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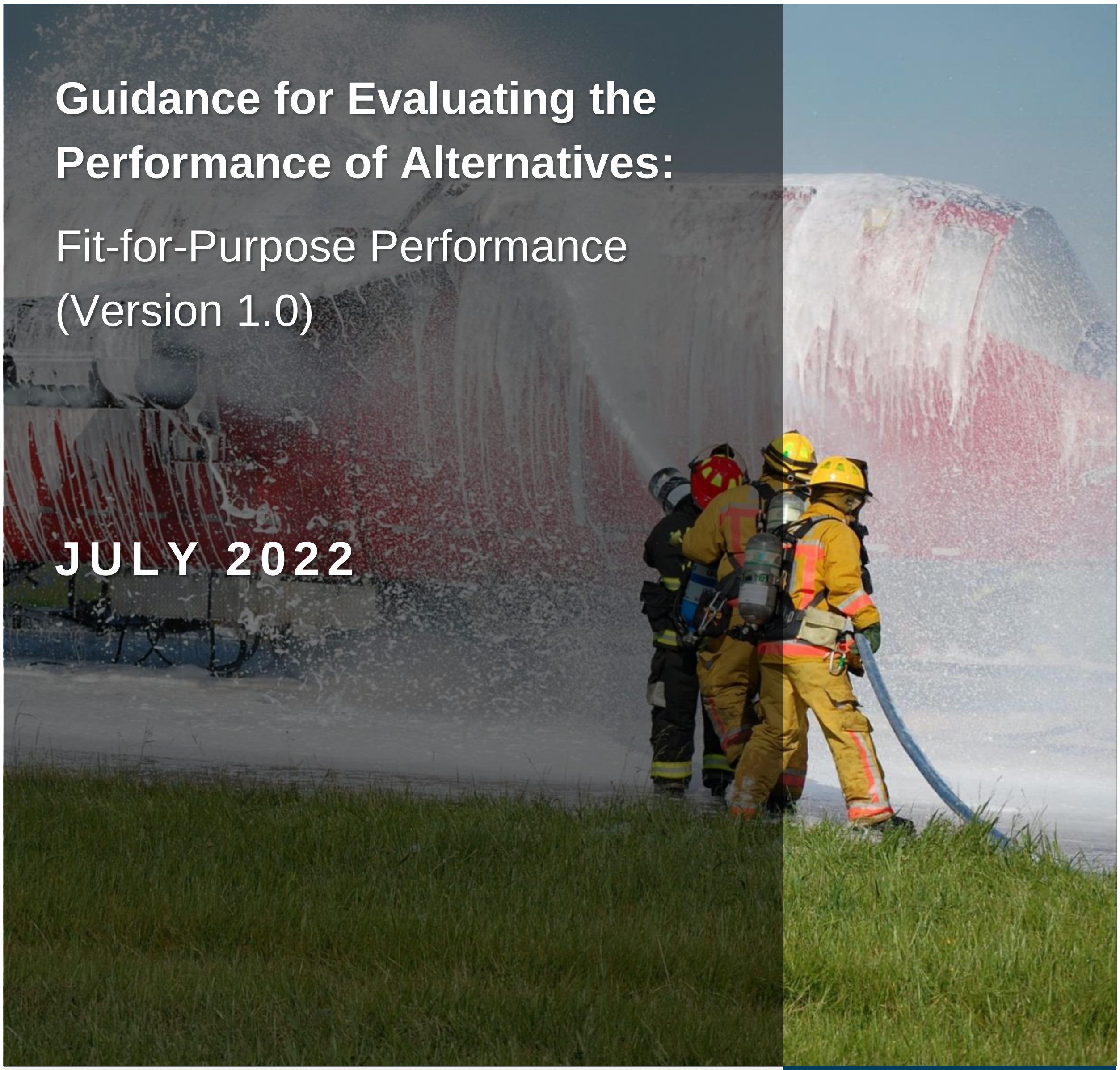

Guidance for Evaluating the Performance of Alternatives:

Fit-for-Purpose Performance (Version 1.0)

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Sustainable Chemistry Catalyst

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The Lowell Center for Sustainable Production at UMass 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.

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Established by the Massachusetts Toxics Use Reduction Act (TURA) of 1989, TURI at UMass Lowell collaborates with businesses, community organizations and government agencies to reduce the use of toxic chemicals, protect public health and the environment and promote the competitiveness of Massachusetts businesses.

For more information, visit www.turi.org.

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.

Sustainable Chemistry Catalyst

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LIST OF ABBREVIATIONS

AFFF	Aqueous Film Forming Foam
IC2	Interstate Chemicals Clearinghouse (Alternatives Assessment Guide)
MILSPEC	Military Performance Specification MIL-PRF-24385F(SH)
NRC	National Research Council (Framework on the Selection of Chemical Alternatives)
PFAS	Per- and polyfluoroalkyl substances
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonate
QPL	Qualified Product List
US DoD	United States Department of Defense

EXECUTIVE SUMMARY

This guidance is intended to support decision-making by governments, businesses, and others associated with the evaluation of performance in the conduct of an alternatives assessment. It emphasizes a focus on *fit-for-purpose* performance, a strategy for assessing performance based on application-specific contexts. This guidance builds on and broadens the thinking around performance when evaluating and choosing safer alternatives and draws primarily from two well-established alternatives assessment frameworks: The Interstate Chemicals Clearinghouse (IC2) Alternatives Assessment Guide and the National Research Council (NRC) Framework on the Selection of Chemical Alternatives.

Regrettable substitutions can occur if specific performance metrics cannot be achieved under real-world conditions. However, performance can also be a barrier to the adoption of safer and available alternatives if evaluations are based around a single “best in class” performance metric, require performance through specific mechanisms, or require consideration of adoption feasibility as part of the performance evaluation. This guidance was developed to help minimize extended debates over whether alternatives perform equally to the incumbent chemistry. A fit-for-purpose performance approach underscores the importance of evaluating whether the function of the chemical, material, product, or process of concern achieves sufficient performance, recommends using a range of acceptable thresholds, and acknowledges important considerations around tradeoffs with environmental health and safety performance.

Six guiding considerations shape this performance evaluation process. Depending on the context, some considerations may be revisited more than once, as the evaluation is an iterative process. The amount of information and testing required to address each consideration is likely case specific. These guiding considerations balance the need for detailed key performance criteria but include flexibility for a broad range of alternatives that achieve sufficient performance for the intended application. They include:

1. **Determine the *function* of the chemical/material/product/process of concern for the specific application and understand this function within the production chain.**
    - *What is the function of the chemical, and is it necessary?*
    - *If upstream processes are changed, is the function of the chemical/material/product/process of concern needed?*
    - *If the function is still needed, is it changed in any way?*
2. **Define the *application*-specific scenario(s) in which the substance of concern is used and identify alternatives that are suitable for that particular purpose.**
    - *For what application(s) is the chemical/material/product/process of concern being used?*
    - *Do alternatives under consideration meet the functional performance need for the application(s) (even if they are used in different ways for other applications), perhaps with minor adjustments?*
3. **Establish and/or use performance standards that have been developed *independent* of the existing chemicals/materials/products/processes of concern (as much as possible) and adjust them based on available alternatives or alternatives on the horizon.**
    - *What are the technical/standard performance requirements that the potential alternatives need to meet? Are there regulatory, industrial sector, customer, and/or other specification requirements?*

- *Were performance standards built around specific existing technologies or mechanisms of action? If so, can new iterations of the standard be adopted that are more function-oriented?*

4. **Develop and use a *range* of performance standard benchmarks, from "inadequate" to "sufficient" to "best in class" to evaluate the alternative for the specific application(s).**
   - *Have potential alternatives already been eliminated based on binary performance criteria (meets or does not meet a gold standard) that should be reconsidered?*
   - Define a range of fit-for-purpose performance criteria that encompass "inadequate", "sufficient", and "best in class" benchmarks for the application. *How do different alternatives compare within this range?*
5. **Consider technical performance *separately* from technical feasibility (feasibility of adoption) of potential alternatives.**
   - *When only performance is considered (and not the feasibility of their adoption), what are the alternative solutions that can be assessed and compared?*
   - *What additional process/product modifications may be needed to increase the feasibility of adoption?*
6. **Consult *stakeholders* to determine acceptable tradeoffs between performance results and other elements such as environmental health and safety.**
   - Hold discussions with an appropriately diverse group of stakeholders on the tradeoffs that would occur for each alternative under consideration. *Which tradeoffs are acceptable under various application-specific scenarios and chemical exposure scenarios?*
   - *What alternatives under consideration best minimize potential trade-offs between performance and environmental and health and safety concerns?*

These considerations are elaborated in the guidance itself, and a version that differentiates the considerations established by the IC2 and NRC frameworks from the considerations proposed here can be found in the appendix. Throughout this guidance, a case example on aqueous film-forming foam (AFFF) in military land-based firefighting applications is used to illuminate different aspects of performance. The case study is built from interviews conducted with firefighting experts as part of a Department of Defense (DoD) sponsored project to improve the use of alternatives assessment in evaluating alternatives to AFFF. Ultimately, the performance evaluation will form part of a broader alternatives assessment process that considers hazard, comparative exposure, economic feasibility, and other factors to compare alternative solutions to replace the chemical, material, product, or process of concern.

INTRODUCTION AND CONTEXT

The performance of a product or process is a priority for manufacturers and consumers. When a chemical, material, product, or process is identified as problematic for environmental or human health, manufacturers must evaluate replacement options with regards to their ability to meet specific performance requirements and expectations (in addition to other requirements). Alternatives assessment is a critical tool to support the transition to safer and effective alternatives, minimizing the potential for regrettable substitutions. The approach has been used by governments, businesses, and other organizations to evaluate potential chemical and process/product redesign options to arrive at a safer solution. Alternatives assessments include evaluation of performance, economic feasibility, hazard, and exposure, but may also include components on social impact and life cycle considerations.

This guidance focuses on the performance component of an alternatives assessment, the traditional approaches to which have often constrained a wide range of options as they were not conceived in the context of supporting the transition to safer alternatives. These limits include tying performance of potential alternatives to specific performance metrics (which may be rigid and unnecessary for many applications), comparing performance of potential alternatives to the incumbent chemical/material/product/process of concern, or including feasibility of adoption as integral to the assessment of performance. As a result, lower or different performance is often used as an argument against transitioning to safer alternatives. For example, the European Chemicals Agency (ECHA) authorized the continued use of lead chromate – derived from lead, a neurotoxin, and hexavalent chromium, a carcinogen – in pigments used in road markings for years as it was argued by product manufacturers that no other replacement could provide the bright color needed on road surfaces to prevent vehicle accidents, though it had already been phased out in other places. This may be due to a limited view of what constitutes an "alternative" or how performance is defined. Often, specific performance criteria and acceptable types of options are dictated by standards. Other times, policies may note the need for equal performance; and still other times, there may be a resistance to performance changes that necessitate changes in process, customer education, or worker retraining.

This guidance outlines critical questions that can be used to reshape the evaluation of performance in the alternatives assessment process. In the guidance, a "fit-for-purpose" focus is emphasized, defined as *an alternative solution that achieves sufficient performance for a specific context or application, even though it may perform differently in other applications*.

The first step for evaluating the performance of potential alternatives is to determine the *function* of the existing chemical/material/product/process of concern in the application. This function can range from simple to complex, with the chemical/material/ product/process of concern involved in several different functions required to achieve the desired product or process level outcome. Determining these details will help an assessor appropriately determine whether a safer alternative can provide "sufficient" performance for the intended application, a concept discussed in more detail below. If no alternative can provide sufficient performance, then new options may need to be developed.

For chemicals/materials/products/processes of concern that have been in use over decades, there is often an assumption that the key performance criteria are immutable. However, as technologies and understanding advance over time, these criteria should be reexamined and reset as appropriate, opening more opportunities to evolve expectations about functional needs. This process requires first *letting go of the expectation that an alternative should demonstrate equivalent performance compared to the chemical of concern it is intending to replace*. One of the most important – and most difficult – responsibilities of an alternatives assessment practitioner is to challenge manufacturers and specifiers to reevaluate performance expectations and key performance indicator setpoints. The goal is to look at the process with a willingness to innovate and identify performance criteria that fit the purpose of the application.

This guidance builds on existing government and industry approaches for evaluating performance for assessing alternative options as well as the Interstate Chemicals Clearinghouse (IC2) (Interstate Chemicals Clearinghouse 2017) and National Research Council (NRC) (National Research Council, 2014) performance evaluation frameworks. Throughout this guidance, aqueous film-forming foam (AFFF), a widely used fire extinguishment agent and product of concern, is used as a case example to demonstrate the guiding considerations presented. The case study includes the perspectives of several experts and users of AFFF or their alternatives in a series of interviews conducted in the summer of 2021 as part of a Department of Defense (DoD) project to improve the use of alternatives assessments in evaluating alternatives to AFFF.

What is AFFF and the MIL-PRF-24385F?

AFFF is a fire suppressant applied with mechanical foam-generating equipment that forms a film over the ignited fuel to suppress and extinguish the fire. AFFF contains per- and poly-fluoroalkyl substances (PFAS). After AFFF application, PFAS can enter adjacent water bodies and bypass conventional water treatment systems to enter drinking water and human bodies. Scientific research has presented concerning data connecting PFAS exposure to human health effects (Pelch et al. 2019), spurring several initiatives to develop PFAS-free alternatives to AFFF (Dubocq et al. 2020; Hinnant et al. 2020). The U.S. Department of Defense (DoD) has stated that its goal is to “validate more environmentally sustainable PFAS-free fire suppression alternatives against the current performance requirements outlined in MIL-PRF-24385F” (Department of Defense 2021).

DoD performance specifications for AFFF are designated by MIL-PRF-24385F. This performance specification requires extinguishing a 28 ft^2 fire in 30 seconds, with a minimum burnback time of 360 seconds. The MIL-PRF-24385F also outlines other performance-related characteristics such as spreading coefficient, foamability and film formation and sealability, as well as physicochemical properties such as viscosity, pH, and corrosion rate. The MIL-PRF-24385F designates the maximum amount of two PFAS chemicals, perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA), allowed in AFFF and includes an aquatic toxicity threshold that must not be exceeded. Importantly, AFFF must meet these and all other specifications on the MIL-PRF-24385F to be listed on the Qualified Product List (QPL) for procurement purposes.

CONCERNS WITH EXISTING APPROACHES FOR EVALUATING PERFORMANCE

Many challenges exist with performance evaluation frameworks used today, including that they may be limited to evaluating a single performance metric, require performance through a specific mechanism, or include feasibility of adoption as a component of a performance evaluation. For instance, overly rigid performance requirements can lead to the conclusion that no feasible alternatives exist or that only potentially regrettable substitutes (i.e., alternatives that are structurally similar to the incumbent and may therefore exhibit similar toxicity) can meet a specific function. This type of framing locks in one type of technology or chemical mode of action and can hinder innovation, limits investment into innovation of alternative technologies, and limits the range of potential alternatives that could achieve the necessary function.

The development of the MIL-PRF-24385F and fire extinguishment times

PFAS-based fire suppressants were developed in the 1960s first as "protein foam" and then as "light water", which included foam that formed a more suppressant-efficient film. AFFF was then developed and the MIL-PRF-24385F standard was written around its performance. Over time, the MIL-PRF-24385F standard evolved as AFFF and deployment technology evolved. For instance, initial versions of the standard designated that fires be extinguished in 180 seconds, while the current version's requirement is 30 seconds, presumably based solely on the fire extinguishing efficiency of available AFFF products. A critical question is whether these replacement products need to meet the very specific and technical performance specifications outlined in the MIL-PRF-24385F. For instance, it may not be necessary for a fire suppressant to extinguish a fire at an airport. If the aircraft is not salvageable, the goal may be to suppress the fire long enough to save lives.

Any MIL-PRF should achieve the required results with criteria for verifying compliance, but without stating the methods for achieving the required results. A performance specification defines the functional requirements for the item, the environment in which it must operate, and the interface and interchangeability characteristics. Ideally, the MIL-PRF-24385F would allow for functional flexibility to meet a desired result, with the recognition that an overly specific standard may constrain performance. However, the overly prescriptive approach for AFFF may be counter to the intent of the use of a MIL-PRF. For instance, it may be unnecessary for a fire suppressant to form a film if it achieves sufficient performance through another mechanism. Once these contexts and goals for the fire suppression are established, then the functional aspects of alternatives can be analyzed as to whether they – or any modification or reformulation of the product – sufficiently meet the performance needs for the specific context.

More emphasis could be placed on understanding the function of the chemical/material/product/process of concern, especially for the context in which it is used. Too often, failure to comprehensively understand the functional requirements for performance can result in:

- Overlooking potential alternatives that could meet the functional needs of the application but were eliminated because the criteria were not well-defined or were overprescribed to achieve a specific goal (i.e., assuming performance is achieved by a certain mechanism, chemical ingredient, or that the function is required to achieve an end goal),
- Failure of an alternative to perform as needed under specific circumstances, and/or
- The inability to differentiate performance levels among the alternatives, especially if only binary performance requirements are provided.

Challenges in developing alternatives that match the fire suppression performance of AFFF

AFFF is a one-solution-fits-all product that can be used for any fuel fire extinguishment scenario. Many PFAS-free products, including non-film-forming products, achieve the MIL-PRF-24385F performance requirements for many aviation-based fire and rescue events, but may fail in other contexts. Although the details of a fire event may be unclear at the onset, having multiple products available specific to certain scenarios, or having an alternative that can achieve sufficient performance for most scenarios, may be the most effective way to transition to safer products. Deployment gear such as hoses, nozzles, and applicators are important aspects of firefighting performance. An alternative could pass technical specifications but might not work depending on the deployment device and application scenario. For instance, adjusting or changing the proportioning system, adding an aspirating system, or enhancing firefighter training may be important for thinking about performance.

In many cases, products must comply with government, industry, or sector-specific standards or certifications that outline specific performance specifications. These certifications may have been developed decades ago, when the context of performance and hence performance needs were very different or were developed by the "owners" of a specific technology, locking in its use. Some of these certifications may be relevant during the beginning stages of product development such as for material purchasing, some may be relevant during product development such as design specifications, and some may be relevant once the product is completed, such as specifications built into procurement programs. For instance, procurement standards that detail conditions that must be met for a product to be considered for purchasing may move the focus from functionality and may limit alternative solutions. Institutional procurement groups are key stakeholders to engage in conversations around appropriate performance indicators (**see guiding consideration #6**), though the result of these conversations should not restrict the development of potential alternative solutions.

AFFF and Related Certifications

The MIL-PRF-24385F is the DoD specification that specifies characteristics of AFFF and its fire suppressant performance, but there are many other standards within the MIL-PRF-24385F, for instance that test the storage containers for AFFF, the deployment equipment for AFFF, and environmental toxicity, among others. For example, the National Fire Protection Association NFPA 412 is the standard for evaluating aircraft rescue and firefighting (ARFF) equipment that deploy foam and is referenced by the MIL-PRF-24385F. All of these individual component standards within the MIL-PRF-24385F need to be satisfied by testing before a product can be listed for procurement and sold.

Outside of the United States, the United Kingdom's Civil Aviation Authority (CAA) uses the International Civil Aviation Organization (ICAO) standards for onshore civilian airports which specify three levels of performance certification for heptane-based fires; the tests for these levels range from extinguishment of a 2.8 m^2 fire at an application rate of 4.1 $L/min/m^2$ for Level A to extinguishment of a 7.32 m^2 fire at an application rate of 1.75 $L/min/m^2$ for Level C performance. In non-aircraft situations, other standards related to AFFF use might be important, such as NFPA 11, which is the standard for low-, medium-, and high-expansion foam and covers the design, installation, operations, testing, and maintenance fixed, semi-fixed, and portable systems for interior and exterior hazards. It is important to be aware of all the related standards that may be important for applications where AFFF or a potential alternative may be used.

The term "feasibility" can be used in several ways in an alternatives assessment (e.g., technical feasibility, economic feasibility, etc.). In this evaluation guidance, feasibility is considered with regards *to the technical performance* of the chemical/material/product/process of concern and the associated alternative solutions. For the purposes of this guidance, *technical feasibility* is considered separately from performance, focusing on the feasibility of adoption using existing technologies or whether there are transition barriers or challenges that may make adoption more difficult (e.g., cleaning application equipment). Considering these two concepts at the same time may hinder the landscape of potential options if some options require further research and development, process modification, or training to becoming a more viable and potentially advantageous solution. *Ideally, the feasibility of adoption related to cost, training needs, and other factors should be discussed after performance-specific testing has been completed* (**see guiding consideration #5**).

Testing and training challenges for AFFF and alternatives

Performance tests have been scaled down over the years and today firefighters rarely train via full scenario simulated fires, which can limit firefighters' experience and ability to respond effectively. The MIL-PRF-24385F designates a smaller-than-realistic fire area to be extinguished within a certain time frame. This standardized test is used when screening potential AFFF alternatives and is a tool to distinguish products that perform well from those that do not. While a potential alternative may pass this test, its performance is not necessarily representative of how it would perform during an actual fire event. As one firefighting professional noted, "if we were able to train on full-scale scenarios with a PFAS-free alternative without worrying that it would negatively affect the environment, we would be much better prepared, which can translate into saving lives."

"BEST PRACTICE" PERFORMANCE EVALUATION CONSIDERATIONS

The performance evaluation component of an alternatives assessment generally occurs after both a hazard evaluation and a comparative exposures evaluation have been completed, potentially resulting in some alternatives being eliminated from the assessment due to health and environmental concerns. However, performance is also considered at the scoping phase of an alternatives assessment. At this stage, it is important to articulate general parameters for solutions and any new approaches or designs that could be considered during the alternatives assessment, to expand the range of options to be considered for further evaluation. Scoping can also be used narrow the range of options to be considered, for example, if a substitution is required over a limited timeframe, which may limit the assessment to only readily available or ready to scale options.

The function of the chemical/material/product/process should be clearly defined when conducting a performance evaluation. In addition, assessors must be open to considering chemical and non-chemical (process or product design change) solutions that might fully or partially fulfill the function as defined. Chemical alternatives under consideration may not work as well as or may work differently from the incumbent. Process changes are typically even more complex, potentially impacting numerous other components of the assessment (for example hazard and life cycle attributes). In these cases, it is important to not eliminate such options right away, but rather, to investigate to see if these alternatives can fulfill the functional and/or performance requirements if amended in some way. Assessors can use the alternatives scoping process, as described in the NRC alternatives assessment guidance, to document this process, including consideration of innovations to meet functional and/or performance requirements. The scoping process is where the decision-rules, performance needs, timelines for substitution, and stakeholder engagement aspects of an alternatives assessment are outlined.

With the appropriate framing of function and performance requirements, stakeholder engagement, and a willingness to innovate, more optimal outcomes can be achieved that:

- Lead to the conclusion that the chemical of concern can be eliminated without affecting product performance
- Lead to the conclusion that existing alternatives or alternatives on the horizon can replace the chemical of concern to meet the functional requirements and performance specifications, and/or
- Lead to collaborations with other organizations that result in the development of a range of options to meet the performance needs in safer ways for specific applications.

Guiding Considerations for a Performance Evaluation

This guidance creates a comprehensive, yet flexible approach to support the identification and evaluation of safer alternatives. The amount of information and testing required to implement the guidance will depend on the specific context of its use. For example, in some contexts, such as for policy decisions, the availability of an alternative that meets the specific functional need may be sufficient to support a substitution decision. However, in other contexts, such as for a procurement decision, more detailed performance discussions and testing will be required.

The guidance is underscored by the concept of “functional substitution” or the use of functional information to identify fit-for-purpose options for the identified application. These options will undergo a performance evaluation to determine their sufficiency (do they adequately meet performance needs), which should involve consultation with stakeholders such as process and product engineers, vendors, manufacturing line supervisors and/or operators, quality control managers, and other key stakeholders. This guidance is based on six guiding considerations that suggest to:

1. **Determine the *function* of the chemical/material/product/process of concern for the specific application and understand this function within the production chain.**
    - Key questions to consider:

    - *What is the function of the chemical, and is it necessary?*
    - *If upstream processes are changed, is the function of the chemical/material/product/process of concern needed?*
    - *If the function is still needed, is it changed in any way?*
- Starting a substitution process by identifying the function of the chemical/material/product/process of concern provides a solutions-oriented approach to reducing risk (Tickner et al. 2015). Understanding the production chain and how upstream process changes can influence functional requirements may lead to making changes that remove or reduce the need for the chemical/material/product/process of concern (Tickner et al. 2019). This may require access to current or historical production line data from in-house experts.
- Another initial question that should be considered is whether the function of the chemical/material/product/process of concern is in fact necessary. This question of "essentiality" is being debated in Europe in the context of the Chemicals Strategy for Sustainability and elsewhere (Cousins, et al., 2019). In some cases where a particular chemical use is deemed not essential – for example decorative uses – a detailed performance assessment is likely not needed. In others, considering function and performance requirements may help determine whether a chemical application is essential. For now, simply asking whether a function is necessary based on the intended use of the resulting product or process should be part of any performance evaluation. Maintaining some independence of thought in considering this question can be challenging. This is an opportunity to solicit external stakeholder perspectives.

2. **Define the *application*-specific scenario(s) in which the substance of concern is used and identify alternatives that are suitable for that particular purpose.**

    - <u>Key questions to consider</u>:
        - *For what application(s) is the chemical/material/product/process of concern being used?*
        - *Do alternatives under consideration meet the functional performance need for the application(s) (even if they are used in different ways for other applications), perhaps with minor adjustments?*
    - The application context of the chemical/material/product/process of concern needs to be well-defined to establish "sufficient" performance criteria appropriately (**see guiding consideration #4**). If there are various functional use scenarios satisfied by the incumbent (or the incumbent chemistry works effectively in multiple applications), it is important to be open to finding alternatives that act as solutions for some, but not all, scenarios. In this case, finding more than one alternative that provides sufficient performance for the full suite of functional use scenarios is the goal.
    - Assessors must look for industry/technology-related scientific journal articles, conferences, or other business or technical organizations that can provide insight into the opportunities around functional substitution. This should include considering alternatives that provide sufficient performance for different but compatible uses. For example, a safer surfactant used in a cleaning formulation could provide necessary functionality for use in a textile dyeing application.

3. **Establish and/or use performance standards that have been developed *independent* of the existing chemicals/materials/products/processes of concern (as much as possible) and adjust them based on available alternatives or alternatives on the horizon.**

   - <u>Key questions to consider:</u>

     - *What are the technical/standard performance requirements that the potential alternatives need to meet? Are there regulatory, industrial sector, customer and/or other specification requirements?*

     - *Were performance standards built around specific existing technologies or mechanisms of action? If so, can new iterations of the standard be adopted that are more function-oriented?*

   - Assessors should identify relevant performance specifications established by customers, regulators, or other entities. It is best practice to look for the historical evolution of those performance standards. Performance standards that developed in parallel with the development of a related chemical/material/product/process may have evolved over time to become overly specific, narrow, or rigid, making it difficult for other options to be considered, thus impeding innovation. In some cases, it may be optimal to rewrite a performance standard altogether rather than to work with an incumbent standard. Performance standards that focus on functional needs (performance-based design), and that are determined as independently as possible from existing products can allow for more product innovation development to meet those standards. An important consideration is how the performance goal is defined.

   - In cases where the performance standards were built around specific existing technologies, the assessor should determine if the standard can be modified to accommodate a more function- and performance-oriented approach. When standards are internal to a company, this is a relatively straightforward thing to do. When standards have been developed by external stakeholders like customers, specification bodies, or regulators, the assessor should engage in dialog to evaluate the possibility of collaborating to modify those standards. This is a far less straightforward process, regardless of where the assessor sits (e.g., as a user, a customer, or a regulator). As fields develop and technology advances, it may be necessary for the specification and certification bodies to revisit specifications and update them accordingly, in a way that allows for innovation and that focuses on fit-for-purpose performance.

4. **Develop and use a *range* of performance standard benchmarks, from "inadequate" to "sufficient" to "best in class" to evaluate the alternative for the specific application(s).**

   - <u>Key questions to consider</u>:

     - *Have potential alternatives been eliminated based on binary performance criteria (meets or does not meet a gold standard) that should be reconsidered?*

     - Define a range of fit-for-purpose performance criteria that encompass "inadequate", "sufficient", and "best in class" benchmarks for the application. *How do different alternatives compare within this range?*

   - "Sufficient" performance should be established by those most familiar with the chemical/material/product/process of concern and the application-specific context, for instance manufacturing and customer stakeholders. Likewise, a range of relevant performance criteria around "sufficient" should be established by these experts so that when several alternatives are assessed, it is clear how each one ranks against the others (as is the case of the ICAO standard which includes three levels of performance for firefighting foams). This requires thoughtful discussions from experts across the supply chain as well as end-users to determine a range of quantifiable performance metrics for the defined application.

- Absolute minimum criteria should be used to determine the lower bound of the performance range. This may be a controversial process, requiring debate about the goal of the chemical/material/product/process and what is acceptable with various stakeholders. For example, in some contexts, the fact that an alternative is available for a specific application may be adequate to determine sufficient performance but not "best in class", an upper tier of alternatives or incumbents that exceeds the defined criteria for "sufficient" performance. The expectation is that alternatives should achieve "sufficient" performance for the application, but over time can strive to perform at the "best in class" level for a specific or multiple applications.
- It is important that performance evaluation metrics be consistent and robust. It is equally important that the process be adaptable for different contexts (Jacobs et al. 2016). Establishing minimum standards to achieve sufficient performance as well as ideal/optimal setpoints of performance criteria creates benchmarks that can be used when assessing alternatives, allowing for new alternatives to be developed over time. Testing against these benchmarks will help identify which alternatives are inadequate, sufficient, or best in class for a range of applications. These benchmark criteria can be set by an expert committee and can also evolve over time as new alternatives emerge, are tested, and are evolved. They also help set goals for innovation in new alternatives.

5. **Consider technical performance *separately* from technical feasibility (feasibility of adoption) of potential alternatives.**

- Key questions to consider:
    - *When only performance is considered (and not the feasibility of their adoption), what are the alternative solutions that can be assessed and compared?*
    - *What additional process/product modifications may be needed to increase the feasibility of adoption?*
- Technical performance relates to whether the alternative adequately achieves the desired function in a chemical/material/product/process for a specific application, whereas technical feasibility relates to issues of availability and adoptability (i.e., barriers and challenges to making the transition to an alternative – including supply, reformulation, retraining, etc.). Consideration of technical performance and technical feasibility are often intertwined in the alternatives assessment process. This can initially inhibit consideration of certain alternatives (for instance alternatives that may reduce operating costs over time but require initial retooling investments) and should be considered secondarily. For example, a potential alternative may be high-performing but may require significant equipment changes and further research to be technically feasible – this alternative should be kept on the table for later discussions on the tradeoffs of adoption for the potential alternatives (**see guiding consideration #6**).
- Determining the feasibility of an option requires considerations of limitations associated with very specific use scenarios, such as are seen in individual manufacturing facilities. The assessor needs to gather information from a wider range of stakeholders within facilities to determine feasibility. An equally important role for the assessor at this point is to question information presented that would indicate the infeasibility of an alternative (e.g., initial capital costs exceeding available cash) and to develop additional strategic actions to improve

an alternative's feasibility. This may include additional research and development, work to provide utilities necessary for manufacturing, etc.

6. **Consult *stakeholders* to determine acceptable tradeoffs between performance results and other elements such as environmental health and safety.**

   - Key question to consider:
     - Hold discussions with an appropriately diverse group of stakeholders on the tradeoffs that would occur for each alternative under consideration. *Which tradeoffs are acceptable under various application-specific scenarios?*
     - *What alternatives under consideration best minimize potential trade-offs between performance and environmental and health and safety concerns?*
   - Stakeholders such as companies (including workers), consumers, environmental groups, and the public are important throughout the performance assessment process. Assessors need to first determine the range of stakeholder perspectives needed, including from those involved in the production of chemistries and equipment, sourcing and use of products, and potentially impacted communities and ecosystems. Obtaining and synthesizing such input into choices of chemistries can be challenging given the potentially wide-ranging perspectives presented. A narrower net is more manageable but can limit access to creative ideas that could yield more long-term sustainable and competitive solutions.
   - Once other elements of the process have been completed, stakeholders can help the assessor determine acceptable tradeoffs between performance, feasibility of adoption, and other environmental and human health considerations (within the context of specific applications and chemical exposure circumstances). Ideally, these scenarios would be described in a matrix that lays out the cost of the options along with other performance and environmental characteristics. There will almost always be tradeoffs associated with adopting alternatives, so it is best to have all information available for decision-makers to view.
   - Gathering the perspectives of diverse stakeholders is important for vetting the acceptability of potential alternative solutions, including discussing challenges that alternatives would need to overcome, such as industry standards, procurement considerations, and acceptability. Stakeholder discussions can be particularly important to help avoid regrettable substitutions and assure that human and environmental health are adequately considered regarding viable options. Engagement of stakeholders helps ensure that environmental performance is considered on par with technical performance (Tickner et al. 2017).

Despite rethinking performance requirements, there may be no option that meets technical performance, technical feasibility, and environmental health expectations. In these cases, investment in the development of alternatives will be required. However, applying the questions in this guidance will likely open-up a broader range of potential options to explore, including options on the horizon.

Sweden and Denmark's approach to transitioning to a PFAS-free alternative

As more became known about the hazards associated with AFFF, both Sweden and Denmark switched to using PFAS-free foams in 2012. For both countries, the change was able to be made rapidly by prioritizing the switch to the alternative first and then later adjusting to other factors such as the number of vehicles and people needed to fight the fire. The transition was relatively easy because the alternative could be used in the existing AFFF deployment system. The alternative performed similarly to AFFF following minor adjustments to account for viscosity differences, however, Denmark and Sweden are in the process of re-examining performance requirements such as the "time to control" and "time to extinguishment" specifications for alternatives in specific fire event scenarios.

Performance Evaluation Guidance Using AFFF as an Example

In this section, AFFF is used as a case example to demonstrate how this performance assessment guidance outlined above would work for a specific application. This case example is not an in-depth assessment of all the potential PFAS-free alternatives, nor does it provide detailed answers to the guiding considerations. Rather, it presents a high-level context, walks through the general thinking that might take place in of each of the six considerations, and in some cases offers follow-up questions to explore. This case example was developed before MIL-PRF-24385F was re-written for PFAS-free alternatives.

1. **Determine the *function* of the chemical/material/product/process of concern for the specific application and understand this function within the production chain.**
   - *What is the function of the chemical, and is it necessary?*
     - PFAS were traditionally important surfactants used in foams. The surfactants reduce surface tension, helping the foam spread quickly as a film over a burning fuel to suppress it. AFFF formulations are proprietary, so it is difficult to determine individual constituent performance, but PFAS-free surfactants used in AFFF have been shown to provide the film-forming function necessary for the extinguishment of fuel fires indicating that PFAS are not exclusively necessary. Industry and most standards rely on the film-forming aspect provided by the PFAS surfactants, so it is reasonable to say that the function at this point is necessary, though limiting since options using other mechanisms to extinguish fires do exist.
   - *If upstream processes are changed, is the function of the chemical/material/product/process of concern needed?*
     - Potential non-foam alternatives may not require the function of surfactants at all. From a broader and more long-term perspective, transitioning aircraft away from highly flammable fuels could reduce the overall fire hazard and fire suppression need.
   - *If the function is still needed, is it changed in any way?*
     - For some foam-based alternatives, modifications to the proportioning system and in some cases the addition of an aspirating system allow the alternative to perform as well as traditional AFFF. However, the function in this case remains the same or similar.
2. **Define the *application*-specific scenario(s)in which the substance of concern is used and identify alternatives that are fit for that particular purpose.**
   - *For what application is the chemical/material/product/process of concern being used?*
     - Examples of different scenarios for the application of AFFF include aircraft fires, hangar fires, and shipboard fires, among others. The MIL-PRF-24385F dictates performance as the total extinguishment of a 28 ft^2 fire within 30 seconds under testing scenarios. However, the performance needs under real fire event conditions should be defined. For example, is it important to continue using AFFF to suppress a fire if there are no lives at stake and property damage is minimal? Another question to consider is what is “safe enough to get people out of fire situation,” minimizing risks to life and health.
   - *Do alternatives under consideration meet the functional performance need for the application(s) (even if they are used in different ways for other applications), perhaps with minor adjustments?*

    - AFFF is being used for aircraft fire and rescue scenarios. Currently, several PFAS-free foams work with existing deployment equipment and meet most of the performance requirements of the MIL-PRF-24385F, but as described above, some of these alternatives require minor adjustments to the deployment equipment to function well. These alternatives may not meet performance needs in other contexts where AFFF would be used, or they might require different kinds of adjustments compared to the adjustments made for an aircraft fire and rescue scenario.

3. **Establish and/or use performance standards that have been developed *independent* of the existing chemicals/materials/products/processes (as much as possible) and adjust them based on available alternatives or alternatives on the horizon.**

- *What are the technical/standard performance requirements that the potential alternatives need to meet? Are there regulatory, industry sector, customer, and/or other specification requirements?*
    - The MIL-PRF-24385F designates an extinguishment requirement as described above, with a minimum burn back time of 360 seconds. This standard is also a procurement specification, where all aspects of fire performance, foam characteristics, and toxicity testing need to be met before the product can be certified for purchase.
- *Were performance standards built around specific existing technologies or mechanisms of action? If so, can new iterations of the standard be adopted that are more function-oriented?*
    - The MIL-PRF-24385F is a stringent standard designed around AFFF with few opportunities to deviate, and currently, PFAS-free foam alternatives are held to the same fire extinguishment standards as traditional AFFF. Perhaps in future iterations of the MIL-PRF-24385F, other performance aspects such as foam characteristics and toxicity from environmental and human health exposure pathways could be adopted as separate but required components when considering alternatives.

4. **Develop and use a *range* of performance standard benchmarks, from “inadequate” to “sufficient” to “best in class” to evaluate the alternative for the specific application(s).**

- *Have potential alternatives already been eliminated based on binary performance criteria (meets or does not meet a gold standard) that should be reconsidered?*
    - Currently, alternatives either “pass” or “fail” the MIL-PRF-24385F. Under the current performance specification paradigm, there is no option for considering the use of alternatives that failed.
- Define a range of fit-for-purpose performance criteria that encompass “inadequate”, “sufficient”, and “best in class” benchmarks for the application. *How do different alternatives compare within this range?*
    - A binary system rather than criteria ranges are used in the MIL-PRF-24385F. However, future specification revisions that establish ranges of performance criteria would support use of products that show performance that is within the range of sufficiency to be used for certain firefighting scenarios.

5. **Consider technical performance *separately* from technical feasibility (feasibility of adoption) of potential alternatives.**

- *When only performance is considered (and not the feasibility of their adoption), what are the alternative solutions that can be assessed and compared?*

    - For alternatives that currently exist, they could be tested against the current MIL-PRF-24385F specifications, with current deployment equipment for foam-based technologies. The use of current deployment equipment has been a limiting factor for consideration of alternatives, except in cases where equipment is near retirement age. Or, as described in guiding consideration #4, ranges of performance criteria could be developed, which may be more appropriate for non-foam-based alternatives.

- *What additional process/product modifications may be needed to increase the feasibility of adoption?*
    - Several foam-based PFAS-free alternatives exist already, have been tested for sufficient performance, and are in use. Several others are in development but may not have been tested yet for technical performance or adopted for other feasibility considerations (for example the need for new deployment equipment or retraining). Other ideas for alternative solutions, including application equipment changes or modifications, may still be in the conceptual phase and require further development. All these potential options should remain at this point for consideration.

6. **Consult *stakeholders* to determine acceptable tradeoffs between performance results and other elements such as environmental health and safety.**

- Hold discussions with an appropriately diverse group of stakeholders on the tradeoffs that would occur for each alternative under consideration. *Which tradeoffs are acceptable under various application-specific scenarios and chemical exposure scenarios?*
    - A first step is to consider is who are the people, organizations, and other entities that can contribute thoughtful and productive insights towards understanding and weighing of the trade-offs between the range of performance criteria required for each of the alternatives and the potential environmental and health impacts for each. This group of stakeholders may look different in areas with different PFAS issues, communities, histories, etc. The stakeholder group for the specific place will help determine what the tradeoffs considerations are and how they are weighted.
- *What alternatives under consideration best minimize potential trade-offs between performance and environmental and health and safety concerns?*
    - AFFF alternatives may perform well in different ways. Or, they may perform similarly in different scenarios, but stakeholders for each of these scenarios may perceive the tradeoffs differently, depending on the factors that are important for each group (e.g., persistence, impacts on a wildlife population, association with a disease risk, etc.). Only upon consultation with the stakeholder group can it be useful to understand these factors and especially in the context of choosing an appropriate alternative.

The future of PFAS-free foams and avoiding regrettable substitutions

Globally, the firefighting industry is moving to PFAS-free fire suppressants, and there are many examples of governments and companies that have already made the transition to safer alternatives. One major question raised by firefighting professionals is “What are we transitioning to?” When AFFF was first developed, it was considered a product that performed extremely well with minimal risk to human health or the environment. Likewise, an alternative could be adopted that is supposed to be better, but the data about long-term impact might not become clear until years or decades later. More firefighting and health experts are now calling for multiple health and environmental endpoints to be considered when evaluating potential alternatives, with a focus on ensuring that replacements are not persistent. One positive aspect of this transition is that fluorosurfactants are expensive to both produce and clean up. By removing them from the supply chain, financial resources may become available for the research, development, and testing of PFAS-free alternatives.

CONCLUSIONS

This guidance is intended to serve as a “best practice” performance evaluation guide for decision-making on potentially safer alternatives, emphasizing a focus on *fit-for-purpose* performance, a strategy for assessing performance based on application-specific contexts. This approach highlights the importance of evaluating the function of the chemical, material, product, or process of concern, expands the thinking around performance as a range, and acknowledges important considerations around tradeoffs with environmental health and safety performance. The challenges that exist with current performance evaluation frameworks are outlined, such as their focus on a single performance metric, requiring performance through a specific mechanism, or including feasibility of adoption as a necessary component during performance evaluations. These factors can hinder the transition to safer and effective options.

Building on the IC2 and NRC frameworks, the guidance provides an iterative set of six primary considerations and leading questions to evaluate the performance of alternatives in a broad range of contexts, starting with functional needs. A high-level overview of how AFFF could be assessed using these guiding considerations is presented. The guidance considerations encourage users to be flexible over time as new alternatives emerge, are tested and adopted, and as more performance and environmental health data are collected. Performance assessment is context-specific and hence there is no one approach to evaluating performance. Different companies, sectors, and technical applications may have specific performance requirements. Decisions made at the government policy level versus at the product design or procurement level require differing levels of granularity in understanding performance. Many perspectives (e.g., toxicologists, engineers, consumers, etc.,) are required to both contribute to and interpret a performance evaluation for the most robust outcomes, and many other stakeholders may be required when debating the tradeoffs inherent in evaluating and adopting potential alternatives.

Overall, performance evaluations that focus on scoping the function of the chemical, material, product, or process of concern and on critically assessing the specific performance requirements of the product or application provide a strong foundation for a broader range of fit-for-purpose, safer solutions. The ultimate goal of this guidance is to facilitate the transition to safer and effective options to meet identified functional needs, while avoiding “paralysis by analysis” or the frequent “there is no alternative that meets the same performance” rationale to avoid substitution. Ultimately, potential tradeoffs between these need to be transparently discussed during decision-making. Where options do not currently exist that can meet environmental, technical, and economic performance requirements, investments in R&D in new options will be required.

Additional case examples using the guidance are needed, to refine and add more specific detail to the performance assessment process – including minimum information requirements and information sources. As a result, the guidance is expected to evolve based on these examples and other insights from experts conducting alternatives assessments in the future.

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APPENDIX A: Definitions

“Fit-for-purpose” performance refers to an alternative solution that achieves sufficient performance for a specific context or application, even though it may perform differently in for other applications.

Functional substitution refers to identifying the function of the chemical of concern as a starting point for exploring potential alternatives beyond drop-in chemical substitutions. This approach requires thinking more broadly of how system modifications, product use modifications, or other non-chemical solutions could be employed to achieve an acceptable outcome (Tickner et al. 2015).

Essentiality refers to whether the use of a chemical/material/product/process is needed for the health, wellbeing, or functioning of society, whereby determining essentiality can help with substitution decision-making (Cousins et al. 2019). Essentiality is not a particular focus of this guidance.

MIL-PRF is a performance specification that states the compliance requirements for a product but without stating the methods for achieving the required results. A performance specification defines the functional requirements for the item, the environment in which it must operate, and the interface and interchangeability characteristics.

Technical performance refers to how well the alternative performs against the appropriate performance criteria when tested. Data collected from these assessments can be used to determine technical feasibility (Interstate Chemicals Clearinghouse 2017).

Technical feasibility or feasibility of adoption refers to the ability of an alternative chemical/material/product/process in question to be adopted in practice for the specific application. Considerations include the possibility of process adaptations, product design changes, capital investments or training that may need to be put in place in order for the alternative to adequately perform the desired function (Gil 2011).

Technical standards industry, government, or customer standards or specifications that may be required for a particular application (Interstate Chemicals Clearinghouse 2017).

Economic feasibility refers to whether it is financially reasonable to implement the proposed alternative. Considerations include the potential change in costs and revenues from implementing the alternative, including the pass-through of costs to customers (Gil 2011).

APPENDIX B: Summary of the Interstate Chemicals Clearinghouse (IC2) & National Research Council (NRC) Performance Evaluation Frameworks

Two alternatives assessment frameworks were specifically reviewed in the development of this guidance. The first is the Alternatives Assessment Guide, originally published in 2013 and updated in 2017 by the Interstate Chemicals Clearinghouse (IC2), an association of state, local and tribal governments and supporting members from industry and the environmental community. The second is the National Research Council (NRC) document "A Framework to Guide Selection of Chemical Alternatives" published in 2014. The performance evaluation aspects of these frameworks are summarized below as a jumping off point for the objective of this guidance – to further the thinking of performance evaluations beyond what has been outlined in existing guidance documents.

Interstate Chemicals Clearinghouse (IC2) Alternatives Assessment Guide

The IC2 Guide was developed to assist companies (particularly smaller companies not well versed in assessing alternatives thoroughly) in identifying viable alternatives to their use of chemicals of concern. It includes a Performance Evaluation module as a critical component of an alternatives assessment framework, and it ensures that the chemical alternatives under consideration meet the performance requirements for the desired application. The module identifies three levels of evaluation: Basic, Extended, and Detailed Performance Evaluations. The Basic Performance Evaluation uses qualitative information of alternatives readily available from manufacturers and other sources, the Extended Performance Evaluation additionally uses quantitative data of alternatives reviewed by technical experts, and the Detailed Performance Evaluation additionally uses data from specified tests that were reviewed and validated by technical experts.

The Performance Evaluation module is designed to be used by a wide range of assessors to determine performance characteristics. For a Basic Performance Evaluation, the main questions assessors may ask to determine whether alternatives under consideration meet performance standards are:

1. What are the performance needs for the application, process, or product that contain the chemical of concern? Why is the chemical being used? Is the chemical a byproduct, an impurity of another chemical, or a historical artifact (a chemical intentionally added in original formulations but which might not enhance the product)?
2. Can the chemical be eliminated without affecting performance? If so, perhaps an alternatives assessment can be avoided.
3. Is the addition of the chemical required by legislation or some type of technical specification? Is the use of an alternative chemical specifically prohibited? If so, an alternatives assessment may not be able to be conducted.
4. Has a favorable alternative already been identified that does not result in the byproduct or impurity? Is it already being used by others for the same or similar application? If the alternative only reduces the hazard, by how much and are there other opportunities for reduction?
5. Has an authoritative body demonstrated and documented adequate performance of identified alternatives? Have identified alternatives been deemed as *not* favorable based on performance?

For an Extended Performance Evaluation, additional questions assessors may ask technical experts in determining whether alternatives under consideration meet performance standards are:

- Are specific tests available that would indicate the likelihood of the alternative satisfying the performance criteria for this application? Have the tests been conducted and are the associated data readily available? If not, can technical feasibility (technical performance) be determined by other means?
- Would the use of an alternative have an adverse impact on the reliability of the process or product, the quality and useful life of the final product, acceptance of the product by consumers, the efficiency or throughput of the associated production process, or the maintenance requirements of the associated manufacturing process? If so, are there known modifications that could mitigate these impacts?

For a Detailed Performance Evaluation, additional questions assessors may ask technical experts in determining whether alternatives under consideration meet performance standards are:

- Has the alternative passed the thresholds according to the appropriate test protocols? If no, can the product or process be modified to accommodate the alternative?
- Do the test results support the assessment of the technical experts and indicate the product meets performance criteria? If no, is the discrepancy sufficient to disqualify the alternative?

National Research Council (NRC) Framework to Guide Selection of Chemical Alternatives

The NRC alternatives assessment framework is a summary review of many existing frameworks, including the IC2 Guide. Many of these frameworks include a performance evaluation component, ranging as an optional to a required component, and from simple to comprehensive evaluations. The performance evaluation component for the NRC framework is optional on the basis that that assessor may not have the ability to test and thoroughly evaluate alternatives. However, while the NRC framework acknowledges that the characterization of function and performance requirements is often an undervalued part of alternative assessment frameworks, it emphasizes that it is essential for the effective prioritization and adoption of alternatives.

In particular, the NRC framework emphasizes understanding the particular *function* or service the chemical of concern provides in the product or process. This approach enables assessors to determine how and why a chemical is used to broaden the scope of potential solutions beyond drop-in replacement chemicals. This scoping approach helps appropriately determine specific performance criteria within the context of safer options and may lead to innovative ways to meet the performance requirements. The framework highly encourages conducting this scoping process in the initial problem-formulation stages so that the information can be used later during the performance testing stage of potential alternatives.

This NRC framework specifically suggests to:

- Define the specific function of the chemical of concern within the product, process, or application. This process may open the possibility of having non-chemical options achieve the desired performance, such as through material substitutions or design changes.
- Define acceptable criteria for alternatives at the chemical, material, product, or process level. These might include ranges of specific properties such as boiling points, vapor pressure, or water solubility that are determined based on process or use conditions.

- Determine the appropriate methods for testing alternatives, and if standard methods are not available, qualitative or specialized test methods might need to be developed.
- Identify regulatory, customer, specification, and/or any certification requirements that the alternative would be required to meet. Stakeholders can provide insights on performance requirements that might lead to favoring one alternative over another.
- Identify process or use conditions or constraints? which might include a specific temperature range, pH, purity, or drying time, among other factors, which might be useful in identifying potential exposure pathways.

Conducting this evaluation produces both an understanding of and documentation of the chemical function and performance requirements needed for the alternative, as well as a plan for the testing of the chemical or non-chemical alternative. It is important that when alternatives are first considered overly conservative predictions of their performance do not lead to the elimination of potentially viable alternatives that could be further developed to meet the performance requirements.

APPENDIX C: Schematic Exhibiting the Thinking of the IC2/NRC Guidance and the Additions of this Guidance

For the six guiding considerations presented in this guidance, baseline thinking outlined in the IC2 and NRC frameworks related to these considerations is shown in black, and the evolved thinking presented in this guidance is shown in red.

1. **Determine the *function* of the chemical/material/product/process of concern for the specific application and understand this function within the production chain.**
    - Why is the chemical being used? What is the function of the chemical, and is it necessary?
    - Is the function of the chemical overprescribed?
    - If upstream processes are changed, is the function of the chemical/material/product/process of concern necessary?
    - If the function is still needed, is it changed in any way?
2. **Define the *application*-specific scenario(s) in which the substance of concern is used and identify alternatives that are suitable for that particular purpose.**
    - What are the performance needs for the chemical/material/product/process?
    - For what application is the chemical/material/product/process of concern being used?
    - Do alternatives under consideration meet the functional need for this application (even if they are used in different ways for other applications), perhaps with minor adjustments?
3. **Establish and/or use performance standards that have been developed *independent* of the existing chemicals/materials/products/processes of concern (as much as possible) and adjust them based on available alternatives or alternatives on the horizon.**
    - What are the technical/standard performance requirements that the potential alternatives need to meet? Are there regulatory, customer and/or other specification requirements?
    - Were performance standards built around specific existing technologies? If so, can new iterations of the standard be adopted that are more function-oriented?
4. **Develop and use a *range* of performance standard benchmarks, from “inadequate” to “sufficient” to “best in class” to evaluate the alternative for the specific application(s).**
    - Define the acceptable performance criteria for alternatives at the chemical/material/product/process level. Have potential alternatives been eliminated based on performance?
    - Have potential alternatives already been eliminated based on binary performance criteria that should be reconsidered?

- Define a range of fit-for-purpose performance criteria that encompass “inadequate”, “sufficient”, and “best in class” benchmarks for the application. How do different alternatives compare within this range?

5. **Consider technical performance *separately* from technical feasibility (feasibility of adoption) of potential alternatives.**
    - Can performance be determined through available and established tests?
    - When only performance is considered (and not the feasibility of their adoption), what are the alternative solutions that can be assessed and compared?
    - Then, what additional modifications may be needed to increase the feasibility of adoption?
6. **Consult *stakeholders* to determine acceptable tradeoffs between performance results and other elements such as environmental health and safety.**
    - Gather stakeholders that might provide insights on performance requirements that might lead to favoring one alternative over another.
    - Hold discussions with an appropriately diverse group of stakeholders on the tradeoffs that would occur for each alternative under consideration. Which tradeoffs are acceptable and what alternatives under consideration meet these conditions?

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