including electronics.
Enhesa	SciVera Lens® chemical management platform and chemical assessment repository based on verified chemical assessments and rigorous standard criteria.
Healthy Building Network	The Pharos Project provides access to thousands of chemical assessments, an automated screening tool, and other chemical related information. Despite its primary focus on building materials, its extensive database is applicable across multiple industries.
Certifications, Labelling, and Outreach Organizations	
Clean Productions Action (CPA)	Home to the GreenScreen® assessment methodology which serves as the basis for the GreenScreen Certified™ Standard for Cleaners and Degreasers Used in Manufacturing.
Global Electronics Council™(GEC)	Home to the EPEAT ecolabel, which is currently being updated for PFAS-related criteria. GEC also offers a free product registry for all EPEAT certified products as well as purchaser guides, webinars, and supporting research to help improve the sustainability of electronics.
Clean Electronics Production Network (CEPN)	Multi-stakeholder outreach organization dedicated to eliminating workers' exposure to toxic chemicals across the electronics supply chain. CEPN offers several services in support of this mission.

Research and Collaboration for Successful Substitution

Collaboration can play an important role in substitution efforts, especially when there is a lack of clearly available alternatives that are safer and perform well. While large brands may benefit most from collaborating directly with their suppliers, other avenues may be effective, particularly for smaller producers or when the substitution challenge spans an entire industry. Collaboration can be as simple as a company reaching out to a technical assistance organization. For example, the Massachusetts Toxics Use Reduction Institute (TURI) helps companies within the state to achieve toxics reduction and safer substitution solutions and recently helped Transene Company, a manufacturer of advanced materials for the electronics industry, remove PFAS from etching processes for applications involving microwave chips and lasers, among other applications[21]. TURI supported Transene by providing technical research support and assistance with alternative testing.

Pre-competitive collaborations between companies can also be beneficial in expediting substitution processes, reducing resources. These be established so that companies share information on potential solutions and undertake joint testing, utilizing agreements, where needed, to avoid compromising confidential business information. For example, TURI established a lead-free electronics consortium to evaluate alternatives to lead solder[22]. Change Chemistry (formerly known as the Green Chemistry & Commerce Council, GC3) organized a collaborative innovation challenge where 11 brands, 2 retailers, and 6 chemical suppliers collaborated to both define criteria for safe and effective preservatives for consumer products and conducted an open-innovation challenge for safer substitutes, evaluating the solutions on both their toxicity and performance against the criteria. Change Chemistry hosts several additional collaborative innovation challenges, such as one focused on evaluating low-VOC solvents[23,24]. The main goal for using a collaboration-oriented approach is to support informed substitution across sectors in a more cost and resource effective manner, achieving goals faster.

[21] Toxics Use Reduction Institute. Danvers-based Transene Company replaces toxic "forever chemicals" in partnership with TURI. Available at: https://www.turi.org/About_Us/News/Press_Releases/Danvers-based_Transene_Company_replaces_toxic_forever_chemicals_in_Partnership_with_TURI

[22] TURI (2009). Evaluation of Lead-Free Solders. https://www.turi.org/Our_Work/Industry_Small_Business/Industry_Sectors/Electronics/New_England_Lead-Free_Electronics_Consortium/Articles/Evaluation_of_Lead-Free_Solders

[23] Green Chemistry and Commerce Council. Projects Overview. Available at: https://greenchemistryandcommerce.org/projects/overview

[24] Becker, M, Tickner, JA. (2020). Driving safer products through collaborative innovation Lessons learned from the Green Chemistry & Commerce Council's collaborative innovation challenge for safe and effective preservatives for consumer products. Sustainable Chemistry and Pharmacy; 18: 100330. https://doi.org/10.1016/j.scp.2020.100330

IMPACTS ON INDUSTRY FROM CONTINUED PFAS USE

Continued use of PFAS presents a regulatory, litigation, and reputational risk for firms. The ECHA restrictions proposal is the culmination of an increasing number of PFAS restrictions globally for specific products such as fire-fighting foams, textiles, and food packaging. As in Europe, some U.S. states, such as Maine and Minnesota, are also taking broad class-based measures, restricting the sale of any product containing intentionally added PFAS[d,e]. In addition, litigation is increasingly resulting in companies having to pay for clean-up costs associated with PFAS contamination. For example, in 2022 Massachusetts Attorney General Maura Healey sued PFAS manufacturers for contaminating drinking water and damaging natural resources, in efforts to cover the $110 million in costs that the state has spent to address the contamination[f]. Taking a "wait-and-see" stance with regards to PFAS may not only put companies behind when regulations are implemented but increase the financial risk for companies that may be legally obligated to address PFAS contamination as a result of continued use.

CONCLUSION

PFAS are used in a multitude of applications in electronics products, providing critical functionality and performance. Hence, replacing their uses with safer solutions is not easy. Alternatives assessment can help the electronics industry be proactive in identifying the functional needs for PFAS in certain applications and in thoughtfully identifying and evaluating the alternative chemicals, materials, or product redesign solutions for their hazards, exposure potential, cost, performance, lifecycle impacts, and other factors. Alternatives assessments can also help identify where R&D is needed if no suitable alternatives exist. Alternatives assessment is a practical tool that can support electronics companies in phasing out PFAS uses in ways that both efficiently and effectively lead to safer, high-performing substitutes that benefit the company, consumers, and the environment, and that avoid costly regrettable substitutes that can impact reputation.

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