University of Massachusetts Lowell

UMASS

ANALYZING SUCCESS FACTORS TO ACCELERATE COMMERCIALIZATION OF NEW TECHNOLOGIES THAT REPLACE INCUMBENTS

Lessons for green chemistry commercialization

October 2022

Sustainable Chemistry Catalyst

AUTHORS AND PROJECT ORGANIZATIONS

Joel Tickner, Lowell Center for Sustainable Production, UMass Lowell

The Lowell Center for Sustainable Production at the University of Massachusetts Lowell is a leading academic center for action-oriented research, policy development, and collaborative initiatives focused on eliminating hazards in products, workplaces, and communities by promoting the development, evaluation and adoption of safer and sustainable chemistries, materials and products. For more information, visit www.uml.edu/research/lowell-center.

Amanda Cattermole, Cattermole Consulting Inc.

Cattermole Consulting is a sustainability consultancy that helps organizations develop and implement chemical management strategies that result in safer products made in greener supply chains.

Clients include large corporations, small mission-based companies, NGO's and Foundations. For more information, please visit www.cattermoleconsulting.com or email Amanda Cattermole at acattermole1205@gmail.com.

ABOUT

This report was produced by the Sustainable Chemistry Catalyst for the Green Chemistry & Commerce Council (GC3), a multi-stakeholder collaborative that drives the commercial adoption of green chemistry by catalyzing and guiding action across industries, sectors, and supply chains. GC3 members include major retailers and brands, large and small chemical suppliers, consultants, academia, and NGO's. GC3 accelerates the commercialization of green chemistry through three general strategies: creation of active learning communities; collaborative innovation across sectors and the value chain; and market activation and transformation.

The Catalyst works to understand barriers and opportunities to commercialization of safe and sustainable chemistry, identifies model solutions and strategies, develops methods to evaluate safer alternatives, and builds a community of expertise to support the transition to safer, more sustainable chemistries and technologies.

Sustainable Chemistry Catalyst

University of Massachusetts Lowell
Lowell Center for Sustainable Production
61 Wilder St., O'Leary 540, Lowell, MA 01854
www.uml.edu | www.sustainableproduction.org

EXECUTIVE SUMMARY

The Green Chemistry & Commerce Council (GC3) commissioned this report to develop practical insights and strategic lessons on how to accelerate the commercialization and scale of green chemistry technologies more effectively. To inform these, the Sustainable Chemistry Catalyst of the Lowell Center for Sustainable Production (UMass Lowell) conducted four instructive case studies coupled with online research and expert interviews to explore examples in which incumbent chemistries and technologies were successfully replaced with alternatives. The case studies and research were designed to i) uncover the strategies that were used to scale the alternative and accelerate the shift away from the incumbent, ii) the process by which the transition occurred and iii) how these lessons can be applied to accelerate transitions in the future.

Previous GC3 commissioned research has identified key drivers, barriers, and enablers to green chemistry innovation. Knowing these factors is a critical piece of the puzzle, but understanding how a transformative shift occurred, and the strategies that enabled those shifts, provides additional insights that may help accelerate green chemistry commercialization.

In each case study, we examined the timeline, key accelerators, the role of collaboration, whether a tipping point that ultimately catalyzed the substitution occurred, and if there was a domino effect where a sector followed the lead of a frontrunner company or companies. Importantly, the case studies were not focused on whether alternatives were "safer" or "more sustainable" but rather the process by which the substitution occurred and how to accelerate these transitions in the future.

Twenty-eight interviews were conducted for the four case studies (lessons and insights summarized in **Table 1**), which were:

i) Per- and polyfluoroalkyl substances (PFAS) replacement for durable water repellents (DWR) in fashion and outdoor apparel.

ii) Bisphenol A replacement in food packaging, for both reusable plastic bottles and can linings.

iii) The shift towards biobased household cleaning products (fabric care, toilet cleaners and surface cleaners).

iv) Hexabromocyclododecane replacement with BLUEDGE™ Polymeric Flame Retardant Technology (*Butadiene styrene brominated co-polymer*) originally developed by Dow, now DuPont, in expanded and extruded polystyrene foam for building materials.

Additional examples that compliment lessons from the four case studies were also identified. Finally, interviews probed the question of what is needed to accelerate commercialization of green chemistry and what role value chain and sectoral collaboration may play in achieving scale.

TABLE 1: Key insights and lessons from case studies and research

KEY INSIGHT	PROMISING PRACTICES	CASE STUDY OUTCOMES
Sectoral and value chain collaboration is critical in commercializing and scaling green chemistry	*Collaboration works best if there is a common problem that companies cannot solve by themselves.* *Successful collaboration should be facilitated through a stakeholder group, have a governance process, and provide a pre-competitive working space where information can be shared freely and confidentially.* *Chemistries for collaboration should be chosen carefully so as to avoid those that are key market differentiators.* *Shared technology knowledge (including protected information) can enable a clearer understanding and help to find optimal solutions.* *Collaboration between NGOs and businesses can advance the scale and adoption of alternatives through a combination of market and policy measures.* *A clear set of requirements should be established so that everyone is aligned on the same goal, shares similar values, and understands their role.* *Successful collaboration requires strong, effective working relationships and trust..*	The Outdoor Industry Association Chemical Management Working Group (OIA CMWG) provided a safe, precompetitive working space where members could learn from each other, share ideas, and develop tools and resources for the replacement of PFAS for DWR. They facilitated meetings three times a year, developed a strategic plan and a governance process on how to work collaboratively in a precompetitive space laying the groundwork for adoption of alternatives. In 2009, four blood transfusion companies collaborated to develop a new connector technology for blood transfusions to improve patient safety. They shared development costs and advocacy and aligned on a single connector standard. Greenpeace collaborated with appliance manufacturers, major brands, and the Consumer Goods Forum to develop and implement safer substitutes to HFC refrigerants and advance international policy to support the transition. Zero Discharge of Hazardous Chemicals (ZDHC) is spearheading the replacement of DMF, a solvent used in synthetic leather manufacturing. Because this is an industry-wide problem, a stakeholder group overseeing the work is more effective than brands individually looking for alternatives.
Licensing technology can accelerate scale and ensure a consistent supply	*Shared development and licensing of technologies to suppliers can accelerate scale and consistency resulting in a mutually beneficial relationship.*	Dow (now DuPont) developed and licensed its BLUEDGE™ flame retardant. It chose to license the technology because i) it is not in the flame retardant business and ii) to ensure supply was available as it rolled out across different countries and regions in a phased approach. By licensing, Dow allowed its three licensees to make process modifications and develop new use cases and value propositions.

Look back to look forward. The solution may already exist and be on the shelf	*Reviewing available off-the-shelf technologies before starting new development makes good business sense.*	Many PFAS - free replacements for DWR already existed including waxes, silicones, and urethane coatings. Oleoresins could be used to line cans for certain foods. Other existing BPA-free alternatives included epoxies, vinyl, acrylic, and polyester. Biobased surfactants from coconut oil, palm oil, and palm kernel oil had been used prior to the synthetic surfactants that replaced them. Greenpeace, in partnership with German scientists, resurrected a hydrocarbon butane/propane mix of refrigerants that were used in the 1930s prior to the introduction of CFCs.
NGO campaigns can accelerate change	*NGO campaigns can serve as a driver for safer chemicals as they raise consumer awareness and catalyze action.* *Collaboration with key NGOs can leverage pressure and consumer trust that drives change.*	The Greenpeace *Detox My Fashion* campaign targeted numerous apparel brands and retailers to phase out of 11 classes of hazardous chemicals by 2020. The campaign resulted in the formation of the Zero Discharge of Hazardous Chemicals (ZDHC) collaboration and significant action in the sector. NGO pressure was critical to catalyzing the replacement of BPA in food packaging. NGO reports targeting products that contained BPA resulted in large retailers (CVS, Wal-Mart, and Toys "R" Us) pledging to eliminate products with BPA from their shelves. The *Mind the Store* campaign's work with major retailers provided an impetus for retailers to substitute *ortho*-phthalate plasticizers in vinyl flooring and methylene chloride in paint strippers.
Savvy marketing can accelerate change and enhance education	*Focusing innovation efforts on products that contain "chemicals of concern" and have wider consumer awareness may result in a faster time to scale.*	"BPA-free" marketing on plastic bottles and other food packaging increased consumer awareness that helped accelerate the shift to alternatives. This followed earlier Greenpeace efforts to push for "phthalate free" toys.

Market leaders with considerable buying power can force widespread change by initiating a domino effect	*Well recognized innovators and early adopters have the power to advance change in a sector.* *A market leader that is willing to share information for the greater good causes a domino effect.*	H&M GROUP phased out of PFAS in 2013, which caused other fashion brands, especially those with Greenpeace commitments, to quickly follow suit. When REI eliminated sales of polycarbonate water bottles that contained BPA, Nalgene quickly announced a similar phase out and other retailers and water bottle brands soon followed. Lowe's was the first retailer to ban methylene chloride and NMP in paint strippers. Sherwin-Williams, The Home Depot, Walmart, and several other retailers soon followed. And then the EPA instituted a national ban on the retail sale of methylene chloride-based paint strippers. Method and Seventh Generation showed "proof of concept" catalyzing larger brands to adopt biobased ingredients in their product lines. Levi Strauss & Co. open-sourced their waterless techniques for denim finishing and The North Face donated a process on how to measure sustainable fibers.
Cost matters but it depends on the product	*Cost is not necessarily a barrier to commercialization because there are often supply chain solutions to address them.* *Cost decreases as demand increases and economies of scale are achieved.*	Tritan™, a replacement for polycarbonate from Eastman Chemicals, was more expensive. CamelBak, which entered the market with a Tritan™ bottle that cost more, found no barrier to REI sourcing it for their stores. Biobased ingredients are more expensive than synthetic ingredients, but Seventh Generation and Method's value proposition negated the higher cost of their products. BLUEDGE™ is more expensive than other alternatives. DuPont created incentives for flame retardant manufacturers to use it including relief on the licensing costs.
Regulations and voluntary restrictions accelerate innovation, commercialization, and adoption	*Restrictions in specific countries, regions, and states can accelerate action.*	In 2008, Health Canada announced that BPA was a "dangerous substance" and banned it on some products prompting other countries to follow suit, thereby triggering R&D. Several U.S. states have restricted the use of specific flame retardants in furniture and other products, BPA in baby bottles, and PFAS in packaging. Japan voluntarily reduced BPA in consumer products in 1998 triggering some epoxy resin formulators to develop alternatives and get a head start on possible U.S. regulations.

Shifting away from an incumbent is a complicated and long process	*Commercialization takes time, money, patience, and effort.* *Government R&D funding and support can hasten the commercialization of alternatives.*	Eliminating PFAS from DWR started in earnest in 2011 when Greenpeace launched its DeTox campaign. Availability of PFAS-free alternatives are increasing, but the suggested tipping point will not be until 2024 when all PFAS are expected to be regulated under REACh. PFAS, including long-chain PFAS, are still found in numerous consumer textiles including home, bedding, and outdoor apparel. BPA replacement in food cans began in 1999 and finally picked up speed in 2012 when a series of regulations came into force. Government funding and partnership programs such as SEMATECH in the semi-conductor industry and the National Nanotechnology Initiative provide strong evidence that government funding and support can accelerate solutions in the marketplace.

The case studies, literature review, and interviews demonstrate several promising practices that can accelerate commercialization of green and sustainable chemistry solutions across supply chains, though context specific strategies are also important. There are clear drivers for, and economic benefits of, investment in green chemistry solutions. However, there are significant barriers to commercialization and adoption. Any effort to accelerate green chemistry innovation will need to be cognizant of, and address the many, often context-specific barriers.

The goal of this research was to explore what interventions can help accelerate transitions to green and sustainable chemistry solutions. Clear market and policy drivers are an important starting point. Other interventions that are critical include:

- Sectoral and value chain collaborations to understand technology needs and establish a common language and standards
- Creating strong and unified demand signals and or commitments
- Leveraging partnerships, joint ventures, licensing, and other mechanisms to drive technology growth
- Providing a clear value proposition and marketing solutions.

Commercialization and adoption of green chemistry solutions is a slow and resource intensive process. Accelerating that process will require government or market interventions and sectoral collaborations (often with NGOs) that mobilize an entire sector, such as building materials or apparel and footwear, to take a leadership position in addressing the sustainable chemistry of its product lines. Identifying and engaging key alpha movers that have national or global recognition also plays an integral role in creating a domino effect that increases innovation adoption rates.

Ultimately, to accelerate innovation, commercialization, and adoption of green chemistry solutions that transition from incumbent chemistries, a combination of promising practices is required. These multiple practices create a "perfect storm" where there are clear and consistent drivers, performance and cost considerations are met, the solution becomes widely known, and companies achieve economies of scale through increased supply. Understanding and adapting the interventions that have worked will be essential to successfully reaching a safe and sustainable materials future.

TABLE OF CONTENTS

INTRODUCTION

The mission of the Green Chemistry & Commerce Council (GC3) is to accelerate R&D, commercialization, scaling, and adoption of green chemistry solutions. GC3 creates opportunities for companies to collaborate to accelerate technology innovation, initially in pre-competitive areas where companies making and selling products have common technology needs. Building on its earlier efforts in collaborative innovation to advance the development of safe and effective preservatives for consumer products, the GC3 embarked in 2020 on a pilot of its new Commercialization Hub, an effort to develop collaborations and strategic roadmaps to accelerate commercialization of green chemistry technologies. The pilot focused on one strategy to accelerate commercialization, a "Shark Tank" where companies with innovative preservation solutions could pitch their solutions to interested downstream partners and then GC3 could facilitate multi-partner solutions consortia.

FIGURE 1: The GC3 goal is to accelerate the growth of green and sustainable chemistry solutions

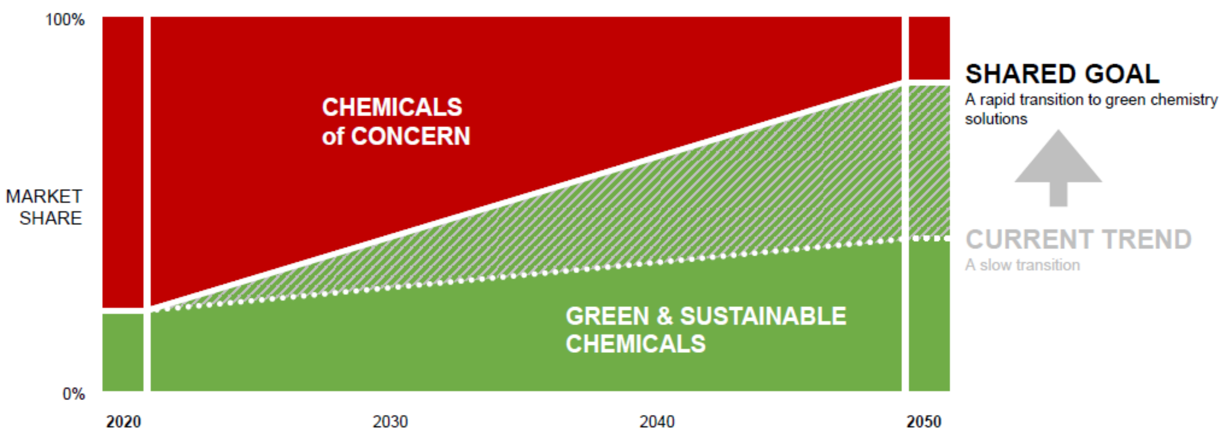


IMAGE SOURCE: Institute for Safer Chemical Alternatives, 2021

To further understand strategies to accelerate commercialization and scale of green chemistry, the GC3 asked the Sustainable Chemistry Catalyst of the Lowell Center for Sustainable Production from UMass Lowell to conduct four case studies, coupled with online research, to identify examples in which incumbent chemistries were replaced with alternatives. The case studies and research were designed to uncover strategies that were used to both scale the alternative and accelerate the shift away from the incumbent.

Previous GC3 commissioned research has identified key drivers, enablers, and barriers to green chemistry innovation.

FIGURE 2: Deterrents and accelerators to green chemistry adoption

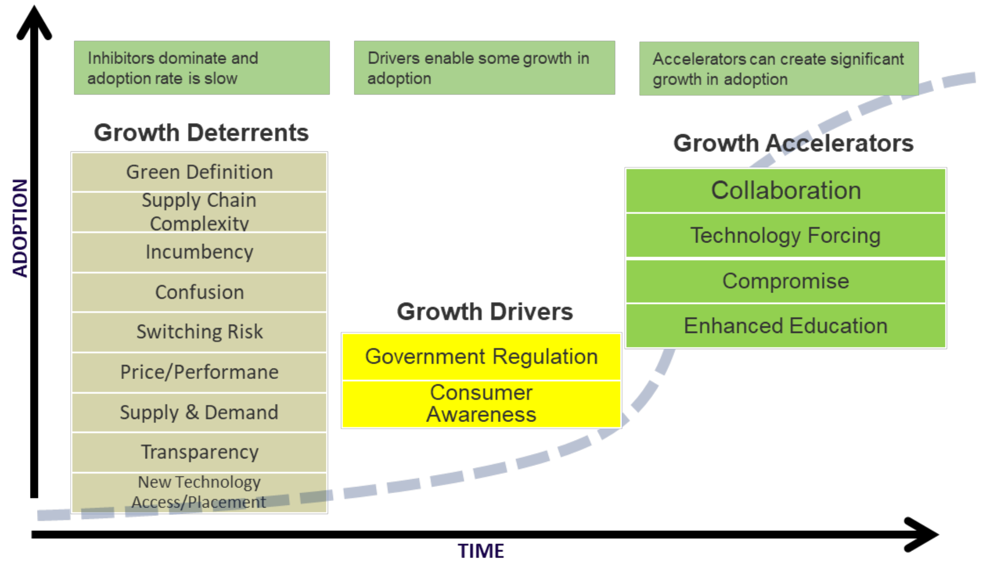


IMAGE SOURCE: T. Fennelly & Associates, Inc. (for the Green Chemistry & Commerce Council), 2015

Additional GC3 case study research has identified factors inhibiting and supporting adoption of substitutes. Knowing these factors is a critical piece of the puzzle, but understanding how a transformative shift occurred, and the strategies that enabled those shifts, provides additional insights that may help accelerate green chemistry commercialization. For example, did one company lead or was it a collaborative approach where competitors joined forces? How long did the transition take, what were the key accelerators, and what was the tipping point that ultimately drove the market change? And finally, what was the role of policy, investment, and incentives in effecting the transition? Case studies provide practical examples from which future strategies can be developed.

PURPOSE OF THE REPORT

This report aims to identify key promising practices that can accelerate the commercialization and adoption of green chemistry solutions. Four case studies, as well as literature on technology commercialization, were analyzed to draw lessons on how to scale alternatives. The Sustainable Chemistry Catalyst conducted case studies in apparel, food packaging, household cleaning products, and flame retardants in building materials, specifically expanded and extruded polystyrene foam.

For each case study, we examined the timeline, key accelerators, whether collaboration played a role, and whether a tipping point, occurred. In addition, we explored whether there was a domino effect, where frontrunners changed the marketplace in a particular case. We also explored the role of "alpha movers", which refers to *a brand or company that gains a competitive advantage by being the first to market with a product or service.*

FIGURE 3: Alpha movers (innovators to early majority) can cause a domino effect to speed the adoption curve

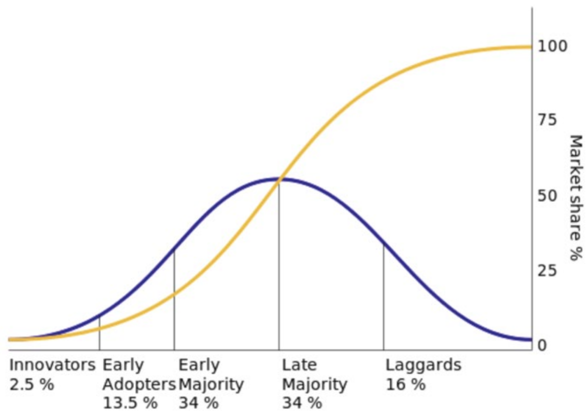


IMAGE SOURCE:
Diffusion of Innovations, Everett M. Rogers, 1962

A further set of questions probed what is needed to scale green and sustainable chemistry solutions, and what role value chain and sectoral collaboration may play. Importantly, we attempted to develop an understanding of the drivers for the transition away from the incumbent chemistry in each case. It was outside the scope of this study to thoroughly evaluate the alternatives selected or policy and market drivers. Concerns have been raised about the safety of alternatives to the incumbent chemistry in specific cases. For example, the switch from bisphenol-A (BPA) to other bisphenols was considered by the scientific community as a regrettable substitution. In this report, *we are not focused on determining the best alternatives, but rather the process by which the substitution occurred and how to accelerate these transitions in the future*. It is critically important that new alternatives be designed using the principles of green chemistry and that they are assessed employing the tools of alternatives assessment to support the transition towards safer, more sustainable chemicals and products.

METHODS

The case studies were developed through 28 interviews and document analysis. Additional online research and interviews were used to identify examples of where incumbent technologies have been replaced by alternatives. These examples are described in the discussion section of the report.

Questions (see Appendix A) were designed to uncover how the shift to alternatives occurred. For each case study, we mapped a timeline that shows key drivers, accelerators and other important attributes that supported the transition away from the incumbent chemistry. Where possible, a tipping point was also identified based on expert interviews and the literature review.

The full case studies are published as separate reports. The four case studies are:

i) Per- and polyfluoroalkyl substances (PFAS) replacement for durable water repellents (DWR) in both fashion and outdoor apparel.

ii) Bisphenol A (BPA) replacement in food packaging, for both reusable plastic bottles and can linings.

iii) The shift towards biobased household cleaning products (including fabric care, toilet cleaners and surface cleaners).

iv) Hexabromocyclododecane (HBDC) replacement with BLUEDGE™ Polymeric Flame Retardant Technology (*butadiene styrene brominated co-polymer*) by DuPont (BLUEDGE™)[1]. in expanded and extruded polystyrene foam for building materials.

It is important to note that the case studies were developed based on the understanding of individuals at companies and other stakeholder organizations involved in each case. Information obtained from interviews was not verified except with those interviewed; but where additional documentation was available, it was considered in the development of the case study.

[1] Initially developed by Dow Chemical Company but is now owned by DuPont after the merger between Dow Chemical Company and E.I. du Pont de Nemours & Company in 2017.

CASE STUDY SUMMARIES

Per- and polyfluoroalkyl substances (PFAS) replacements in apparel

This case study identifies promising practices that accelerated the substitution of PFAS, a class including more than 3,500 chemicals, some of which are used to achieve Durable Water Repellency (DWR) and stain management properties in apparel. The case study excludes the fluorinated polymer (PTFE or Teflon) used as a water repellant, breathable membrane in the outdoor industry, which remains a major barrier for PFAS substitution in outdoor textiles. This substitution encompasses fashion and outdoor products, but does not include school uniforms, workwear, and home furnishings. Fashion and Outdoor are different use cases because the approach to substitution of PFAS is different for each category and some outdoor apparel brands still use PFAS for certain products within their portfolios.

We interviewed two brands, KEEN Footwear and H&M GROUP, because they successfully phased PFAS out of their product assortments. These two companies are not representative of the entire outdoor and fashion apparel segments, but they provide insights that may be applicable to the broader strategy of scaling and commercializing green chemistry solutions. The Outdoor Industry Association, chemical companies, consultants, and other stakeholder groups were interviewed for this case study.

PFAS were widely introduced in the apparel market in the late 1980's but gained momentum in the early 2000's as consumers delighted in apparel that provided performance benefits such as stain management and durable water repellency. In 2002, Dockers launched GoKhaki® with Stain Defender®, using Teflon, a branded PFAS from DuPont[2]. Stain management completely transformed men's casual apparel, and by the mid 2000's, it was used on almost all business casual slacks and chinos. The outdoor industry also enjoyed growth as more people embraced the outdoors and trade deals incentivized greater global production. For example, quotas were removed in 2005 and replaced with tariffs and bilateral agreements between the Global North and China.

In the mid to late 2000's, the apparel industry grew very quickly, due to the introduction of fast fashion[3] coupled with inexpensive manufacturing in developing countries. Brands introduced product innovations and performance attributes, such as easy care, stain resistance, stretch, and durable water repellency, to name a few, to differentiate themselves from their competitors. By 2013, PFAS were used on many types of clothing from jackets to jeans, sweaters, shirts, and shoes.

Health and safety concerns with PFAS surfaced in the 1990's and concern has grown over time as more and more data become available. Many PFAS chemicals bioaccumulate and take a long time to break down in the environment. According to the EPA, the scientific literature supports that PFAS chemicals can be endocrine disruptors, carcinogens, create developmental delays, negatively impact fertility, and interfere with important immune system functions. Due to these concerns, the Environmental Working Group is currently tracking PFAS contamination in drinking water supplies across the United States. An increasing number of NGO campaigns and government regulators are targeting specific uses of PFAS or the complete class of chemicals for restriction. Due to toxicity concerns and the presence of two PFAS – Perfluorooctanoic Acid (PFOA) and Perfluorooctane Sulfonate (PFOS) - in

[2] **Teflon** is made by Chemours, a chemical manufacturer that was spun out of DuPont in 2015

[3] Fast fashion is a term used to describe a profitable business model based on replicating high-fashion designs and mass-producing them at low cost. The term *fast fashion* is also used to generically describe the products of the fast fashion business model. There are numerous environmental and human health consequences of fast fashion, and much of the production occurs in developing countries that have cheap labor and little to no environmental regulations.

blood nationally, 3M began a voluntary phase out of Scotchgard water repellant coatings in 2000, which are made with PFOS. In 2006, eight major PFAS manufacturers agreed to the voluntary EPA 2010/2015 PFOA Stewardship Program including a commitment to phase-out long chain PFAS by 2015, which are generally considered more dangerous to human health and the environment. The pre-competitive discussions, as part of the initiative, represented a starting point for moving away from long chain to short chain PFAS, which is now considered by many as a regrettable substitution. These commitments and the Greenpeace Detox My Fashion campaign accelerated a shift away from all PFAS coatings beginning in 2011. Emerging PFAS concerns drove some chemical companies to start developing non-PFAS alternatives in the early 2000's, even though there was little interest in them by brands and other customers for almost a decade, until the pressure to eliminate PFAS increased. For example, RUDOLF GmbH developed a PFAS-free DWR in the early 2000's, but it wasn't until 2013 that brands began asking for it.

There were few, if any, government incentives to accelerate the shift of apparel manufacturers away from using PFAS. In the absence of incentives, H&M GROUP was an alpha mover, and their PFAS-free product line caused a domino effect in the fashion sector. In 2013, it was one of the first companies to require and market PFAS-free alternatives, which was not a large challenge because water resistant apparel represented a very small part of the overall business. H&M GROUP reviewed its performance standards and accepted PFAS-free alternatives because they met internal performance standards for children's products treated with a DWR finish. However, some brands had higher performance standards for certain products, which could only be met with PFAS. Available PFAS-alternatives do not offer the same degree of durable water repellence required on some products, nor do they provide oil repellency. Other fashion brands followed suit in approximately 2015, mostly driven by the commitments they made to Greenpeace.

Outdoor brands have been slower in transitioning to PFAS alternatives, and a domino effect has not occurred. For the outdoor industry, the alternatives, even the shorter chain) PFAS alternatives initially offered by the chemical industry, did not perform as well as the incumbent. Performance concerns were a clear barrier that slowed their adoption, even though the costs between PFAS and PFAS-free alternatives were similar. Through successful collaboration via the Outdoor Industry Association Chemical Management Working Group (OIA CMWG), a useful exchange of information helped educate brands about PFAS. The OIA CMWG successfully convened brands and users of PFAS to develop understanding of the information stakeholders needed about the topic. An important barrier to the transition to PFAS alternatives identified by some stakeholders is that many of the leading brands rely on third party sustainability standards or restricted substance lists like OEKO TEX, bluesign®, and AFIRM, and to date none of these restrict the entire PFAS class.

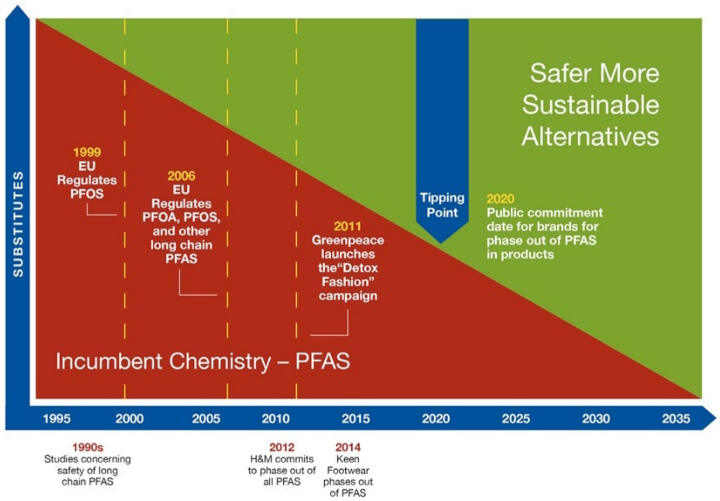
Many brands took a nuanced approach to using PFAS. Instead of using it on most of their products, PFAS were only applied to those products that needed exceptional DWR performance. The North Face, Patagonia and some other brands offer jackets with different levels of DWR, depending on the use of the garment. For very high-performance needs, such as mountaineering, PFAS may be used to provide DWR, whereas urban jackets may be treated with PFAS-free DWR. KEEN Footwear first eliminated PFAS from its sandals without looking for a replacement because DWR is not needed for a product that is designed to get wet. That decision represented a significant business volume. KEEN Footwear also eliminated PFAS from specific materials used in its product portfolio, and over a six year period between 2014 and 2020, it eliminated PFAS from its entire product portfolio.

All these changes led to a domino effect in the chemical industry to develop PFAS-free alternatives. Today, many DWR's are "PFAS-free" and different types of alternatives are available from numerous chemical companies. However, whether they are widely used by clothing manufacturers and other textile producers may not be the case as indicated by the recent report from Toxic Free Future that found PFAS in 72% of textiles[4] marketed as stain resistant or DWR. The sheer number of alternatives, however, shows that they have scaled and are readily available in the market.

[4] Outerwear apparel, home textiles such as bedding, and napkins were tested.

Efforts by NGOs including ChemSec[5], the Green Science Policy Institute, and Mind the Store are accelerating the shift to alternatives by encouraging retailers and brands to move away from PFAS in numerous applications, including beauty care, food packaging, and apparel. Catalyzed by Greenpeace and accelerated by others, the tipping point away from PFAS for major fashion brands occurred in 2020, despite recent evidence that PFAS is still widely used in many products labeled stain and water resistant. A tipping point for outdoor brands is theorized to be in approximately 2024 when the whole PFAS class is expected to be regulated by the EU and some U.S. states including California and Washington. A scorecard launched in 2022 by the Natural Resources Defense Council (NRDC) that builds on Greenpeace's effort to spotlight brands and retailers may accelerate the process.

FIGURE 4: Accelerators, timeline, and tipping point for removal of PFAS from apparel



TIMELINE: Per- and polyfluoroalkyl substances (PFAS) replacements in apparel

DATE	ACTION
1990's	Science community publishes concerning reports about safety of long chain PFAS, especially PFOA and PFOS
1999	PFOS regulated in the EU
1999	3M voluntarily phases out Scotchgard, which is made from PFOS
2006	EU regulates PFOA, PFOS and other long chain PFAS
2006	EPA voluntarily reduction of a 95% reduction of PFOA precursor chemicals by 2010 total elimination by 2015
2006	Chemical companies start to research replacement to PFAS
2011	Greenpeace launches the Detox Fashion campaign requiring the fashion industry to phase out of hazardous chemicals, including PFAS, by 2020
2012	H&M is the first brand, targeted by Greenpeace, to phase out of ALL PFAS
2014	PFOA regulated in the EU
2014	Keen Footwear phases out of PFAS
2020	Brand public commitment due date to phase PFAS out of products
2018 - 2022	Numerous brands provide apparel products that are free from long chain PFAS and PFAS-free in response to regulations and NGO pressure
2022	Research that all rainwater worldwide is contaminated with PFAS above U.S. EPA determined safe limits

[5] Many apparel brands retailers including H&M GROUP, Bestseller, Nudie jeans, Lacoste, and New Balance, to name a few, have recently joined the ChemSec "No to PFAS" movement, where advocacy is driving retailers and brands to seek alternatives to PFAS.

Bisphenol a (BPA) replacements on plastic bottles (polycarbonate) and can linings for food

This case study identifies promising practices that led to the substitution of BPA in food packaging in two different use cases: reusable polycarbonate water bottles, where BPA is a precursor to polycarbonate plastic, and can linings for food and beverages made from epoxy resins derived from BPA. Polycarbonate bottles have generally been replaced with either reusable metal bottles or Tritan™, a copolyester, drop-in replacement from Eastman Chemical. The transition to alternatives in can linings has started but is not yet complete. Some beverage cans are still lined with epoxy resins derived from BPA or structurally similar compounds, BPS or BPF, because some alternatives absorb and eliminate flavorings in certain beverages.

The Sustainable Chemistry Catalyst interviewed CamelBak, REI, and Valspar. CamelBak and REI successfully transitioned out of polycarbonate bottes and Valspar, a resin supplier, developed a suite of replacements to can linings using their Safety by Design product development process that included input from external health experts and NGOs. Other resin suppliers, such as Dow, have also developed non-BPA alternatives for can linings.

Scientists started to raise concerns about BPA in the early 1990's, especially its use in food packaging. BPA is recognized by many scientists as an endocrine disruptor, which can cause health impacts at very low levels of exposure during development. By the late 1990's, as more scientific studies and data became available, environmental health and consumer NGOs worked with scientists and initiated campaigns to educate consumers, brands, and retailers about the health effects of BPA. These campaigns increased awareness and promoted change at the local, regional, and national levels.

Polycarbonate Plastic

For reusable water bottles, the shift away from polycarbonate bottles was swift, starting in the Outdoor Industry, specifically with REI and Mountain Equipment Coop (a Canadian retailer) in 2006/2007. Drop-in, high performing, but more expensive replacements were available. Eastman Chemical had a heat resistant plastic called Tritan™ that CamelBak used to enter the reusable water bottle segment (in close collaboration with Eastman), and KleanKanteen had a stainless-steel bottle that didn't need a lining. When Nalgene announced a move away from polycarbonate for its outdoor reusable bottles in April 2008, REI, in the same month, restricted BPA in its own bottles. It then restricted sales of all polycarbonate bottles, thus creating a domino effect where other bottle makers were forced to quickly find polycarbonate replacements. Manufacturers had little choice because REI, an alpha mover, and a large, well-respected retailer, did not accept products containing BPA.

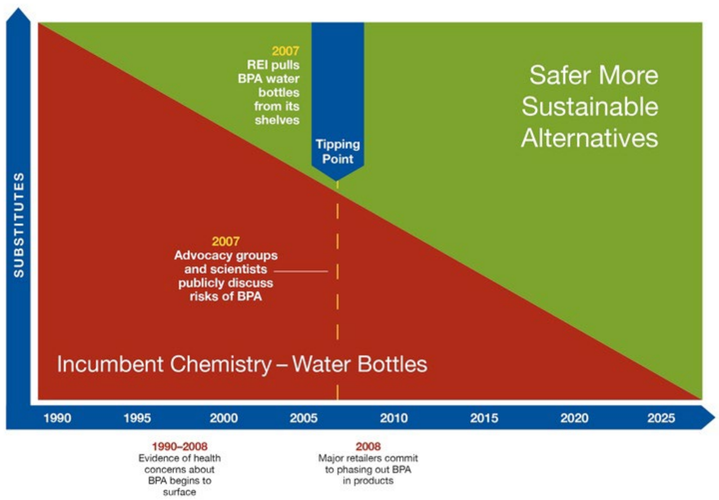
Action on reusable water bottles led to additional studies on BPA in baby bottles by environmental and public health groups in the U.S. and Canada. In 2008, Health Canada announced that BPA was a dangerous substance and restricted polycarbonate baby bottles. Additional NGO reports, and a campaign focused on retailers, soon after led to public commitments from Toys "R" Us and Wal-Mart to stop selling baby bottles made from polycarbonate. Numerous U.S. state regulations targeting BPA were initiated in 2008.

NGO campaigns, savvy "BPA-free" marketing from brands and retailers, and retail policies restricting BPA from certain products all played a role in accelerating the phase out of BPA in plastic bottles. The key factors working in combination with each other were as follows:

- A drop-in alternative was available
- Reusable water bottles are high margin products that can absorb the cost increase
- The product was reusable, which was a sustainability trend that consumers cared about
- A well-respected retailer led the effort, which catalyzed others to act

It is hard to determine the exact tipping point, but it was likely in 2008 after REI announced its restrictions on polycarbonate bottles and was supported by savvy "BPA-free" marketing targeted towards brands, suppliers, and consumers.

FIGURE 5: Timeline and tipping points of BPA removal from water bottles



Can Linings

Government, academic, and non-government organization studies identified BPA contamination in foods and baby formula starting in the 1990s. In 2007, the Environmental Working Group (EWG) conducted studies finding widespread exposure to BPA from a broad set of canned foods and infant formula. Later studies by the Silent Spring Institute and others found similar results.

Phasing out of epoxy resins derived from BPA in can linings was more difficult and took much longer than polycarbonate for many reasons:

- The performance requirements for alternatives were challenging due to the different food content of the cans (what works for beans may not work for tomatoes)
- Development times for alternatives were long, 7-10 years
- There was no appetite for a price increase. Food cans are low cost, disposable materials
- There were no drop-in replacements for all applications (food and beverage)
- BPA is an inexpensive commodity chemical that provided excellent protection for all foods and beverages
- BPA was not restricted in can linings

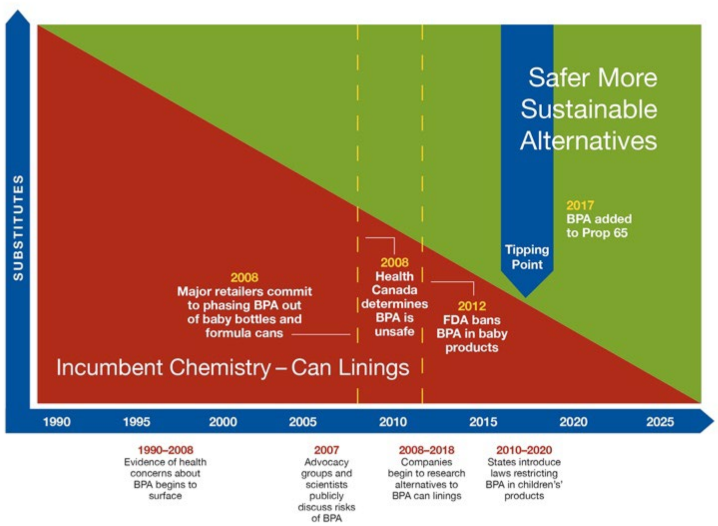
Between 1998 and 2003 Japanese companies voluntarily reduced the use of BPA in consumer products. This was noticed by epoxy resin formulators who then started to develop alternatives, some from existing chemicals that had already passed regulatory hurdles. After 2010, there was significant effort to restrict BPA in the U.S., the EU, Canada, and China, which pushed certain elements of the food and beverage packaging industry to start in earnest to eliminate BPA from food packaging. France, for example, first banned BPA in children's food packaging in 2013 and then expanded the ban in 2015 to include all packaging intended for contact with food. Earlier efforts to develop alternatives were accelerated by these regulatory and market actions.

Collaboration existed between the FDA and can lining formulators. The FDA facilitated and accelerated approvals of non-BPA materials, which allowed for food contact notifications for numerous uses to be submitted. Collaborations between companies and the EPA to bring safer new bisphenol-based molecules to market – such as [Valspar's Valpure® non-BPA linings] – were also critical.

In 1999, [Eden Foods] was the first food brand to replace BPA in most of its products. It returned to linings that it used prior to BPA and absorbed the higher cost of the alternatives. It would take several years for other brands to follow, and Eden Foods was seen as an outlier rather than an alpha mover. For other brands, cost was an issue to substitution, and the alternatives were more expensive, at least initially. As such, there was no domino effect, which could be due to lower broad application performance coupled with cost increases.

The tipping point, which is hard to define, was probably reached in either 2015 due to the French ban, or in 2017 when BPA was added to California's Prop 65 list of chemicals that may cause cancer or reproductive effects. Today most food cans and approximately 70% of beverage cans are lined with alternatives to BPA.

FIGURE 6: Timeline and tipping points of BPA removal from can linings



TIMELINE: Bisphenol a (BPA) replacements in food packaging

DATE	ACTION
1990 - 2008	Evidence of health concerns about BPA begins to surface
1999 - 2017	EDEN foods introduce BPA free can linings for canned beans, one of their largest products. This starts their journey to become a BPA-free company
2003	Japanese companies voluntarily reduce the use of BPA between 1998 and 2003.
2007	Advocacy groups and scientists talk publicly about the risks of BPA
2008	Health Canada says BPA is unsafe
2008	Major retailers commit to phasing BPA out of certain baby products, including water bottles and formula cans
2008 - 2018	Formulating companies begin to research alternatives to BPA can linings
2010 - 2020	Numerous states begin to introduce laws to reduce exposure to BPA in certain products, starting with children's' products
2012	FDA bans BPA in baby products
2016	Investigation shows that 33% food cans are BPA-free
2017	BPA added to Prop 65
2017	Investigation shows that 62% food cans are BPA-free
2020	Investigation shows that 96% food cans are BPA-free

Biobased products in the household care market

This case study identifies strategies that have led to the substitution of petroleum-based ingredients and the increased use of biobased ingredients in the global household care market, which includes fabric care, carpet spot cleaners, dishwashing, hard surface cleaners and toilet care. This is a large consumer segment, (USD 115 billion in 2018), and it is estimated that 3 - 10% of the total market is represented by biobased products. It is projected to grow at a CAGR of 1.5% between 2021-2026, to reach USD 126 billion by 2026 due to growth in Asia and South America.

Biobased products are derived from biomass, which includes plants and other renewable agricultural, marine, and forestry materials. They can offer improved functionalities with reduced greenhouse gas emissions, less toxicity, less waste, and better end-of-life options for final disposal.

The Sustainable Chemistry Catalyst interviewed Seventh Generation, Method, and P&G (Tide) for this case study. Seventh Generation and Method are recognized as brand alpha movers, however, once P&G's Tide Purclean™ was launched in 2017, it demonstrated that biobased household care products had gone mainstream due to the volume, name recognition, and distribution of the Tide brand. In 2014, over 40 million American households used Tide. DuPont was also an alpha mover due to its renewable ingredient strategy. In the early 2000's, DuPont invested 10% of its $1.3 billion research budget into developing biobased raw materials to protect against fluctuating oil prices and to respond to regulators, environmentalists, and shareholders.

Biobased household care products started to emerge in the 1990's in natural food markets, which offered products to attract environmentally conscious consumers. Seventh Generation started in 1988 as a catalog marketer of environmentally conscious products, but it wasn't until the early 1990's that it focused on making non-toxic cleaning products that expanded quickly into Whole Foods Market. Over the next couple of decades, awareness of environmentally friendly, non-toxic household cleaning products grew as consumers were exposed to a greater offerings and marketing of "green", "natural" and "biobased" products. In 2002, Method products were offered in Target, and in 2009 Clorox launched Greenworks, the first large consumer goods company to issue a green option. Today, eco-conscious, household care products are widely available in retailers across the nation.

The USDA BioPreferred Program, which started in 2002 and has been recently revamped, has increased consumer awareness because its logo is used by many brands to advertise their products. In 2017, the biobased industry in the U.S. supported over 4.6 million people and created $470 billion in value added. The same research demonstrates that products with certifications or claims of green chemistry are growing several-fold faster in the marketplace than their incumbent competitors.

Performance of biobased products was an initial barrier, but a flurry of R&D and innovation activity in the bioeconomy in the mid 2000's, in addition to formulators learning how to use biobased ingredients, resulted in products that are as effective as the incumbents in most uses.

The cost to commercialize biobased ingredients (up to $500 million) was prohibitively high for those small biobased ingredient startups that failed to develop partnerships with large chemical companies. Some went out of business because they could not compete, even though, in approximately 2010, venture capital firms were heavily investing in biotechnology and the bioeconomy. This investment period was short-lived due to i) the advent of hydraulic fracking, which significantly lowered natural gas prices and ii) the often very long return on investment (ROI) for biobased ingredients, especially when compared to other sectors, such as social media companies (Facebook, Twitter, etc.) that were financed by venture capital and had very quick ROI.

Cost was and continues to be a barrier to adoption and scale of biobased ingredients by brands. Smaller brands were eager for big national brands to launch biobased products, even though they are competitors, because their entry into the market would create stability and cost reductions, leading to longevity and lower risk. Initial high costs were somewhat offset by greater demand from national brands coupled with "maturing" biobased supply chains that are more efficient.

Today, ingredient availability is the biggest barrier to scale because large, national brands have entered the market. There are simply not enough biobased ingredients to replace incumbents in such a large consumer category.

Acquisitions, collaboration, synergies, and partnerships have played an outsized role in this sector, not only to secure availability of biobased ingredients, but also for initial pilot testing, scaleup and brand testing. A few examples include:

i) Partnerships between ingredient providers and brands to address scale, technology transfer and cost. Method, with limited volume needs, met the volume capabilities of smaller ingredient startup manufacturers such as Segetis[6]. A synergistic relationship ensued where Method had access to novel high-performing ingredients and Segetis had a highly visible buyer for its products.

ii) Large manufacturers, such as BASF, could produce Method "market volumes" in their pilot plants, which allowed them to test and commercialize new ingredients in real time.

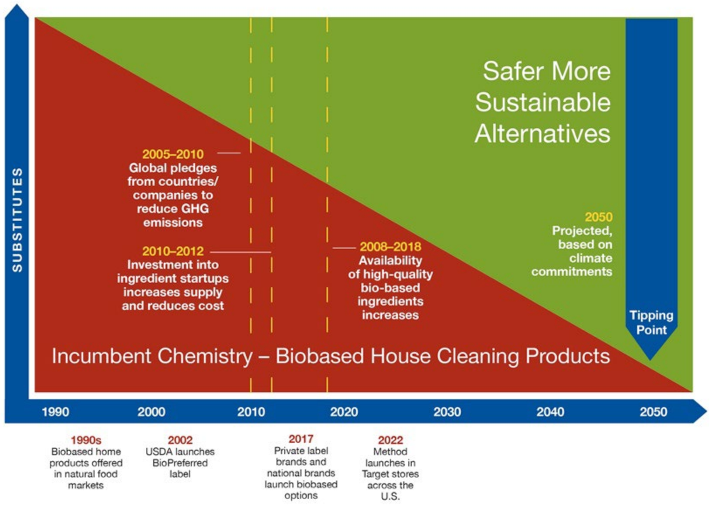
iii) Some chemical companies collaborated to scale specific biobased building blocks at a manageable cost. DuPont collaborated with Genomatica (now Geno) to scale 1,4 butanediol using Genomatica's biotech expertise.

There has not been a domino effect with one firm leading a transition among others. Rather, the shift to biobased household care products has been gradual and is still ongoing. Due to growing consumer awareness and company "sustainability" pledges, it is accelerating quickly, with a proposed tipping point in 2050 given the net zero goals for climate change and GHG emissions reduction targets. Countries and individual companies are making corporate commitments to cut their carbon footprints. For example, Unilever has pledged $1 billion to eliminate fossil fuel in cleaning products by 2030. Central to this pledge is its Carbon Rainbow, which is a novel approach to diversify carbon. Interviewees suggested that the 2030's will focus on carbon reductions and scope 3 emissions, and in the 2040's, technologies will scale and GHG emissions will decrease until net zero.

Given that 2050 net zero goals have been widely embraced by industry, governments, and countries, and knowing that biotech is one solution, national governments have provided incentives for biobased chemicals and materials. In 2012, the Obama administration launched the "Blueprint" for the bioeconomy which was updated in September 2022 with a Biden Administration Executive Order. A similar Bioeconomy strategy was lunched in Europe in 2012 and has been updated since. These efforts provide significant investment and procurement incentives to use biobased ingredients.

FIGURE 7: Timeline and tipping points of removing petroleum-based and replacing it with bio-based

[6] Segetis is no longer in business due to the enormous startup costs of manufacturing. Joint partnerships have somewhat mitigated this issue.



TIMELINE: Biobased products in the household care market

DATE	ACTION
1990's	Biobased home products are offered in natural food markets
2002	USDA launches BioPreferred label
2002	Method launches in Target stores across the U.S.
2005 - 2010	Global pledges from countries and companies to increase the use of bio-based products to reduce GHG emissions
2008 - 2018	Availability of high-quality bio-based ingredients increases
2010 - 2012	Investment into ingredient startups increases supply and reduces cost
2016	P&G launches Tide Purclean nationally
2017	Numerous private label brands and national brands launch biobased options
2020	Covid 19 spotlights cleaning products that include biobased options
2050	Suspected Tipping point due to climate change, regulations and other factors

Hexabromocyclododecane (HBCD) replacement in extruded polystyrene foam (XPS) and expanded polystyrene foam (EPS) insulation products in the building industry

This case study identifies strategies that supported the substitution of HBCD, a brominated flame retardant applied to polystyrene foam to provide thermal insulation in building materials (both for extruded polystyrene – XPS -and expanded polystyrene – EPS). The replacement was the BLUEDGE™ Polymeric Flame Retardant Technology by DuPont[7]. (B*utadiene styrene brominated co-polymer*). DuPont was interviewed for this case study given its outsized role in the replacement.

Pressure to substitute HCBD began in the early 2000s, when it was identified and classified as a persistent organic pollutant (POP). HBCD has been regulated by several countries since 2008 due to its persistence, toxicity and ecotoxicity, and these regulations were the driving force to identify a replacement technology. During the development process, which began in 2005, Dow reviewed existing technologies and realized that non-persistent, high performing alternatives were not available. Dow developed a novel, large molecule flame-retardant technology from scratch, and collaborated with the flame-retardant industry to ensure the replacement met specific criteria for human and environmental health, as well as performance. As part of the development process, Dow aligned with other flame-retardant manufacturers to establish the criteria for analyzing replacements.

In 2011, after extensive testing, Dow identified BLUEDGE™ as a replacement to HBCD , brought it to market in 2013 and scaled its use quickly through licensing agreements to ensure an adequate, stable supply. Dow also created an alliance with its licensees to establish a large voice for BLUEDGE™ adoption, with consistent messaging. Importantly, the EPA's Design for Environment (DfE, now Safer Choice) analysis of flame retardant alternatives to HCBD identified the BLUEDGE™ technology as a safer option.

In 2014, Japan was the first country to ban HBDC. Dow worked with its licensees to ensure there was adequate supply to respond to restrictions in other markets, notably Canada in 2015, Europe in 2015, and the United States in 2017. This phased approach allowed for a controlled conversion process that ensured business' regional quality requirements were met while at the same time product availability met regional market demands and all relevant regulations.

The biggest barrier to EU adoption was supply, due to the August 2015 sunset date under European REACh legislation. Supply chain and government discussions created stability of supply to avoid shortages or delays, which was part of the rationale for Dow to start licensing BLUEDGE™ to ICL and Chemtura.

Today, expanding BLUEDGE™ to China is the biggest barrier to growth, because there are a number of available, unregulated small molecule alternatives, leading to a challenging business case; while BLUDEDGE™'s environmental profile is preferable, it is more expensive than the other alternatives. The availability of cheaper options in major markets such as China, presents a dilemma and incumbency challenge for companies like DuPont attempting to sell more sustainable options.

Although BLUEDGE™ has a superior environmental profile (it meets criteria for several eco-labels including the Nordic Swan Ecolabel program) and it performs as well as the incumbent, its main

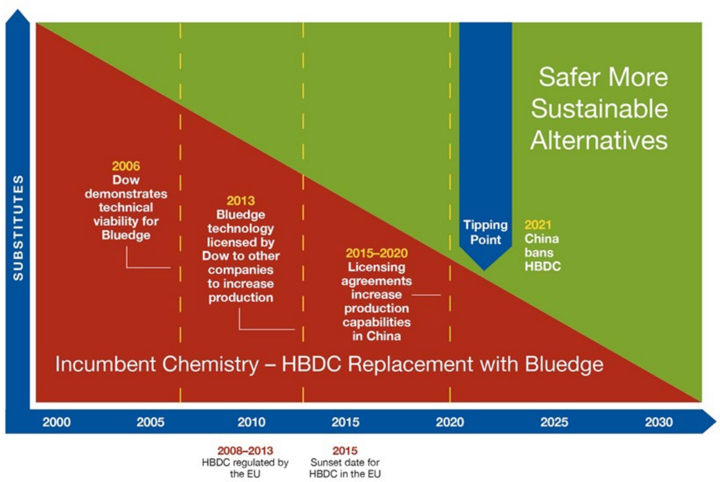
[7] Initially developed by Dow Chemical Company, which is now called DowDupont after the merger between Dow Chemical Company and E.I. du Pont de NemoEDGurs & Company on August 31st, 2017) (same comment on the evolution of this merger since 2017)

success and growth was due to co-development and licensing agreements with flame retardant suppliers. Collaboration with BASF demonstrated utility of BLUEDGE™ in EPS Foam. By licensing its technology, Dow, which from its perspective is not in the flame retardant supply industry, allowed its three initial supply partners, Chemtura, Albemarle and ICL to "go into any channel they choose and to tweak the material as needed." Demonstrating technology feasibility at manufacturing scale using existing assets by Chemtura led others to follow. Over years, the BLUEDGE™ team has built strong relationships with stakeholders in partner companies, which has led to technology improvements. These licensing agreements allowed quick adoption as the flame-retardant companies already had established markets. This licensing model has remained, and today DuPont continues to create licensing agreements with the flame-retardant supply industry, including in China, to support BLUEDGE™ use in both XPS and EPS.

A domino effect occurred in that as soon as the first licensee demonstrated that they could manufacture BLUEDGE™ in 2013, other licensees soon followed suit. As BLUEDGE™ is more expensive than other alternatives, to offset the cost increase DuPont offered relief on licensing costs in the EU.

The technology tipped in Japan, the EU, the U.S., and Canada when specific country regulations took effect, especially the August 2015 EU HBDC sunset date. However, China may prove to be a challenge, and the higher cost compared to newer small-molecule alternatives may require additional stakeholder engagement to build its customer base.

FIGURE 8: Timeline and tipping points on HBCD substitution with BLUEDGE™ technology



TIMELINE: Hexabromocyclododecane (HBCD) replacement in extruded polystyrene foam (XPS) and expanded polystyrene foam (EPS) insulation products in the building industry

DATE	ACTION
2004 - 2011	Dow develops BLUEDGE™ technology
2006	Dow demonstrates technical viability for BLUEDGE™
2008 - 2013	HBDC regulated by the EU
2013	BLUEDGE™ technology licensed by Dow to other companies to increase production
2014	Japan bans imports and production of HBDC
2014	EPA determine BLUEDGE™ is a safer alternative to HBDC via hazard a profile
2015	Sunset date for HBDC in the EU
2015 - 217	Dow increases BLUEDGE™ production to support Canada, US and EU demand via licensing agreements
2015 - 2020	Additional licensing agreements increase production capabilities to support China volume
2021	China bans HBDC

DISCUSSION

This section outlines some key lessons from the case studies and other literature that provide insights on strategies to accelerate the commercialization, adoption, and scale of green chemistry solutions across supply chains.

GC3 published a report in 2015 to understand the barriers to adopting green chemistry and the ways to accelerate green chemistry in supply chains. Four accelerators that lead to a faster growth of green chemistry were identified:

1. Collaboration between value chain partners and other stakeholders
2. Technology forcing where retailers and brands make commitments to drive alternatives
3. Compromise where value chain partners are willing to address cost or performance challenges
4. Enhanced sectoral and value chain education.

Additional GC3 commissioned research, published in 2021, focused on enablers and barriers to adoption of plasticizer alternatives. That research identified the availability of suitable alternatives, regulations, brand awareness and action, customer demands, and NGO campaigns as key motivators for adoption. These accelerators and drivers of adoption resonate with many of the insights identified in the current case studies and outlined below.

Sectoral and value chain collaboration is critical in commercializing and scaling green chemistry.

Collaboration plays an outsized role in commercializing green chemistry solutions and in accelerating growth. Collaboration can be between two or more organizations in a value chain, for example through partnerships or licensing agreements; it can be through a stakeholder group such as the Outdoor Industry Association Chemical Management Working Group; or it can happen through collaborations between NGOs and business organizations. The GC3 Collaborative Innovation Challenge for Safe and Effective Preservatives demonstrated the value of such collaborations. Additional examples, include:

Outdoor Industry Association Chemical Management Working Group (OIA CMWG)

Efforts to improve chemicals management in the outdoor industry were initiated in 2011 through the Outdoor Industry Association Chemical Management Working Group (OIA CMWG), a collaboration between the OIA and the Sustainable Apparel Coalition. It provided a safe, precompetitive working space where members could learn from each other, share ideas, develop tools and resources, and address chemical challenges in the industry such as the use of PFAS for DWR. This was a critical need because brands were unsure what to do and many did not have chemists on staff to inform and assist them in identifying safer alternatives. The OIA CMWG met face to face at least three times a year, and the group included retailers, outdoor brands, chemical suppliers, and other stakeholders. The group developed a strategic plan and a governance process on how to work collaboratively in a safe, precompetitive space.

The OIA CMWG successfully convened brands and users of PFAS and identified what information stakeholders needed to understand the topic. It collected reports, conducted research, and developed a supplier vetting tool. The group played an important role in managing, but not solving, the PFAS issue for the sector. Because DWR is a performance attribute that brands market, brand collaboration was limited to precompetitive topics. Little was shared about what alternative chemicals to use or performance standards.

A key lesson from this collaboration is that *successful collaboration should be facilitated through a stakeholder group, have a governance process, and provide a pre-competitive working space where information can be shared freely and confidentially.*

Blood bag manufacturers: Terumo, Frezenius, Macropharma and Heomonetics

Another excellent example of precompetitive collaboration occurred in the medical devices industry. In 2009, Terumo, Frezenius, Macropharma and Heomonetics, four major blood transfusion companies, collaborated to develop a new connector technology and standard, called the Correct Connect System, to improve patient safety following a series of serious patient incidents. To avoid using an incorrect connector that could cause harm to patients, the four companies shared development costs and advocacy, aligned on a single connector standard, and worked together for the benefit of the industry. This led to an immediate transition in the industry. Similar collaborations have occurred in the food and water filtration industries where any failures can impacts the industry as a whole.

A key lesson from this collaboration is that *shared technology knowledge (including protected information) can enable a clearer understanding of problems and help to find optimal solutions.*

Greenpeace and Greenfreeze

Environmental NGO–business collaborative partnerships, known as *green alliances*, encourage corporate *enviropreneurship*, i.e., entrepreneurial innovations that address environmental problems and result in operational efficiencies, new technologies and marketable 'green' products.[8]

In the early 1990's, Greenpeace successfully collaborated with German and American Government Aid programs and some appliance manufacturers to develop and implement Greenfreeze, an ozone and climate-safe hydrocarbon refrigerant to replace chlorofluorocarbons (CFC's).

Greenpeace understood the potential of Greenfreeze, due to its success in Germany, and initiated a "solutions campaign," defined as a campaign that *identifies technologies that address environmental problems that may be stifled by industry because they threaten status quo technologies, market positions, or profits*.[9]

Using traditional activism and green alliances, Greenpeace championed Greenfreeze among industries, governments, and consumers to increase market demand and legitimize greener refrigeration technologies. Its advocacy of Greenfreeze was the group's first experiment in using market interventions to transform the German refrigeration industry. Its success caused Greenpeace to promote the refrigerant in China and other developing countries.[10]

Following the development and execution of successful technology, in the mid-2000s Greenpeace identified champions in the consumer products industry to drive the transition away from HFC refrigerants, due to their potent greenhouse gas properties. These large consumer brand champions leveraged corporate commitments and engaged the Consumer Goods Forum (CGF), a collaboration of retailer and brand executives in the consumer goods space. After examining HFC replacements, the CGF issued a strong statement calling for the phase out of HFCs in refrigeration and supported the Kigali Amendment of the Montreal Protocol in 2016 to require a global phase out. However, because brands needed non-HFC alternatives to be available at scale, they worked with NGOs to engage environmental regulators to ensure that non-ozone depleting and non-greenhouse gas replacements were rapidly reviewed.

---

[8] Stafford, E. R., Polonsky, M. J., & Hartman, C. L. (2000). *Environmental NGO-business collaboration and strategic bridging: a case analysis of the Greenpeace-Foron Alliance. Business Strategy and the Environment, 9(2), 122–135.*

[9] Stafford, E. R., Polonsky, M. J., & Hartman, C. L. (2000). *Environmental NGO-business collaboration and strategic bridging: a case analysis of the Greenpeace-Foron Alliance. Business Strategy and the Environment, 9(2), 122–135.*

[10] Edwin R. Stafford; Cathy L. Hartman; Ying Liang (2003). *Forces driving environmental innovation diffusion in China: The case of Greenfreeze., 46(2), 0–56.*

A key lesson is that NGO's and businesses collaborating can advance the scale and adoption of alternatives through a combination of market and policy measures.

Identifying and facilitating partnerships between chemical companies and start-ups, or between smaller early-stage chemical companies and brands can accelerate commercialization

In the biobased ingredients case study, partnerships, often between startups and larger chemical companies or between start-ups and leading brands, played an oversized role in scaling ingredients. These synergistic relationships have been critical for both the survival of startups that frequently don't have the financial means to commercialize their products and for large chemical companies that may not have the specialized technology in their portfolio. The larger chemical companies have the capacity to scale the technology. For example:

DuPont collaborated with Genomatica in 2012 to scale 1,4 butanediol (BDO) at the DuPont Tate and Lyle facility using Genomatica's biotech expertise.[11]

Method and Segetis formed a partnership in 2011 to develop many biobased chemicals, including methyl levulinate, which can be further reacted to produce levulinic acid.

Aditya Birla Chemicals acquired Connora Technologies in 2019. Connora Technologies, a California start-up, developed its Recyclamine technology that enables end-of-life recyclability and zero-waste manufacturing to global epoxy customers. Aditya Birla Chemicals Limited in Thailand, a global leader in manufacturing epoxy resins and curing agents, collaborated with Connora Technologies via a 2016 Joint Development Agreement to scale up the manufacturing of Connora's recyclable epoxy thermoset technology.

Nouryon, formerly Akzo Nobel, worked with Unilever and the GC3 on its "Imagine Chemistry Collaborative" innovation challenge in 2019. Challenge winners, often start-ups, were granted awards ranging from joint development and research agreements to dedicated support from Imagine Chemistry partners. Unilever, a challenge partner in the "Sustainable bio-based surfactants" challenge, offered winners the opportunity to collaborate with its R&D teams and test facilities to move their ideas to the next phase of development.

In 2017, PepsiCo partnered with Danimer Scientific to develop biodegradable film resins for sustainable flexible packaging.

In 2014, P&G partnered with DuPont to use cellulosic ethanol as a solvent in Tide® Plus Coldwater Clean. DuPont makes ethanol from corncobs and stalks at their Iowa facility and supplied bio-propanediol to household cleaning companies.

A key lesson is that partnerships play an important role in scaling biobased ingredients. These synergistic relationships help startups commercialize their products and help large chemical companies gain specialized technology.

Technology licensing can accelerate scale and ensure a consistent supply

Dow developed and then licensed its BLUEDGE™ flame retardant, initially to a few select flame retardant manufacturers.

Dow licensed the technology because i) it is not in the flame retardant supply industry and ii) to ensure supply was available as it rolled out the technology across different countries in a phased approach.

[11] This is critical for start-up biobased companies short on funds. Many startups that chose not to partner with well-established chemical companies are no longer in business, for example BioAmber and Segetis.

By licensing, Dow allowed its three supply partners, Chemtura, Albemarle and ICL to make process modifications and develop new use cases. This licensing model has remained and through collaboration with BASF DuPont continues to create licensing agreements to ensure that BLUEDGE™ is used widely in both XPS and EPS. In addition, DuPont has formed a green flame-retardant alliance with its licensees to create a large voice with consistent messaging.

A key lesson is that *shared development and licensing of technologies to suppliers can result in a mutually beneficial relationship that accelerates consistency and scale.*

Look back to look forward. The solution may already exist and be on the shelf.

In three of the case studies, alternatives already existed. This is an important advantage given the long lead times, high cost of scale up and regulatory hurdles faced for new molecules.

For PFAS replacements in DWR, many alternatives, including waxes, silicones, urethane coatings and branched polymers (dendrimers) already existed. Because their performance was not as good as PFAS, some outdoor brands either had to modify their performance standards or stay with PFAS.

For can linings, due to rigorous performance requirements and varied performance needs in different applications, a drop-in replacement was not available. For some "unreactive" foods such as beans, oleoresins were acceptable liners, which allowed first movers to act quickly. Other alternatives included epoxies, vinyl, acrylic and polyester. Some replacements could be formulated from chemicals that had passed regulatory hurdles and were listed as "acceptable for food contact". However, for beverages and some foods, a new development approach was needed. Valspar, a manufacturer, made a strategic decision in 2009 to develop high performance non-BPA coatings that would meet all end uses. Valspar instituted a product development process called Safety by Design that interfaced early on with regulatory agencies and other stakeholders including the EPA, European Chemicals Agency, European Food Safety Agency, scientists and NGOs to vet and resolve issues that could arise prior to the regulatory testing and approval phase.

For biobased household products, biobased surfactants from coconut oil, palm oil and palm kernel oil had been used almost exclusively prior to the synthetic surfactants that replaced them.

Refrigerants, such as freon and other chlorofluorocarbons, were targeted for replacement in the late 1980's as part of the globally binding Montreal Protocol. Initial replacements promoted by the chemical industry were hydrofluorocarbons (HFCs) and hydro-chlorofluorocarbons (HCFCs), but these were not environmentally benign. In 1992, Greenpeace, in partnership with German scientists resurrected a hydrocarbon butane/propane mix of refrigerants used in the 1930s prior to the introduction of CFCs.

A key lesson is that *reviewing available off-the-shelf technologies before starting new development makes good business sense*

NGO campaigns can accelerate change

NGO campaigns have been very successful in accelerating the shift to replacing incumbents, especially for consumer-facing products that contain chemicals of concern.

In July 2011, Greenpeace launched its Detox My Fashion campaign that targeted numerous large apparel brands and retailers to phase out of 11 classes of hazardous chemicals by 2020, which catalyzed the formation of ZDHC. Awareness of the hazardous chemicals used in the apparel industry has increased significantly since DeTox my Fashion. ZDHC represents a successful sectoral level initiative to drive a broad change in manufacturing chemistry towards alternatives. Similar market-based campaign efforts have occurred in the electronics, healthcare and building product sectors, leading to sectoral collaboration to address chemicals challenges.

For BPA, NGO pressure, which gained momentum in 2007 and was supported by engaged scientists and with scientific research raising concerns since the 1990s, catalyzed the replacement of BPA in reusable bottles and food packaging. National NGOs including the Environmental Working Group (EWG) and Coming Clean published reports targeting products that contained BPA. The campaigns targeted baby products, such as bottles and infant formula, which went right to the emotions of parents concerned about safety. This resulted in large retailers including CVS, Wal-Mart, and Toys "R" Us pledging to eliminate products, particularly baby bottles, with BPA from their shelves.

When Greenpeace implemented Greenfreeze, an ozone and climate safe refrigerant that replaced CFC's, at the 2000 Olympics in Sydney, Australia, their strategy was multifaceted and included i) forging ties with scientists to tap their expertise about Greenfreeze, ii) partnering with Sydney's Olympic committee to generate a "Green Games" concept, iii) lobbying by appealing to the UN Multilateral Fund to finance developing-country transitions from CFC's to Greenfreeze and iv) publishing reports about the impacts of refrigeration on ozone depletion and climate change to raise public awareness. Greenpeace also identified consumer products industry champions to drive the transition away from HFC refrigerants. These champions then leveraged corporate commitments and engaged the Consumer Goods Forum (CGF) which issued a strong statement calling for the phase out of HFCs in refrigeration and supported the Kigali Amendment of the Montreal Protocol in 2016 to require a global phase out.

Safer Chemicals, Healthy Families, through its on-going Mind the Store campaign rates large national retailers on their chemicals management activities and works with them to eliminate chemicals of concern in products on store shelves. Some of the chemicals targeted for elimination include i) PFAS in food packaging, ii) methylene chloride in paint strippers and iii) certain phthalates in vinyl flooring. Mind the Store's campaign has led some major retailers to make phase out commitments to eliminate targeted chemicals of concern in specific product categories.

A key lesson is that *NGO campaigns can serve as a driver for safer chemicals as they raise customer awareness and catalyze change.*

A key lesson is *collaboration with key NGOs can leverage pressure and consumer trust that drive change.*

Savvy marketing can accelerate change and enhance education

Although the replacement of polycarbonate water bottles was triggered by scientific reports and advocacy groups that highlighted the dangers of BPA, savvy marketing, which resulted in increasing consumer awareness, helped accelerate the shift to alternatives.

In this case, the stars were aligned in that a well-known, credible, large retailer (REI in the U.S.) was an alpha mover that acted decisively because i) an alternative was available, ii) it was a high margin product where the retailer could absorb the cost increase and iii) the product was reusable, which was a sustainability trend that consumers cared about.

"BPA-free" language on hang tags appeared quickly at retail shows and trade fairs. This followed earlier NGO efforts to push for "phthalate-free" toys. "Paraben-free", "PFAS-free" and other "free of" claims are also used to market consumer-facing products. There is evidence that these products are growing faster than incumbents in the marketplace and that consumers and institutional buyers are driving demand for green chemistry products.

A key lesson is that *focusing innovation and substitution efforts on products that contain "chemicals of concern" and have wide consumer awareness may result in a quicker time to scale.*

Market leaders with considerable buying power can force widespread change by initiating a domino effect

Large companies and other organizations that have influence due to either their size or reputation can force and accelerate change.

When H&M GROUP phased out PFAS and used a RUDOLF GmbH PFAS-free alternative, two things happened; i) other brands quickly followed suit, although Greenpeace pressure may have catalyzed that action; and ii) many brands in Scandinavia marketed their PFAS free water-resistant products with the RUDOLF GmbH "Bionic Finish", the same product used by H&M GROUP.

When REI decided to eliminate polycarbonate water bottles from its shelves, other brands, retailers, and water bottle manufacturers soon followed. This shift happened quickly, due to REI's reputation and influence in the industry, and its sheer size.

Once Wal-Mart made a public commitment to phase out of plastic baby bottles made with polycarbonate, other retailers, notably CVS and Toys "R" Us quickly followed suit.

Lowes was the first retailer to ban methylene chloride in paint strippers in 2018 due, in part to the ongoing Mind the Store Campaign. In the same month, Sherwin-Williams, Walmart, and The Home Depot, the largest home improvement retailer, followed their lead.

SC Johnson, Clorox, and Unilever have focused on acquiring high profile "green" brands, such as Method and Seventh Generation, or initiating niche product lines, such as Tide® Purclean™, that show proof of concept, create market draw, and then growth throughout entire product lines.

A key lesson is that *well recognized innovators and early adopters have the power to advance change in a sector.*

Cost matters but it depends on the product

One would expect a more expensive alternative would prevent its adoption, but this was not the case in many of the case studies, especially for brand alpha movers. In some cases, such as many DWR's, the cost of the replacement was the same as the incumbent. In other cases, the cost had to be the same for it to be considered, i.e., most can linings.

However, first mover brands or retailers were less concerned about cost if the replacement performed adequately. In 1999, Eden Foods replaced BPA with oleoresins and absorbed a 14% increase in cost.

Tritan™, a plastic replacement for polycarbonate water bottles was more expensive than polycarbonate. CamelBak was Eastman Chemical's first Tritan™ customer. It entered the market with Tritan™ and never used polycarbonate. The resulting bottle was more expensive, but it didn't stop REI from selling it in stores.

Biobased ingredients are generally more expensive than synthetic ingredients, but Seventh Generation and Method's value proposition negated the higher cost of their product.

In 2007 and 2008, Walmart was the biggest purchaser of organic cotton. To help with organic cotton supply, Wal-Mart purchased 12 million lbs. of transitional cotton at the same premium cost as certified organic cotton. They did not pass along increased costs to consumers. Instead, they compromised their profits by accepting lower margins and at the same time provided a necessary multi-year business demand to transitional farmers[12] who needed to sell their crops. Programs like Walmart's help lessen the burden of farmers who want to adopt environmentally responsible practices.

BLUEDGE™ is more expensive than other alternatives. DuPont created incentives for flame retardant manufacturers to use it, and in the EU, Dupont offered relief on the licensing costs.

A key lesson is that *cost is not necessarily a barrier to commercialization because there are often supply chain solutions to address them.*

[12] Transitional cotton is grown on fields that are in the process of becoming organic. Farmers who have adopted organic practices harvest transitioning crops for three years. To grow the organic cotton industry, farmers who are moving to organic farming need financial support because crop yields are lower, and risks are higher during the transition.

A key lesson is that *cost should decrease as demand increases and scale is achieved.*

Regulations and voluntary restrictions accelerate innovation, commercialization, and adoption

Global regulations can accelerate research and development of alternatives. There are few global policies and regulations are location dependent. However, certain countries and some U.S. states are proactively regulating hazardous chemicals and serve as a driver for innovation in safer chemicals and products.

Lack of a key regulatory driver can also slow scale. In 2003, RUDOLF GmbH, a German chemical company developed a non-PFAS alternative DWR but did not commercialize it for 10 years because i) brand and consumer awareness regarding PFAS was still in its infancy, and ii) short chain PFAS were not regulated and assumed to be safe. Lower standards in some countries that have large consumer markets, such as China, can also hinder commercialization and scale of alternatives.

Between 1998 and 2003 industries in Japan voluntarily reduced the use of BPA on consumer products. This was noticed by epoxy resin formulators, some of which started to develop alternatives, mostly from existing chemicals that had already passed regulatory hurdles. The industry got a head start even before studies on impacts of low dose exposure to BPA were completed.

In early 2008 Health Canada announced that BPA was a "dangerous substance." Canada had a set of strategies to reduce BPA exposure to infants and newborns that included i) banning polycarbonate baby bottles, ii) developing stringent migration targets for BPA in infant formula cans, iii) working with industry to develop alternatives and iv) listing BPA under Schedule 1 of the Canadian Environmental Protection Act. This ban had an immediate effect on manufacturers, retailers and brands that made and sold products containing BPA. France also banned BPA, first in 2013 for plastic food packaging intended for children under 3. In 2015, the ban expanded to all food packaging, regardless of age.

A key lesson is that *restrictions in specific countries and regions can accelerate action.*

Don't hold your breath - shifting away from an incumbent is a complicated and long process.

Individual brands may move quickly to replace a chemical of concern, but shifting a whole sector usually takes a long time.

PFAS replacement for DWR started in earnest in 2011 when Greenpeace launched its DeTox campaign. Prior to that date, the outdoor industry was educating itself on the issue rather than taking action to replace DWR containing PFAS. Although more brands are using less PFAS due to a nuanced approach where they choose chemistry based on specific end use performance requirements, the tipping point probably will not be reached until 2024 when the whole class is expected to be regulated under REACh. However, chemical companies based in Asia will no doubt still produce PFAS because they may not need to abide by EU regulations for Asian markets.

BPA replacement in plastic bottles occurred between 2000 to 2007, which is relatively fast. Once REI was informed and decided to remove products made from BPA from its stores in 2007, a domino effect happened, and reusable polycarbonate drinking water bottles were eliminated very quickly.

BPA replacement in food cans began as early as 1999, although it did not pick up speed until 2012 when a series of regulations came into force. The tipping point was in approximately 2017 when BPA was added to Prop 65. Even today, BPA is still used in some can applications.

The biobased home cleaning sector is large and is making progress as it relates to volume, given growing consumer awareness, company pledges to reduce GHG emissions and government incentives. However, the tipping point may not be reached for another 25 years or so.

Government interventions that support R&D and commercialization can help accelerate innovation, commercialization, and scale. For example, the [SEMATECH initiative] in the semi-conductor sector, funded by the U.S. government, convened 14 U.S. manufacturers to regain competitiveness and market for the semiconductor industry. The effort has been described as a model for how industry and government can work together to grow domestic manufacturing industries. Similar efforts have been established to advance solar energy technology, synthetic biology, and nanotechnology. Government laboratories play a critical role in supporting funding and research support for biobased ingredients.

A key lesson is that *commercialization takes time, money, patience, and effort.*

A key lesson is that g*overnment R&D funding and support can hasten the commercialization of alternatives.*

Understanding from experts - what will it take to accelerate the commercialization, adoption, and scale of green chemistry?

In this section, we analyze responses from case study interviewees to understand, based on their experience, what it will take for companies to work together to accelerate the commercialization and adoption of green chemistry. The results have been broadly categorized into three key themes.

What would trigger companies to work collaboratively to advance green chemistry solutions?

1. **A common challenge** that organizations cannot get done by themselves. For many companies to collaborate, they need to **work on challenges that are not key differentiators,** such as replacing hazardous solvents in different applications, which is an industry wide problem that needs to be addressed.
2. Having a **common set of measurement criteria or standard for alternatives.** These should be based on the best available science and technical knowledge to increase alignment.
3. **"*There is no other choice*".** A clear policy, market mandate, or public commitment is critical. Changing chemistry is easier said than done. It takes time and resources and is a financial risk because success is not guaranteed. For example, new capital or reformulation may be needed or performance may be different. Such mandates or commitments reduce uncertainty (as to when change might happen) and supply chain disruption, provide time to develop and implement solutions, and create a level playing field for everyone.

   During World War II, the natural rubber supply from Southeast Asia was cut off, which meant that the United States and its allies lost a strategic material. As a result, the U.S. government sponsored a consortium of companies, with expertise in rubber research and production, to technically cooperate and develop a synthetic rubber on a commercial scale. [The consortium, in collaboration with a network of researchers in government, academic, and industrial laboratories, developed and manufactured in record time enough synthetic rubber to meet the needs of the U.S. and its allies during World War II].
4. **Shared resources.** If there is an ability to share costs of toxicological or performance testing or other development costs, for example, each individual company will save money.

What supports successful collaborations along the value chain to advance green chemistry solutions?

1. **Establish a value chain** that cooperates against a clear set of requirements from the beginning. [Checkerspot,] a biotech company that optimizes microbes to produce structural oils established a value chain to commercialize its technology. It is partnering with outdoor brand [WNDR Alpine,] WL Gore and textile specialty chemical manufacturer [Beyond Surface Technologies]. All are aligned on the same goal of using renewable resources, have similar values, and understand their role in the value chain. It is a winning formula for all

participants. The value chain for BLUEDGE™ consisted of Dupont, BASF, and flame-retardant manufacturers, which had different types of expertise, but cooperated in a synergistic fashion against a set of criteria coupled with the threat of impending regulations.

2. **Establish a collaborative working group, grounded in trust,** with a diverse set of stakeholders who are responsible for developing common goals and are willing to put competition aside to solve challenges. This often works best when champions can marshal leadership in major companies to collaborate to drive change. Based on experience, the collaborative process should include the following steps:
    a. Identify a facilitator that is responsible for the work and the group.
    b. Ensure the right individuals are at the table, with the right personalities, so that they can work together, be open and work effectively.
    c. Ensure the right expertise is in the room to solve the situation at hand.
    d. Set governance and ground rules within the working group. Be mindful of what is best for the group and the industry rather than a specific company.
    e. Ensure there is alignment on the outcome and common measurement criteria.
3. Choose the **right collaboration topic** and partner with a credible, **well-respected organization**.
    a. The Green Chemistry & Commerce Council (GC3) is a trusted convenor of companies across the value chain. In its preservatives collaborative innovation challenge, GC3 convened 11 brands, 2 retailers, and 6 chemical suppliers to develop criteria for safe and effective preservatives for consumer products, a precompetitive pain point for many companies. The effort demonstrated that companies will collaborate to achieve common goals, reducing costs and pushing the innovation accelerator.[13]
    b. The work should be **precompetitive,** which is how brands commonly collaborate. In the apparel industry, the OIA and ZDHC are excellent examples.
    c. bluesign® has successfully managed and facilitated chemical company collaboration. bluesign®, a trusted expert, has established a "chemical expert group" that consists of chemists from brands and the chemical industry. The organization identifies broad industry-wide problems and then collaborates to find solutions
4. Identify business opportunities before the work begins. For chemical company competitors to collaborate, there should be a **volume incentive and commitment from brands**. There is little incentive for chemical companies to collaborate unless they jointly benefit from the business opportunity.

What causes a domino effect where action by one or more companies leads others to follow?

1. **When concerns are raised about the incumbent** through advocacy, science, and the threat of regulations.
2. **When a chemical is voluntarily restricted**. Once a large industry player or industry group restricts a chemical, a domino effect can occur because other companies act to manage risk. Governmental regulations create a tipping point because there is simply no other choice but to substitute the regulated chemical.

[13] Becker, M. and J. Tickner. 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 & Pharmacy 16 (2020).

3. **When there is a clear industry front runner and winner**. Netflix took a risk with its streaming service and initially struggled. Today, there are numerous streaming services, and streaming is the preferred way to watch television for a large portion of the population.
4. **When front runner companies pull along others to advance the cause**. A leader (organization or a solution) that is willing to share technology information for the greater good can accelerate change. For example, Levi Strauss & Co. open-sourced their waterless techniques. North Face shared a process on how to measure sustainable fibers, and Patagonia shares their intellectual property after a set time to get growth.
5. **When there is a perfect storm:** i) performance is met, ii) the price is acceptable, iii) the technology can scale, and iv) the solution is widely known through marketing by early adopters.
6. **When the consumer understands the issue at hand.** Market forces drive change, often aided by NGO campaigns – (e.g. "BPA – free" marketing and the ChemSec PFAS – free pledge).

CONCLUSION

There are numerous approaches to accelerate commercialization of green chemistry solutions across supply chains, and the case studies and supporting literature have provided evidence of varied strategies and lessons on successes. Any effort to accelerate green chemistry innovation will need to be cognizant of and address the many, often context specific, barriers to commercialization and adoption.

The goal of this research was to explore what interventions can help accelerate transitions to green and sustainable chemistry solutions. Clear market and policy drivers are a critical starting point – coming from NGO campaigns, regulations, and increasing consumer awareness and demand for more sustainable products. Sectoral and value chain collaborations to understand technology needs and establish a common language and standards, create strong and consistent demand signals, and leverage partnerships, joint ventures, licensing, and other mechanisms to drive technology growth, combined with a clear value proposition and marketing for solutions are also critical. Identifying and engaging alpha movers that have national or global recognition also plays an integral role in creating a domino effect that shifts the innovation adoption curve. Alpha movers are often willing to compromise on cost, and sometimes performance, to support change and gain first mover advantage. Costs may decline after supply chains mature and demand increases, and performance often improves as new technologies become available.

Commercialization and adoption of green chemistry solutions is a slow and resource intensive process. The inertia to leverage collaborations for each chemical function and application is significant. Accelerating that process will require government or market interventions, government R&D and technology support, and sectoral collaborations and commitments (often with NGOs) that mobilize an entire sector, such as building materials or apparel and footwear, to take leadership in addressing the sustainable chemistry of its product lines as a whole. Finally, as 2050 climate neutrality goals approach and as "sustainability" appears to have reached a tipping point for ESG investors, the opportunities to scale green chemistry will only increase as demand for and dependency on fossil fuels for feedstocks declines.

Ultimately, to accelerate innovation, commercialization, and adoption of green chemistry solutions that transitions from an incumbent chemistry, a combination of strategies – a "perfect storm" where drivers are clear, performance and cost considerations are met through collaboration and compromise, the solution is widely known, and there is an ability to scale – will be needed. Understanding the interventions that have worked in the chemicals and other technology spaces to accelerate growth of new technologies will be essential to success in the future.

Sustainable Chemistry Catalyst

University of Massachusetts Lowell
Lowell Center for Sustainable Production
61 Wilder St., O'Leary 540, Lowell, MA 01854