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# Scaling Adoption of Alternatives to Per- and Polyfluoroalkyl Substances in Aqueous Film-Forming Foams: Lessons Learned on Needs and Opportunities

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Sustainable Chemistry Catalyst

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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.

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## ABOUT

The Sustainable Chemistry Catalyst is an independent research and strategy initiative, based at the Lowell Center for Sustainable Production at UMass Lowell, that is focused on accelerating the transition to safer, more sustainable chemistry through research and analysis, and stakeholder engagement with scientists, policymakers, and commercial actors.

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.

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## ACRONYMS USED

| | |
|---|---|
| 6:2 FTS | 6:2 Fluorotelomer Sulfonate |
| AFFF | Aqueous Film Forming Form |
| ARFF | Aircraft Rescue and Firefighting |
| C6 | Carbon chain length of six |
| CBI | Confidential Business Information |
| EN | European Standard, from the German name Europäische Norm ("European Norm") |
| FAA | Federal Aviation Administration |
| IC2 | Interstate Chemicals Clearinghouse |
| ICAO | International Civil Aviation Organization |
| MilSpec | Military Specification MIL-PRF-2435F(SH) |
| NDAA | National Defense Authorization Act |
| NGO | Non-governmental organizations |
| PFHxA | Perfluorohexanesulfonate |
| PFHxS | Perfluorohexanoic Acid |
| PFAS | Per and polyfluoroalkyl Substances |
| PFOA | Perfluorooctanoic Acid |
| PFOS | Perfluorooctane Sulfonate |
| R&D | Research and Development |
| SERDP/ESTCP | Strategic Environmental Research and Development Program/Environmental Security Technology Certification Program |
| UL | Underwriters Laboratories |
| US | United States |
| US DoD | US Department of Defense |
| US EPA | US Environmental Protection Agency |

# SUMMARY

The objective of this project was to explore lessons learned from existing efforts to accelerate the adoption of substitutes for firefighting foams containing per- and poly fluorinated alkyl substances (PFAS). Key objectives included: (1) understanding critical technology, market or policy factors (actual and perceived) that are inhibiting the implementation of alternatives to Aqueous Film Forming Foam (AFFF) and other PFAS containing firefighting products; (2) understanding critical technology, market or policy factors that are enabling and scaling a transition to safer and feasible alternatives to AFFF and other PFAS based firefighting products; and (3) understanding lessons learned from the US Department of Defense's (US DoD) current efforts to accelerate the adoption of safer and effective PFAS-free alternatives that can improve efficacy in firefighting scenarios. Key informant interviews were conducted to explore barriers and enablers in transitioning from AFFF to alternatives. Reviews of the literature, including peer-reviewed publications and reports in the gray literature, were used to delve deeper into topics and themes that emerged in the interviews.

Five primary factors were repeatedly identified as barriers to an effective transition to safer and feasible AFFF alternatives including:

1. **Transition costs:** Although the purchase price of PFAS-free alternatives to AFFF is cost competitive, replacement costs related to equipment/components, decontamination and disposal costs of contaminated components and legacy fluorinated foams may be significant.

2. **Lack of knowledge of performance for specific real-world scenarios:** Proof of concept or demonstration-level performance tests of the PFAS-free alternatives are simply not enough to give assurances to some users that alternatives will work as needed for their firefighting circumstances.

3. **Substitution regret:** Some users are unwilling or unable to transition to PFAS-free alternatives to AFFF because of the lack of certifications/approvals needed in some sectors. There are also lingering questions about the health and safety of alternatives for both workers and the environment given the limited test data on formulations, that need to be addressed.

4. **Standards:** Performance standards/specifications, especially the US DoD performance specification (MIL-PRF-2435F(SH)) (MilSpec) in the US, are hindering adoption of alternatives. In addition, there are an array of standards related to the use of firefighting foams, which has created confusion related to procurement among some entities and has limited continued innovation in fire extinguishment technologies for Class B fires due to costs involved in achieving certifications.

5. **Lack of a coherent national transition strategy:** The lack of a clearly communicated strategy to support the transition to PFAS-free alternatives has left users, especially in the US with more questions than answers about addressing needs related to financial support, technical assistance and training related to both the use of PFAS-free alternatives to AFFF and decontamination and disposal challenges associated with the legacy fluorinated foams and related equipment.

Four primary enabling factors that are working to accelerate a transition to PFAS-free alternatives were also identified, including:

1. **"Just do it" – using direct experience and mock exercises to understand performance of alternatives and adoption needs:** The counterpoint to only having proof of concept/demonstration performance testing is the utility of users participating in large-scale tests. Collaborative testing programs have proven to be effective in demonstrating the capacities of PFAS-free alternatives as well as equipment needs and firefighting tactics to tune performance.

2. **Financial liabilities with continued use of AFFF:** Insurance liabilities and the potential for future litigation and financial responsibilities associated with the continued use and contamination from PFAS containing firefighting products is a significant substitution driver.

3. **Fit-for-purpose performance standards:** Standards designed to reveal varying performance levels that are suitable for a range of firefighting uses have been able to support a quicker transition to PFAS-free alternatives than those designed only for the worst-case/maximum credible event firefighting scenario.

4. **Policy mandates:** Policy requirements to stop using AFFF have been instrumental in the transition to PFAS-free alternatives.

Going forward, priority needs to accelerate an effective and broad-based transition to safer PFAS-free alternatives include:

- **Issuing a comprehensive and collaborative implementation strategy.** Such a strategy should be a multi-agency/institutional effort given the expertise and engagement needed to address the array of substitution challenges including ensuring a sufficiency of market supply of the alternatives, addressing firefighting performance/technical feasibility needs, providing firefighting education and training, addressing occupational health and safety concerns and ensuring environmental compliance and public health protections related to AFFF decontamination and disposal.

- **Enhancing education and training.** Continued education and training activities need to address "resistance to change" that is still being experienced among some facets of fire and rescue personnel, including a lack of understanding of the problem and a lack of confidence about the solution. Training programs will need to be co-developed along with the PFAS-free alternatives to AFFF as changes in firefighting techniques are expected. Programs should also use PFAS-free products that will be deployed in real incidents using the same fuels which will be encountered will increase confidence in the foams ability to extinguish fires.

- **Establishing collaborative performance testing/demonstration sites.** Enhanced collaborative large-scale performance tests are needed where the burden of costs is shared among interested parties/organizational partners who also contribute to designing parameters of the testing protocol. Results of such tests need to be broadly disseminated. Collaboration is also needed to fill gaps in testing to obtain accreditation for specific uses of PFAS-free products (such as in sprinkler systems) where insurers are still not willing to underwrite risk for facilities using these AFFF alternatives.

- **Establishing systems for ongoing monitoring.** Monitoring and evaluation are essential for the early identification of potential unintended consequences of the adoption process. Systems need to include, but are not limited to, environmental surveillance programs to monitor for impacts on a broader array of ecological endpoints, testing to ensure adequate decontamination of PFAS in reused equipment, agree-upon validation testing to ensure that new foams are indeed PFAS-free, industrial hygiene evaluations and discussions with firefighting personnel about the impacts of the transition and to adjust training, equipment and standards of practice as needed. Many of these issues need to be inserted into an AFFF substitution implementation strategy outlined above.

Although substitution efforts for AFFF are ongoing and not every substitution challenge is the same, there are a series of lessons learned that can be generalized from this experience to inform the adoption of safer and feasible substitutes for future chemical-product challenges going forward. Lessons learned include:

- **Policy mandates are a critical enabler for substitution**. Investment in the development of alternatives and broad implementation of substitutes will often be held back unless there are policy (government or private sector) mandates that motivate and accelerate the pace of change.

- **Expand the use of collaborative performance testing programs.** Collaborative and comparative performance testing programs are helpful when there is an array of users that have lingering questions about the performance of alternatives in specific scenarios. Filling gaps in the understanding of performance for specific use scenarios through the expansion of collaborative performance testing programs where costs are shared and distributed among interested stakeholders, who also are involved in designing the test parameters, will support broader trust and understanding of the performance capabilities of alternatives under conditions of use that specifically align with users' needs. Additionally, communities of stakeholders working collaboratively to drive innovation and adoption of safer, and feasible options (a collaborative innovation community) as the US Department of Defense's Strategic Environmental Research and Development Program and its Environmental Security Technology Certification Program (SERDP/ESTCP) has done for AFFF can accelerate the innovation and adoption process, allowing researchers, those conducting performance evaluations, scientists, innovators, and established companies to share and receive knowledge that support solutions.

- **Changes in processes and equipment need to be anticipated when adopting safer alternatives**. This is particularly likely when the safer alternatives are not simply modifications of the same fluorinated chemistry. Implementation of substitutes needs to anticipate: (a) changes to the product or process; (b) changes in work practices; and (c) the need for continuous improvement.

- **Share information about alternatives.** Lack of communication about the viability of alternatives often hampers their adoption. Lack of transparency of ingredient information about formulations hinders research and understanding about hazards. Government agencies, NGOs and trade organizations all play role in sharing and disseminating information about safer and feasible alternatives using forums that best reach user audiences.

- **Anticipate the need for and the promise of continued innovation.** It is important for users to monitor progress in innovations that have the possibility of continued reductions in hazard with better performance for the application of interest. Performance standards and specifications need to also support innovation and avoid criteria around only one product type or option.

There is global interest in replacing AFFF and related firefighting foams with PFAS-free alternatives. Efforts to date demonstrate that substitution is possible. With continued focus on correcting those factors that are inhibiting the implementation of alternatives to AFFF and replicating/scaling those factors that are enabling substitution, we can collectively accelerate substitution of PFAS containing firefighting foams and towards safer, feasible alternatives.

# I. Background and Context

Aqueous film forming foam (AFFF) is a highly efficient fire suppressant agent used for Class B fires – flammable and combustible liquids and gases; petroleum greases, tars, oils and gasoline; and solvents and alcohols. Developed in the 1960s, AFFF is widely used at airports for emergency incidents, fire training exercises, and in sprinkler-based fire-suppressant systems in aircraft hangers. It is also used in the petrochemical sector to extinguish tank fires or fires associated with fuel storage or fuel handling systems. The introduction of AFFF was particularly desirable to the US military complex because it offered rapid extinguishment time, which was considered critical for military crew safety, especially when considering the additional hazards posed by the presence of munitions and related equipment as well as fuel spills at a given fire scene (NAVSEA 2019).

AFFF is formulated with fluorosurfactants, which are part of a class of chemicals known as per-and polyfluoroalkyl substances (PFAS). Additional types of firefighting foams, including film forming fluoroprotein foams (FFFP) and fluoroprotein foams (FP), also contain fluorosurfactants (IRTC 2021).

Up until the early 2000s, the 3M Light Water AFFF product containing perfluorooctane sulfonate (PFOS) was sold and used widely (ITRC 2021). Other forms of AFFF were also used which contained polyfluorinated precursors that could degrade to PFOA (ITRC 2021). As a result of the US Environmental Protection Agency's (US EPA) PFOA stewardship program, between 2010 and 2018 some AFFF was reformulated to diminish levels of PFOS and PFOA content (otherwise known as C8 compounds) and increase the concentration of C6 using perfluorohexanoic acid (PFHxA) precursors such as 6:2 fluorotelomer sulfonate (6:2 FTS) derivatives (ITRC 2021; US DoD 2018; ASTSWMO 2015; Peshoria et al. 2020).

These compounds, while considered key to the "film forming" capability of AFFF, are hazardous to human health and the environment. A growing body of scientific evidence documents that exposure to PFOA, PFOS and additional PFAS are associated with a range of health impacts, including changes in liver enzymes, decreased birth weight, increased cholesterol levels, decreased vaccine response in children, and increased risk of kidney and testicular cancer among other health impacts (ATSDR 2021; Fenton et al. 2021). In addition, PFOS and PFOA are extremely persistent, mobile and bioaccumulative (ATSDR 2021; Lindstrom et al 2011). Analysis of shorter chain AFFF products in 2004 revealed that 20% of the PFAS present were PFOA precursors that had the potential to form PFOA in the environment (Ross and Storch 2020). Although a full understanding of the toxicity of shorter-chain PFAS is still emerging, there are concerns especially regarding breakdown/transformation products of 6:2 FTS under certain environmental conditions, such as the formation of PFHxA which is extremely persistent and mobile in the environment (Rice et al. 2020; Danish EPA 2015; Ross and Storch 2020; ATSDR 2021).

AFFF is a known source of drinking water contamination throughout the US and globally. As of 2017, the US Department of Defense (US DoD) tested 2,445 off-base public and private drinking water systems (US DoD 2019). Nearly 25% of which had PFAS levels that far exceed regulatory drinking water standards now in place in several states (US DoD 2019). Analyses by non-governmental organizations in the US suggest that drinking water sources for over 110 million people in the US may be contaminated by PFAS (EWG 2019). Areas included among the priority sources of contamination are US DoD facilities, municipal and airport firefighting training facilities, and legacy sites where AFFF was used to extinguish residential and industrial fires (EWG 2019).

Industries representing a broad range of firefighting scenarios have transitioned to PFAS-free alternatives, including emergency response and fire and rescue operations in the chemical industry, airports, bulk fuel storage, ports, oil and gas platforms, refineries and some military operations (IPEN 2018). Firefighting foams and their delivery systems have evolved to be far more effective, without a need for PFAS in most circumstances. The first PFAS-free foams were successfully tested at large scale in 2002, with evolving improvements in performance (Ross 2019). Substitution efforts to date have mostly occurred outside of the US, mainly in Europe and in Australia. In the US, restrictive policies are supporting initiatives to identify, evaluate, and adopt PFAS-free alternatives, although substitution efforts are on a slower pace. The National Defense Authorization Act (NDAA) of 2020 requires the US DoD to revise its military performance specification (MIL-PRF-2435F(SH)) (MilSpec) for AFFF to include PFAS-free foams for shore-based applications by 2023 and to phase out the military's use of AFFF by 2024 NDAA 2020). In addition, a number of municipalities and states have issued regulations prohibiting the sale and/or use of PFAS for firefighting training purposes – currently 14 states and growing (Safer States 2021).

Lessons learned from efforts to substitute chemicals of concern to date reveal that even if alternatives are available, implementation of the alternatives can be challenging, and a broad transition may be limited. As outlined by the European Chemicals Agency (2011), implementing alternatives often requires:

- Assurances that alternatives can be produced in sufficient quantities.
- Investments that take resources (time and money) to plan necessary changes such as purchasing and installing needed equipment to train personnel.
- New regulatory approvals or demonstration of meeting specific institutional standards or specifications.
- Customer approvals to ensure that alternatives perform as needed for specific use scenarios.

The US National Academies (2014) expanded on these elements and included additional challenges such as:

- Additional process design or formulation chemistry changes to achieve the necessary functionality that may not have been considered or identified during research and development stages.
- Changes in environmental safety and health management practices to ensure that residual risks associated with the alternatives are sufficiently controlled across the life cycle, including controls for workers, the public and the environment during manufacturing, point of use, and disposal.

Further the incumbency or "lock-in" of existing chemistries, built on existing, capitalized infrastructure and highly integrated into production systems may inhibit innovation and adoption of alternatives (Fennelly, 2015).

## II. Objective and Methods

To support an effective transition to safer and feasible PFAS-free alternatives to AFFF in military applications and beyond, this project sought to explore lessons learned from existing efforts to accelerate the adoption of substitutes for AFFF. Key objectives included:

- An understanding of critical technology, market or policy factors (actual and perceived) that are inhibiting the implementation of alternatives to AFFF.
- An understanding of critical technology, market or policy factors that are enabling and scaling a transition to safer and feasible alternatives to AFFF.
- An understanding of lessons learned from DoD's current efforts to accelerate the adoption of safer and effective AFFF alternatives that can improve efforts to address future material challenges.

Key informant interviews were conducted to explore barriers and enablers in transitioning from AFFF to alternatives. Seventeen interviews were conducted with a range of stakeholders both domestically and internationally to explore challenges and successes in the deployment and adoption of PFAS-free firefighting products. Interviews were conducted with US fire suppression experts, DoD procurement officials, European defense agency environmental safety and health officials, alternative AFFF product developers including those at the R&D and commercialization stages, US fire marshals, emergency management agencies, state environmental departments, and airport firefighting personnel in the US, Europe and Australia. Reviews of the literature, including peer-reviewed publications and reports in the gray literature, were used to delve deeper into topics and themes that emerged in the interviews. Interviews were supplemented by conversations held as part of meetings convened by the US Department of Defense's Strategic Environmental Research and Development Program and its Environmental Security Technology Certification Program (SERDP/ESTCP) program team. Factors that were explored included:

- Difficulties for new alternatives to compete with the incumbent product given issues such as existing infrastructure, established global supply chains, costs, and entrenched supplier-customer relationships.
- Confusion such as potentially conflicting information from studies and research, policy uncertainties, etc.
- Concerns about regrettable substitutions from an environmental health and safety perspective.
- Increased cost.
- Performance, including incompatibility concerns.
- Transition challenges including training, decontamination, and waste.

Perspectives of interviewees are considered confidential and are described in the report in the aggregate. Non-attributed quotes are used in the report to help illuminate notable themes on the primary inhibitory and enabling factors identified.

## III. Primary Inhibitory Factors: Transitioning to AFFF Alternatives

Across interviewees and the literature, five primary factors were repeatedly identified that are inhibiting an effective transition to safer and feasible AFFF alternatives. These include: (A) transition costs; (B) lack of knowledge of performance for specific real-world scenarios; (C) substitution regret; (D) constraining standards; and (E) lack of a coherent national transition strategy. Each are reviewed below.

### *A. Transition Costs*

Transition costs that are inhibiting an effective transition to AFFF alternatives are multi-faceted. Based on the experience of early PFAS-free adopters in Europe and Australia, the purchase cost of PFAS-free products is competitive with AFFF products (Wood, Ramboll and Cowi, 2018). However, additional costs were highlighted as significant barriers associated with the adoption of PFAS-free alternatives, including equipment changes, decontamination challenges, and disposal.

**Equipment Changes**

If current users of AFFF decide on their own, or due to future regional, state or national regulations or programs, to switch out their current AFFF-contaminated fire suppression equipment, interviewees estimated the total quantity of equipment and components that would need replacement to be in the range of 7,500 to 9,000 parts. These include, for example, foam delivery components, such as proportioner pumps, jets and nozzles for discharge (Wood, Ramboll and Cowi, 2018). Replacement costs for specific components are not prohibitive, ranging from ~$6 - ~$200 (converted from Euros) or ~$3,100 for mobile foam units (Wood, Ramboll and Cowi, 2018). However, a recent 2020 progress report from DoD's Per and Polyfluoroalkyl Substances Task Force estimated retrofit costs at nearly $200,000 per vehicle and anticipated that that Aircraft Rescue and Firefighting (ARFF) vehicles may need to be replaced in total, exacerbating cost concerns. Replacement of the US DoD's ~3,000 ARFF vehicles would cost from $4 to $6 billion and may take over 18 years given current commercial production capacity (US DoD, 2020). However, commercial airports in the US employ nearly twice the size of the DoD ARFF fleet (US DoD, 2020). Such costs spiral upwards and will impact the availability and vehicle replacement timelines. Costs associated with equipment replacement for municipal fire vehicles are not currently available nor are the costs for those who use AFFF in industrial sprinkler systems.

Replacing this volume of equipment and components with a transition away from AFFF to PFAS-free alternatives will be a major undertaking due to both the barriers of cost as well as supply. If fire authorities choose to use existing equipment and components, there are concerns about residual PFAS contamination and costs associated with decontamination.

One solution to this barrier noted by interviewees is to replace fire equipment and vehicles alongside a transition to PFAS-free alternatives. The Swedish Air Force is planning to address the issue of transition costs as well as concerns about PFAS contamination of their ARFF vehicles after adoption of AFFF alternatives by coordinating their need to replace 22 vehicles in their fleet with timelines for AFFF substitution. Schiphol Airport in Amsterdam also adopted this strategy and successfully adopted a substitute foam alongside the procurement of its new ARFF trucks (Bruinstroop 2021). Others have noted that based on recent experience within the UK fire services, no new equipment was needed in the transition to PFAS-free foams. Direct experience will help to illuminate whether the concerns regarding transition costs have been over estimated.

**Decontamination Challenges**

PFAS decontamination of existing firefighting trucks and equipment was noted during interviews as a significant substitution barrier. Future entities transitioning to PFAS-free products will need to address the issue of PFAS contamination of their existing equipment, whether with a decontamination process, through purchasing new equipment, or planning to replace equipment at the end of its intended lifespan, as in the case of the Swedish Air Force. Without employing decontamination processes, use of PFAS-free products can create future liabilities related to environmental impacts at application areas. In one case study, samples of fire suppression systems that substituted with a PFAS-free products 20 months earlier demonstrated PFAS concentration in the foam as high as 1.6 g/L after employing a double water rinse clean out method (Ross and Storch 2020). It is believed that PFAS from the former AFFF products are bound to the surface of the fire suppression equipment and can self-assemble into multiple layers of a waterproof coating that continue to dissolve into the substitute foam with use (Ross 2021a; Ross and Storch 2020). Such circumstances can reduce the benefit of switching to PFAS-free foams without an equipment change or proper decontamination.

Interviewees cited a very broad range for decontamination costs: $3,000 to $50,000 per fire truck. However, recent experience suggests that onsite assessments can help to determine whether equipment components need to be “removed and replaced” or “cleaned and retained” resulting in significant cost savings and risk reduction (Horst et al. 2021; Ross and Storch 2020). For example, components that are single use or never contained nor in contact with AFFF do not need cleaning nor replacement. Components such as the interior workings of firefighting equipment that are inaccessible are best cleaned as replacement would require significant costs and prolonged maintenance time that would impact the availability of the fire suppression unit. Newer cleaning agents are coming online that demonstrate efficacies and are orders of magnitude more effective than employing a double water rinse or using hot water (Ross 2021a). For the interior surface of fire suppression systems that were in direct contact with AFFF, it is often more cost efficient to replace certain parts rather than cleaning (Horst et al. 2021).

Interviewees in the US looking to transition from AFFF to PFAS-free products stated uncertainty in what will be required for decontamination of their existing trucks and equipment that have housed AFFF. They voiced a lack of communication and direction from any governing body regarding requirements for decontamination and the lack of currently available financial resources to cover the transition, including disposal costs. Having a well-developed, site-specific strategy in a foam transition could best be accomplished by utilizing a qualified team of fire engineers, environmental engineers/scientists, technology providers, equipment specialists, and operations contractors. Incorporating a cost-benefit analysis regarding whether the situation calls for a “remove and replace” or a “clean and retain” could assist with cost savings and optimizing risk reductions (Horst et al. 2021).

**Disposal**

> *“That disposal piece is a big unknown right now for a lot of people; a lot of (US) states.”*

PFAS waste disposal can be complicated and quite expensive. US fire marshals interviewed for this project do not currently have any guidance on proper disposal of their legacy AFFF product, their contaminated equipment, nor their contaminated rinse waters. They await guidance on future disposal options, including who will pay for the disposal, whether their state, DoD or some other entity. With an estimated cost of $50 per gallon to dispose of AFFF product, disposing of the legacy foam will be very expensive, especially for large cities, with an estimated 11,000 gallons of AFFF to dispose of, equaling with a potential disposal cost for just the foam of $550,000.

Disposal of PFAS products also can impart indirect costs, including continued releases of PFAS into the environment from disposal techniques. Use of incineration is under scrutiny due to evidence of incomplete destruction of PFAS and increasing levels of contamination, including PFAS being identified in residences surrounding incineration facilities (Ross and Storch 2020; Lerner 2020). Alternative destruction technologies is currently an area of active research by the US EPA and other government agencies and research institutes (US EPA 2020). As mandated in the 2022 NDAA, a moratorium on the incineration of AFFF went into effect in April 2022.

### B. *Lack of Knowledge of Performance in Specific Real-World Scenarios*

Standard setting organizations use small scale fire testing to support alternative foam performance certifications. Yet some interviewees questioned an over-reliance on these small-scale fires as proof that products will work as needed under the harsh and demanding conditions of a major fire incident. Some users express concern about how the performance of the new PFAS-free products differ from their experience with AFFF. With AFFF, there is long-standing experience and associated trust such that "proof of concept" testing is simply insufficient to overcome the perceived risk involved when adopting alternative firefighting products. The majority of PFAS-free alternatives developed to date lack the film forming capacity of AFFF. Although this may not be an issue for a small-scale pan fire, some of the interviewees questioned such implications for real world fires and assume that tactical changes in how fires are fought will be needed. They also question if more ARFF vehicles and additional fire personnel would also be needed. The direct experience of peer firefighting authorities is also not sufficient to answer these questions. Users see their own needs and use scenarios as being unique compared to scenarios where evidence is currently available, for example in fires where explosive material or munitions may be present.

> *"The lack of real-scale tests is holding people back."*
>
> *"The standards show proof of concept, but I'm not convinced about their applicability to the military context."*

Heathrow Airport in London is now using PFAS-free alternatives. In a recent article, Heathrow's Fire Service Compliance Manager noted that the PFAS-free product they are using has, "no operational problems and performs perfectly in an ARFF setting. Since purchasing our fluorine free foam, we have used it on two separate aircraft fires, and it worked perfectly." Project interviewees in the US airports have also tested PFAS-free products using existing equipment without any problems. The Danish Air Force indicated they have used PFAS-free products in real world scenarios with good results. LASTFIRE tests have been performed in 2021 proving multiple PFAS-free foams can successfully extinguish very large-scale fires (some 50m in length) in a variety of tests using application rates outlined by the National Fire Protection Agency. However, this evidence is not enough for some users who need additional assurances to better understand the capacities of various PFAS-free products specifically in *their* firefighting scenario or setting.

### C. *Substitution Regret*

Interviewees expressed concern about being an early adopter of PFAS-free firefighting foam products because of the potential for substitution regret if the product they transitioned to is determined not to be what will be required or approved for use in the future. Some US airports have switched to PFAS-free products for the structural environment (buildings, etc.), but are awaiting the Federal Aviation Administration (FAA) to authorize their use for aircraft rescue and firefighting. Although such decisions were anticipated in October 2021 per the FAA Reauthorization Act of 2018, which directed the FAA to cease requiring the use of fluorinated chemicals to meet its fire extinguishment performance standards within three years, no PFAS-free alternative has been approved for use. In its statement issued on October 4, 2021, the FAA stated, that "while fluorinated

> *"PFAS-free manufacturers need to pitch to users about the lack of persistence, biodegradability and mobility attributes given these hazards in AFFF. But for many, the hazard information still isn't available, especially based on testing at the product-level."*

foams are no longer required, the existing performance standard for firefighting foam remains unchanged" (FAA 2021). This situation has created a barrier for US airports that want to transition to PFAS-free products for their structural environment, but still need to have available AFFF onsite as required by the FAA for aircraft rescue operations.

Interviewees also expressed concerns about the potential for regrettable substitutes from an environmental health and safety perspective. Given the health and safety rationale for substituting AFFF alternatives, there remain lingering questions about the safety of PFAS-free products. Data provided on a safety datasheet are insufficient for revealing the health and environmental hazards to new users (NRC 2014). Although the general approach to understanding the hazard of alternative products is focused on the ingredient level, that information may not be available. Further, interviewees expressed the need to test the full product for key endpoints, especially knowing that it will be released to the environment. Some PFAS-free alternatives to AFFF lack data regarding persistence and bioaccumulation, two key hazard traits of PFAS that alternatives need to avoid (Wood, Ramboll and Cowi, 2018). Some alternatives show hazards related to aquatic toxicity – also a concern knowing that releases to the environment will be commonplace (Wood, Ramboll and Cowi, 2018; Hoverman 2021). Enhancing understanding of the hazards of PFAS-free alternatives to AFFF will provide more confidence to new customers and clarify what additional risk mitigation measures will be needed to ensure that emergency personnel, the public and the environment are protected. The US DoD's SERDP program is sponsoring research to test the ecotoxicity of a number of commercially available PFAS-free AFFF substitutes at the product-level (US DoD 2022). This research is being supported in part by requirements in the FY 2021 NDAA for DoD to prioritize research on AFFF alternatives that utilize "green and sustainable chemicals that do not pose a threat to public health or the environment" (NDAA 2021). Programs such as the GreenScreen Certified™ standard for PFAS-free firefighting foams may also ease some concerns.

## *D. Standards*

Regulations and performance standards can both hinder and support a transition away from AFFF use. Standards can run the risk of over prescribing performance needs, inhibiting innovation in safer products/technologies given testing costs and, depending on how they are written, can lock in only one type of technology to achieve the performance function needed. The MilSpec provides important lessons regarding the danger of developing overly prescriptive standards that lock-in the use of only one type of technology to achieve the function of fire extinguishment/ suppression and that are designed for a "worst-case" scenario. Although the Danish military and dozens of airports in Europe and Australia are now using PFAS-free alternatives, adoption of such AFFF substitutes by US airports and its military is in a holding pattern – still hampered by existing standards. Unlike standards for firefighting foams used in Europe such as International Civil Aviation Organization (ICAO) or the European Standard, EN 1568, that have guided the adoption of PFAS-free

> *"I don't believe we will be able to make this transition in the US unless the FAA and DoD give up on the standard of 'equal replacement'….I believe that whatever we find as a suitable replacement will not be equivalent. I just need the men and women to be able to put out that fire."*
>
> *"We don't need an equal substitute for the MilSpec…maybe on a ship but not in other applications."*
>
> *"Is the point to put the fire out or to provide a rescue path …such as to get off the plane? If it's that significant of a fire, the plane is likely lost anyway (without having AFFF to put it out quicker than water only…)"*

alternatives in numerous European countries, both US airports and the US military are limited by provisions in the MilSpec, which mandates the use of fluorinated surfactants in firefighting foams and dictates specific mechanisms and equipment compatibility requirements that only fluorinated products can achieve. ICAO and EN 1568 standards were not written around the capacities of AFFF and thus never precluded non fluorinated products from achieving the specified fire extinguishing performance criteria.

Legislative mandates within the FAA Reauthorization Act of 2018 and the US NDAA of 2020 have paved the way for both airports and the military to phase out their use of AFFF – a significant enabling factor to the transition to PFAS-free alternatives. Yet progress is on a much slower time scale than elsewhere. A revision to the MilSpec is in process, in line with the National Defense Authorization Act of 2020, which mandates the US military to phase out fluorine-based firefighting foams by 2024. As outlined in the FAA Reauthorization Act of 2018, the FAA no longer sets forth requirements for US airports to use fluorinated foams. However, airports remain in a predicament as AFFF remains the only product approved for use by the FAA for aircraft rescue and firefighting operations. The FAA has not met the October 4, 2021, deadline outlined in the FAA Reauthorization Act of 2018 to phase out use of AFFF. In its October 4, 2021, memo the reasons for not moving forward were the inability to identify alternatives that had equivalent performance to AFFF and that existing alternatives could not act as a drop-in replacement (FAA 2021).

> *"If my peers around the world do it [i.e., use PFAS-free products] so can we."*

There is an array of standards related to the use of firefighting foams. This has created confusion related to procurement among some entities. According to interviewees, firefighting foam customers have outlined requirements in their procurement specifications for certifications related to multiple standards that have competing attributes. For example, one standard may favor a foam that spreads quickly over a fuel, while another may favor a foam that penetrates deeper and sticks to substrates to resist burn-back.

Today's firefighting solution may be different than tomorrow's solution. Interviewees expressed the barrier of standards in limiting continued innovation in fire extinguishment technologies for Class B fires due to costs involved in achieving certifications. For example, interviewees noted a $150,000 cost per fire performance test to receive an Underwriters Laboratories (UL) listing. Smaller manufacturers often don't have the budget to undergo certification tests for multiple formulations. One PFAS-free product manufacturer interviewed noted that these cost barriers inhibit manufacturers to innovate further given the dynamics of internal incumbency once specific performance standards/certifications have been achieved. Depending on the amount of tests/listings needed, the cost can run into the millions of dollars for multi-component or multiple formulations of products. However, interviewees also noted that companies do innovate to a standard. In the case of the MilSpec, the revised version will likely require the use of Newtonian (e.g., low viscosity) products whereas most products available currently are non-Newtonian (high viscosity) products. Learning of this provision, several manufacturers have recently launched Newtonian products, showcasing that standards can also drive innovation in specific directions as well.

### *E. Lack of a Coherent National Transition Strategy*

Many end users in both the US and abroad have stated the need for guidance and support as they substitute fluorinated firefighting foams with PFAS-free alternatives. In the US, many states are using AFFF only in emergency measures, but have not received any further guidance from government agencies about next steps such as decontamination needs or new PFAS-free options that are both safer and feasible. Without a national transition strategy in the US, end users such as fire departments and airport fire and rescue/facility personnel are particularly struggling with more questions than answers, such as:

> *"There should be an entity in D.C. that would hold the three areas of health, safety, and environmental performance standards accountable…maybe in the FAA or the DoD."*

- Will the substitution requirements be voluntary or regulatory?
- Will the guidance be issued from the states or from the federal government?
- Who will define criteria for an alternative?
- Who will develop a standard of what is considered "clean" when decontaminating equipment?
- Who will coordinate and implement the decontamination process?
- Where should contaminated components/equipment be sent for disposal and who bears the cost?
- Will there be technical support offered to help change and/or tune equipment and firefighting techniques to maximize the performance of alternatives?
- Who will issue new training guidance?
- What residual human and environmental risks need to be mitigated with regard to the PFAS-free alternatives and what are the strategies for doing so?
- Who will coordinate the collection and final disposal of the legacy fluorinated foam products?

Some interviewees suggested that a potential solution could be the establishment of regional/centralized "cleaning" centers for the decontamination needs. No strategy is available that addresses these needs, and no national agency or interagency task force has taken responsibility for issuing such a strategy.

## IV. Primary Enabling Factors: Transitioning to AFFF Alternatives

Several factors were identified among interviewees as critical to accelerating a transition to AFFF alternatives. Several of these are counterpoints to the barriers noted above. Primary enabling factors included: (A) "just do it" – using mock exercises to understand performance of alternatives and adoption needs; (B) financial liabilities with continued use of AFFF; (C) fit-for-purpose performance standards; and (D) policy mandates.

### *A. "Just do it": Use of Direct Experience and Mock Exercises to Understand Performance of Alternatives and Adoption Needs*

Some entities have already made the transition to PFAS-free firefighting foam products with their existing technology (nozzles, aspirators, etc.). In the early 2010's, based on a parliamentary mandate, the Danish Royal Air Force directed its airports to stop using AFFF products within a two-day period, requiring them to send the legacy product to a central collection site. This was feasible due to their small size and the military governance structure. They received a PFAS-free product to use, and after a couple weeks of adjustment with their equipment to get the correct product viscosity and percentage, they made the transition. It should be noted that they were not required to decontaminate trucks nor equipment.

> *"(The Danish Royal Air Force) delivered the new (FFF) product just in time…the day after we got rid of the old one, we got the new one so that it was quick and easy for us to adapt to the new foam because it worked almost exactly as good as the old one."*

LastFire's large-scale "real life" testing program for tank fires is another example of what is needed for end users in other firefighting scenarios to further understand the capacities of PFAS-free products and what is needed to maximize performance (LastFire undated). This collaborative testing program included the participation of six PFAS-free product suppliers who helped to contribute to the effort by providing funding for fuel costs as well as supplying products for the test (LastFire undated). The US DoD has recently also conducted a large-scale test of 5 commercially available PFAS-free alternatives at its China Lake Facility to support further understanding of product capabilities (Back 2021). Test results suggest that the capabilities of the alternatives mirror the pilot-scale test results in terms of extinguishment times (Back 2021). One interviewee suggested a facilitated convening between those who remain unsure/unclear about the effectiveness of PFAS-free products and those that have converted. Such a meeting would show video recordings of large-scale tests and subsequent discussion could address residual questions, including: (a) effectiveness; (b) anticipated changes to equipment and (c) anticipated changes to firefighting tactics.

### *B. Financial Liabilities with Continued Use of AFFF*

Realization of financial liabilities has provided significant motivation for numerous early adopters to substitute their fluorinated firefighting foams. While some end users who adopted PFAS-free alternatives early raised concerns about financial losses if these are not eventually approved others described a growing trend especially among industrial facility insurers to limit insurance coverage or simply not pay for any type of potential liability associated with PFAS discharges or contamination as part of a fire suppression scenario. Additional liabilities also include potential litigation associated with the past use of PFAS-containing foams that may result in local/regional contamination issues. This is a significant factor motivating users to transition to PFAS-free alternatives.

> *"The main point for facilitating change is with the end-user, once they realize that they carry all the liability (not the manufacturer, not the supplier, not the incident controller) they are the polluter, they are responsible and that the Polluter Pays."*
>
> *"The costs of transition including equipment changes can be significant or not depending on the circumstances, however, the costs are far outweighed by the risks and liabilities to the end-user, other industry and the community of harm caused by PFAS releases on a very broad range of community and environmental values."*

### C. *Fit for Purpose Performance Standards*

Based on existing performance testing of PFAS-free alternatives against the current MilSpec, no PFAS-free product can extinguish a 28 $ft^2$ pan fire within the 30 second requirement of the specification, but several can do so within 45 seconds (Back 2021). Interviewees noted the importance of considering comparable performance versus equivalent performance when it comes to identifying feasible substitutes for fluorinated firefighting foams. Rather than performance standards that are written for the worst-case scenario – as the MilSpec is perceived – interviewees encouraged standards that fit the purpose of a given firefighting scenario. Such standards would help to certify that a product meets a required level of fire extinguishment performance for the most likely event while also recognizing the range of firefighting scenarios that exist. ICAO was mentioned as an example, such that it certifies products based on three levels of performance (levels A-C) leaving it to users to decide which level of performance is necessary for their fire incident needs. To address the issue of different scenarios, use of multiple standards that reflect such scenarios, rather than a one size fits all approach, was also encouraged.

> *"Matching performance and capabilities with various scenarios will be key going forward."*
>
> *"The terminology used to describe the performance difference between a flurosurfactants based foam and a fluorine free (foam) in Europe has been 'comparable' performance…and that some fluorine free foams are better than some C6 AFFF's in putting out fires and some AFFF's are better than some fluorine free foams…they are exhibiting comparable performance."*

### D. *Policy Mandates*

Policy mandates are clearly an enabling factor supporting a transition in the use of PFAS-free firefighting alternatives. As is the case with most chemical substitution efforts, policy is a key driver (Tickner et al. 2019). These mandates have come in various forms, including: (a) changes in policy handed-down from institutional leadership as is the case with dozens of airports and decisions by military officials in Scandinavia, (b) government mandates, such as national policies issued by the Queensland Government of Australia, New Zealand and through programmatic reauthorization legislation issued by the US Congress and (c) state-level government policies in the US, among others.

> *"The Queensland (Australia) foam policy was seen as setting a new best-practice standard with industries operating across Australia, so the support extended to other State regulators, large industry operators and fire brigades using the Queensland Policy as a performance benchmark"*
>
> *"Once the mandate [US National Defense Authorization Act of FY 2020] came online you see all these industries coming up with new products and experiencing progress very quickly."*

The anticipatory effect of potential changes in regulation and policy is also a powerful force for change. The PFAS-free transition at Schiphol Airport in Amsterdam was stimulated in part because their supplier was no longer going to produce/distribute C6 foams due to the increased regulatory focus on PFAS-containing firefighting foams (Bruinstoop 2021). To signal intentions to users and allow for the necessary transition time, funding and training, draft policies, such as those from the Queensland Government, have been an effective tool for industry and other end users. Such policies give end users time to consider all the options as well as time to address decontamination needs of existing equipment (Queensland Department of Environment and Science 2016). The Queensland Government worked with the firefighting community for six years throughout their policy discussions, an inclusive process that enabled impacted entities to address needs along the way.

In the US, the Federal Aviation Authorization Act FY 2020 (FAA Authorization Act 2019) and the NDAA of FY 2020 (NDAA 2019) included provisions that recognized the main factor limiting adoption of PFAS-free alternatives – the MilSpec. Although the US is a "late-comer" to the transition because of modifications needed to this standard, without the two Authorization Acts, a broad transition in the US would be nearly impossible as the MilSpec dictates use of AFFF in aviation and military firefighting. The National Defense Authorization Act also made possible targeted research support on PFAS-free alternatives. These efforts sponsored through US DoD's SERDP/ESTCP activities have helped to address systematic uncertainties in existing knowledge, including equipment capability concerns with the PFAS-free alternatives as well and concerns regarding health and safety, such as aquatic and terrestrial toxicity, that will benefit both PFAS-free developers and end users alike. This research is being supported by requirements in the FY 2021 NDAA for DoD to prioritize research on AFFF alternatives that utilize "green and sustainable chemicals that do not pose a threat to public health or the environment" (NDAA 2021). Interviewees noted that the pace of innovation in and enhanced understanding of the hazards and performance of available alternatives would not have been possible without policy driver and research support made possible through the mandates.

## V. Lessons Learned: Core Recommendations for an Efficient and Effective Transition to AFFF Alternatives and Future Substitution Challenges

### Review of Core Findings

This project identified five primary inhibitory factors that are acting as barriers to an effective transition to safer and feasible AFFF alternatives and four enabling factors as outlined in **Table 1**.

**TABLE 1:** Primary Inhibitory and Enabling Factors Impacting a Transition to Safer and Feasible AFFF Alternatives

| Primary Inhibitory Factors | Primary Enabling Factors |
|---|---|
| Transition costs | "Just do it" – using mock exercises to understand performance of alternatives and adoption needs |
| Lack of knowledge of performance for specific real-world scenarios | Financial liabilities with continued use of AFFF |
| Substitution regret | Fit-for-purpose performance standards |
| Standards that limit innovation | Policy mandates |
| Lack of a coherent national transition strategy | |

A dominant theme across the inhibitory and enabling factors is the issue of performance, including questions about the utility of existing standards, testing programs, compatibility of the PFAS-free alternatives with existing firefighting equipment/components and who decides that a given performance level is sufficient for a given use. There are clear differences of opinion regarding compromising on performance capabilities. As noted earlier, some users feel that we need to move away from seeking replacements for AFFF that are of equivalent performance given that many believe that an alternative's lesser performance is still sufficient in many firefighting scenarios. Others are simply unwilling to take the chance when seconds matter in the ability for fire and rescue personnel to save lives. Policy mandates however are forcing decisions because the clear risks to human health and the environment outweigh the benefits of continued use of AFFF and other PFAS-containing firefighting foams in many current settings.

## Recommendations to Accelerate the Adoption of Safer and Effective AFFF Alternatives

There is growing acceptance that alternatives to AFFF are available. Yet implementation is often the most challenging part of the substitution process and requires planning and ongoing monitoring to identify and minimize potential impacts. The following recommendations to help accelerate successful adoption of safer and effective AFFF alternatives were derived from lessons learned revealed in this project.

**A comprehensive and collaborative implementation strategy.** There is a clear need for a comprehensive implementation strategy to support the transition to PFAS-free alternatives. The strategy needs to support the various fire and rescue user segments that are currently dependent on AFFF. The strategy needs to recognize the varying policies, standards and procurement specifications that impact the use of firefighting foam products. Such a strategy should be a multi-agency/institution effort given the expertise and engagement needed to address the array of substitution challenges including ensuring a sufficiency of market supply of the alternatives, addressing firefighting performance/technical feasibility needs, addressing decontamination, providing firefighting education and training, addressing occupational health and safety concerns, and ensuring environmental compliance and public health protections related to AFFF decontamination and disposal. Such a national strategy should be incorporated into current White House Council on Environmental Quality's effort to coordinate PFAS-response activities across governmental agencies (White House 2021).

The Fire Protection Research Foundation, a research affiliate of the National Fire Protection Association has launched an effort to establish a Firefighting Foam: Fire Service Road Map, whose stated goal is "to develop a strategy roadmap for the fire service while transitioning from fluorinated foam usage to fluorine free foam technology (Back et al. 2022). This Roadmap is an example of the type of guidance needed. Moving forward, it should be expanded upon in collaboration with other authoritative bodies that have a role to play in supporting fire service personal in the transition to PFAS-free alternatives.

**Education and training**. Important to any implementation strategy are provisions related to education and training as noted above. Education and training activities need to address the current "resistance to change" that is still being experienced among some facets of the fire and rescue communities. This resistance is experienced in two ways: (a) a lack of understanding of the problem; (b) a lack of confidence about the solutions. Personnel need to be educated regarding PFAS contamination occurring globally and the contribution of AFFF to the problem. They need to understand the risks that PFAS poses to their own health, the health of their colleagues, the public and the environment. As described earlier, some fire personnel have such trust in the performance and comfort associated with working with AFFF that they don't want to change to something different. Overcoming this resistance requires education about the PFAS-free alternatives in order to alleviate concerns about changes in performance as well as fears that their firefighting tactics will have to change dramatically; these fears are not borne out based on current experience. Changes in firefighting tactics need to be anticipated and thus training programs for AFFF substitutes need to be co-developed alongside results from real-world performance tests (Back, 2021).

In addition, education and training programs need to address topics related to the correct use of PFAS-free alternatives, associated equipment needs and changes, as well as specialized topics such as decontamination and treatment of legacy AFFF foams. Changes to routine training programs will need to be co-developed along with the PFAS-free alternatives as changes in firefighting techniques are expected. However, interviewees suggested that fire fighters are eager to be trained on the PFAS-free alternatives and are used to regular training and changes in technique. Virtual reality training programs could be explored (Engelbrecht et al. 2021). Programs should also train with PFAS-free products that will deployed in real incidents that use the same fuels which will be encountered in order to increase confidence in the products' ability to extinguish fires.

**Collaborative performance testing/demonstration sites**. Real-scale performance tests related to a range of firefighting scenarios is needed to enhance users' understanding of the capabilities of the various PFAS-free products and what is needed to maximize performance. Yet such large-scale comparative tests can be prohibitively expensive. Enhanced collaborative performance tests are needed where the burden of costs is shared among interested parties/organizational partners who also contribute to designing parameters of the testing protocol. Results of such tests need to be broadly disseminated, targeting trade journals/magazines and other media and conference outlets that reach firefighting and facility management professionals.

As mentioned earlier, LastFire and the US DoD's SERDP/ESTCP program provide examples of support for real-scale collaborative performance testing program. In these comparative performance tests, multiple commercially available PFAS-free alternatives were subjected to performance questions relevant to specific fire scenarios, e.g., tank fires, fuel spills, and debris fires (Pepper 2021; Back 2021). Although the testing parameters may not address all residual questions about the performance capabilities in additional firefighting scenarios, these types provide models for future collaborative test programs.

The Massachusetts Toxics Use Reduction Institute has engaged in multiple collaborative performance testing programs over the last two decades. Based on this experience, they outlined 10 criteria to ensure success of such program, which align with the current context of the need for large scale performance testing of PFAS-free substitutes for AFFF (Morose, 2013):

1. Use of a toxic chemical(s) of concern is pervasive in an industry sector
2. The toxic chemical is not used for competitive advantage
3. There are strong market and/or regulatory drivers to reduce the use of the toxic chemical
4. Significant research is required to switch to the use of safer alternatives
5. It is both time and cost intensive for companies to individually conduct research
6. An independent third party is available to manage and coordinate the effort
7. Voluntary participation by government, academic, and industry collaborators is possible
8. Participants provide either in-kind contributions (production equipment, technical expertise, materials, supplies, testing, etc.) or direct funding
9. The intent of participants is to adopt the safer alternative solutions identified
10. All results are made public so that other companies can adopt solutions identified

In addition, the SERDP/ESTCP funding program for AFFF has shown the importance of creating a "collaborative innovation community" of stakeholders working together to accelerate innovation and adoption of safer, and feasible options. Interviewees noted the value of the diverse community created through the SERDP/ESTCP funding for AFFF alternatives, which has allowed researchers, those conducting performance evaluations, military experts, innovators, and established companies to share and jointly develop knowledge that support solutions. Importantly, one small company creating innovative PFAS-free alternatives noted that without this program they would have never had the resources to develop an alternative that may be available in the future. Given the resources and time horizons needed for commercialization and scale of innovative safer alternatives, and the fact that only currently on market options have sufficient scale for military applications, programs such as this can reduce time to market for new entrants that may be improvements over existing available options. This approach should be repeated for additional chemical challenges faced by DoD.

**Systems for ongoing monitoring.** Regular monitoring and evaluation are essential to the early identification of potential unintended consequences from the adoption process. Although performance and environmental/human health impact criteria that are deemed critical to making decisions about a safer and feasible alternative should be well understood at the time of adoption, knowledge gaps will remain. Moreover, controlled testing environments cannot address all factors that may impact the feasibility or hazards/exposures of the alternatives under real world conditions. It is therefore imperative to set up systems for ongoing monitoring and evaluation. Systems need to include but are not limited to environmental surveillance programs to monitor for impacts on a broader array of ecological endpoints, testing to ensure adequate capture of PFAS in reused equipment, use of approved validation testing to ensure that new foams are indeed fluorine-free (the appropriate testing method is under discussion at the time of this writing), industrial hygiene evaluations and discussions with firefighting personnel about the impacts of the transition and to adjust training, equipment and standards of practice as needed.

Substitution is a continuous improvement process and decisions should be regularly revisited and updated. Given that innovation in the PFAS-free market is ongoing, there may be safer, better performing, less costly innovations coming on the market in the future. Adoption decisions are based on the best available information at a given point of time. But new information is to be anticipated, especially for newer chemistries, materials and technologies.

## Lessons Learned from AFFF to Inform Other Substitution Initiatives

Although substitution efforts for AFFF remain ongoing and not every substitution challenge is the same, there are a series of lessons learned that can be generalized from this experience to inform the adoption of safer and feasible substitutes for future chemical-product challenges going forward. Lessons learned include:

**Policy mandates are a critical enabler for substitution**. Research and development in alternatives as well as broad implementation of substitutes will always be held back unless there are clear policy mandates that motivate both innovation and adoption. Policy mandates are often the main enabling factor that can overcome the dominant power that incumbent products (such as AFFF) have in the market, enabling a transition to safer and feasible alternatives.

**Expand the use of collaborative performance testing and demonstration programs.** Users will debate whether existing performance tests are relevant to their needs/use scenarios. Yet performance testing can be prohibitively expensive. Filling gaps in the understanding of performance for specific use scenarios can advance through the expansion of collaborative performance testing programs where costs are shared and distributed among interested user stakeholders, who also are involved in designing the test parameters will support broader trust and understanding of the performance capabilities of alternatives under conditions of use that better align with user’s needs. Such collaborative performance testing programs should be combined with demonstration and knowledge sharing programs where entities that have transitioned can demonstrate their experience and stakeholders can discuss challenges and how these have been addressed. Collaboration is also needed to fill gaps in testing to obtain accreditation for specific uses of PFAS-free products (such as in sprinkler systems) where insurers are still not willing to underwrite risk for facilities using these alternatives.

**Changes in processes and equipment need to be anticipated when adopting safer alternatives.** Past experiences to date suggest that drop-in replacements are mostly viable when substitutes utilize the same class of chemistry, which may provide little to no advantage in terms of improving health and safety. Examples of this abound and include moving from C8 to C6 alternatives in the case of AFFF (Fenton et al. 2020); moving from bisphenol-A to bisphenol-S in resin can linings (Rochester and Bolden 2015) or substituting methylene chloride with 1-bromopropane in paint stripping applications or for the solvent carrier function used in adhesives (Ichihara 2012). Implementation of alternatives needs to anticipate:

- *Changes to product or process.* Identified acceptable alternatives will likely require process or equipment modifications to achieve the desired performance. Such changes will impart costs associated with the substitution process. Often these costs are considered cost-effective given the overall return-on-investment given decreased regulatory, insurance, and liability costs associated with continued use of the incumbent. In addition, costs can be absorbed if substitutes are implemented at the same time equipment needs to be routinely replaced or upgraded.

- *Changes in work practices.* Implementing alternatives will typically require changes in work practice changes. It is always critical to ensure that changes do not affect worker exposure pathways, increase potential hazards, and affect productivity if they do not work as well as the incumbent product. Training will often be needed to address changes in performance or delivery of alternatives.

- *Continuous improvement needs.* Continued monitoring is needed to reveal new information about potential impacts of alternatives across its lifecycle of production, use and disposal and to adjust standards of practice in the use of the alternative to maximize performance and productivity.

**Share information about alternatives.** Lack of communication about the viability of alternatives often hampers their adoption. Lack of transparency of ingredient information in formulations hinders research and understanding about hazards. Government agencies, NGOs and trade organizations all play role in sharing and disseminating information about safer and feasible alternatives using forums that best reach user audiences.

**Anticipate the need for and the promise of continued innovation.** Innovative solutions for a given application can often take 10+ years to commercialize at scale. As such, available substitute for a specific application at a given point and time will evolve. It is important for users to monitor progress in innovations that have the possibility of continued reductions in hazard with equal or better performance for their application of interest. It is also important for government agencies to continue supporting the commercialization and growth of innovative new options. Performance standards and specifications need to also support innovation and avoid criteria around only one product type or option.

# VI. Conclusion

There is global interest to replace PFAS containing firefighting foam with safer and effective alternatives. Efforts to date demonstrate that substitution is possible. With continued focus on correcting those factors that are inhibiting the implementation of alternatives to AFFF and replicating/scaling those factors that are enabling substitution, we can collectively accelerate efforts to effectively move beyond the use PFAS containing firefighting foams and towards safer, feasible alternatives.

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