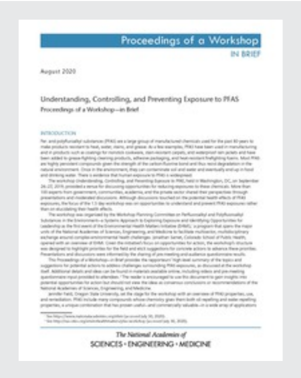

Understanding, Controlling, and Preventing Exposure to PFAS: Proceedings of a Workshop in Brief (2020)

DETAILS

12 pages | 8.5 x 11 | PDF
ISBN 978-0-309-67994-7 | DOI 10.17226/25856

CONTRIBUTORS

Anne Johnson, Marilee Shelton-Davenport, and Ellen Mantus, Rapporteurs; Environmental Health Matters Initiative; Division on Earth and Life Studies; National Academies of Sciences, Engineering, and Medicine

SUGGESTED CITATION

National Academies of Sciences, Engineering, and Medicine 2020. *Understanding, Controlling, and Preventing Exposure to PFAS: Proceedings of a Workshop in Brief*. Washington, DC: The National Academies Press. https://doi.org/10.17226/25856.

Proceedings of a Workshop

IN BRIEF

August 2020

Understanding, Controlling, and Preventing Exposure to PFAS

Proceedings of a Workshop—in Brief

INTRODUCTION

Per- and polyfluroalkyl substances (PFAS) are a large group of manufactured chemicals used for the past 80 years to make products resistant to heat, water, stains, and grease. As a few examples, PFAS have been used in manufacturing and in products such as coatings for nonstick cookware, stain-resistant carpets, and waterproof rain jackets and have been added to grease-fighting cleaning products, adhesive packaging, and heat-resistant firefighting foams. Most PFAS are highly persistent compounds given the strength of the carbon-fluorine bond and thus resist degradation in the natural environment. Once in the environment, they can contaminate soil and water and eventually end up in food and drinking water. There is evidence that human exposure to PFAS is widespread.

The workshop *Understanding, Controlling, and Preventing Exposure to PFAS*, held in Washington, DC, on September 26–27, 2019, provided a venue for discussing opportunities for reducing exposures to these chemicals. More than 100 experts from government, communities, academia, and the private sector shared their perspectives through presentations and moderated discussions. Although discussions touched on the potential health effects of PFAS exposures, the focus of the 1.5 day workshop was on opportunities to understand and prevent PFAS exposures rather than on elucidating their health effects.

The workshop was organized by the Workshop Planning Committee on Perfluoroalkyl and Polyfluoroalkyl Substances in the Environment—a Systems Approach to Exploring Exposure and Identifying Opportunities for Leadership as the first event of the Environmental Health Matters Initiative (EHMI),[1] a program that spans the major units of the National Academies of Sciences, Engineering, and Medicine to facilitate multisector, multidisciplinary exchange around complex environmental heath challenges. Jonathan Samet, Colorado School of Public Health, opened with an overview of EHMI. Given the initiative's focus on opportunities for action, the workshop's structure was designed to highlight priorities for the field and elicit suggestions for concrete actions to advance these priorities. Presentations and discussions were informed by the sharing of pre-meeting and audience questionnaire results.

This Proceedings of a Workshop—in Brief provides the rapporteurs' high-level summary of the topics and suggestions for potential actions to address challenges surrounding PFAS exposures, as discussed at the workshop itself. Additional details and ideas can be found in materials available online, including videos and pre-meeting questionnaire input provided to attendees.[2] The reader is encouraged to use this document to gain insights into potential opportunities for action but should not view the ideas as consensus conclusions or recommendations of the National Academies of Sciences, Engineering, and Medicine.

Jennifer Field, Oregon State University, set the stage for the workshop with an overview of PFAS properties, use, and remediation. PFAS include many compounds whose chemistry gives them both oil-repelling and water-repelling properties, a unique combination that has proven useful—and commercially valuable—in a wide array of applications

[1] See https://www.nationalacademies.org/ehmi (accessed July 30, 2020).
[2] See http://nas-sites.org/envirohealthmatters/pfas-workshop (accessed July 30, 2020).

The National Academies of
SCIENCES · ENGINEERING · MEDICINE

going back to the 1940s.[3,4,5,6] Although biological and even chemical processes do not easily degrade PFAS, they can transform and persist in humans and in the environment in various forms. "[The] carbon-fluorine bond is one of the shortest and strongest in nature," said Field. "That gives rise to many of the properties that have brought our attention to the problem."

As chemical analysis has advanced, scientists have learned more about how PFAS behave and have developed tools for detecting them. However, Field pointed to important gaps, particularly with regard to making detection methods feasible, accessible, and cost-effective. Looking forward, she emphasized that coordinated research efforts are needed to overcome current barriers and better understand PFAS contamination, its sources, and its alternatives, and to identify and implement remediation processes. Participants delved into these topics throughout the workshop's three panel discussions.

UNDERSTANDING HUMAN EXPOSURE TO PFAS

Exposure encompasses what people are exposed to in their environment and how much is being absorbed into their bodies. Understanding human exposure is important in mitigating health effects, yet there are substantial data gaps regarding which PFAS people are exposed to, at what level, from which sources, and through which routes and pathways. Participants discussed current knowledge and key gaps, and how those gaps might be closed.

Current State of Knowledge

Field discussed possible pathways of exposure. Humans can be exposed through use of products that contain PFAS. They can also be exposed to PFAS as they migrate from waste streams at a manufacturing site. Through those pathways, PFAS can contaminate soil, water, food, and air. "What we're seeing is a lot of cycling," she said, adding that, from a remediation standpoint, "the scale of these things [is] really quite large." An estimated 6 million people in the United States have drinking water that exceeds the U.S. Environmental Protection Agency's (EPA's) health advisory level of 70 nanograms per liter, she noted.[7] Although analytical technology is maturing, available tests are not sufficient to cover all PFAS in all types of materials, she said, leading to unevenness in data quality.

Antonia Calafat, U.S. Centers for Disease Control and Prevention (CDC), discussed findings from the National Health and Nutrition Examination Survey (NHANES), which annually collects data from about 5,000 people in 15 counties. NHANES studies measure compounds in participants' blood and urine and have shown that human exposure to PFAS is widespread. Although these studies revealed a decrease in levels of specific compounds, such as perfluorooctanesulfonic acid (PFOS) after manufacturing changes were implemented in the early 2000s, legacy compounds are still present and are even detectable in people born years after these changes. One significant gap in these studies, Calafat noted, is that targeted testing for some specific compounds of interest (e.g., substances within the GenX class[8]) in blood—which provides more reliable results than testing urine—has been rather limited, leading to a dearth of quantitative human exposure information on these compounds.

> "The chemicals of concern [...] get into the food supply, they get into the compost, they get into the environment, they get into people." – Mike Belliveau

Thomas Webster, Boston University School of Public Health, discussed studies of human exposure, which provide insights about the importance of various PFAS sources. For people who live in areas with highly PFAS-contaminated water, water is clearly a primary source of exposure. For the broader public, other routes of exposure have received less attention but are likely important, he said. Diet is a source of human exposure, with PFAS potentially entering food through a variety of pathways, including bioaccumulation, food contact materials, and food processing. Nonstick pans are not thought to be a major contributor, but Webster suggested further study may be warranted. Although dietary perfluorooctanoic acid (PFOA) and PFOS exposure has been

[3] Krafft, M. P. and Reiss J. G. 2015. Selected Physicochemical Aspects of Poly- And Perfluoroalkylated Substances Relevant to Performance, Environment and Sustainability-Part One. *Chemosphere* 129:4-19.

[4] Buck, R. C., J. Franklin, U. Berger, J. M. Conder, I. T. Cousins, P. de Voogt, A. A. Jensen, K. Kannan, S. A. Mabury, and S. P. J. van Leeuwen. 2011. Perfluoroalkyl and Polyfluoroalkyl Substances in the Environment: Terminology, Classification, and Origins. *Integr Environ Assess Manage* 7:513.

[5] Wang, Z., I. T. Cousins, M. Scheringer, and K. Hungerbühler. 2013. Fluorinated Alternatives to Long-Chain Perfluoroalkyl Carboxylic Acids (PFCAs), Perfluoroalkane Sulfonic Acids (PFSAs) and Their Potential Precursors. *Environ. International* 60:242-248.

[6] Erik Kissa. 1994. Fluorinated Surfactants: Synthesis, Properties, Applications. *Polymer International* 36(1):101-101.

[7] Hu, et al. 2016. Detection of Poly- and Perfluoroalkyl Substances (PFASs) in U.S. Drinking Water Linked to Industrial Sites, Military Fire Training Areas, and Wastewater Treatment Plants. ES&T Letters.

[8] GenX is a trade name for the PFAS compound developed as a replacement for perfluorooctanic acid (PFOA) and is used informally to refer to fluorochemical byproducts of that compound's manufacture.

demonstrated,[9] Webster emphasized that more research is needed on other PFAS and noted that an ongoing study[10] by the U.S. Food and Drug Administration may help address this gap. Other potentially important routes of human exposure include inhalation of volatile compounds,[11] ingestion of dust, and dermal absorption, such as through personal care products.[12] However, product labeling issues have impeded study of these potential routes.

Potential Actions to Fill Exposure Research Gaps

Panelists Michael Focazio, U.S. Geological Survey; Christopher Higgins, Colorado School of Mines; Rainer Lohmann, The University of Rhode Island; Laurel Schaider, Silent Spring Institute; and Anthony Spaniola, Need Our Water (NOW) joined Field, Calafat, and Webster for an open discussion of strategies to address knowledge gaps. John Adgate, Colorado School of Public Health, and Elsie Sunderland, Harvard University, moderated the discussion. Some attendees noted concerns regarding PFAS toxicity, but the health implications of PFAS exposure were not a focus of the workshop.

Characterizing Current Human Exposures

> "There are very substantial amounts of unidentified organoflurorines found in human blood, environmental media, and in consumer products. [...] The single most important scientific question in the field right now is to figure out what this stuff is." – Thomas Webster

In light of shifts in PFAS manufacturing and use, many participants stressed the need to determine the types and the characteristics of PFAS to which people are being exposed. Much of the available data on human exposure to PFAS stems from studies of PFOS and PFOA, types of PFAS that have now been phased out by U.S. manufacturers. Far less data is available on newer compounds such as GenX PFAS. To fill this gap, Webster, Calafat, Adgate, and others called for enhanced biomonitoring (studies of human exposures based on measurements in, for example, blood and urine). Webster and Adgate suggested a comprehensive study to examine temporal and geographic trends systematically in human exposures to PFAS. "We need a total PFAS exposure study," said Webster. "No one has ever done that. It would be a great thing to do."

Participants discussed the implications of studies showing substantial amounts of unidentified organoflourines (the common chemical structure in PFAS in blood, environmental media, and consumer products.[13,14] While all PFAS are organofluorines, non-PFAS organofluorines also exist; Webster argued that characterizing the unidentified organoflourines is the single most important scientific question in the field right now. Experts had different views on whether research resources would be better allocated to untargeted studies of total human exposure to organoflourine (which would provide a big picture of PFAS exposure and could inform mitigation of PFAS as a class of chemicals) or to targeted studies of human exposure to specific compounds (which could inform mitigation measures focused on individual compounds in the class). Higgins favored quantifying specific compounds, while Lohmann and Sunderland emphasized the value of measuring total organoflourines to provide a baseline measurement of overall PFAS exposure.

Tracing Sources and Routes of Exposure

To complement biomonitoring and better understand sources and pathways of human exposure, participants also stressed the need for broader environmental monitoring. In particular, Field, Calafat, and Webster underscored the need to investigate non-water pathways of exposure, which they see as likely underappreciated due to limited availability of data.

---

[9] Vestergren R., Cousins I. 2015. Human dietary exposure to per- and poly-fluoroalkyl substances (PFASs). In: Rose M & Fernandes A. Persistent organic pollutants and toxic metals in food.

[10] See https://www.fda.gov/science-research/fda-grand-rounds/analysis-and-polyfluoroalkyl-substances-pfas-foods-analytical-method-development-challenges-and (accessed July 30, 2020).

[11] Makey, C. M., T. F. Webster, J. W. Martin, M. Shoeib, T. Harner, L. Dix-Cooper, and G. M. Webster. 2017. Airborne precursors predict maternal serum perfluoroalkyl acid (PFAA) concentrations. *Environ Sci & Technol* 51(13):7667-7675. PMID: 28535063.

[12] Schultes, L., R. Vestergren, V. Kristina, E. Westberg, T. Jacobson and J. P. Benskin. 2018. Per- and polyfluoroalkyl substances and fluorine mass balance in cosmetic products from the Swedish market: implications for environmental emissions and human exposure. *Environ. Sci.: Processes Impacts* 20:1680-1690.

[13] Miyake, Y., N. Yamashita, M. So, P. Rostkowski, S. Taniyasu, P. K. S. Lam, and K. Kannan. 2007. Trace analysis of total fluorine in human blood using combustion ion chromatography for fluorine: A mass balance approach for the determination of known and unknown organofluorine compounds. *Journal of Chromatography A* 1154(1-2):214-221.

[14] Yeung, L. W. Y., Y. Miyake, P. Li, S. Taniyasu, K. Kannan, K. S. Guruge, and P. K. S. Lam, Nobuyoshi Yamashita. 2009. Comparison of total fluorine, extractable organic fluorine and perfluorinated compounds in the blood of wild and pefluorooctanoate (PFOA)-exposed rats: Evidence for the presence of other organofluorine compounds. *Analytica Chimica Acta* 635(1):108-114.

Field and Webster emphasized the need for a better understanding of how PFAS get into the diet. Although studies have demonstrated bioaccumulation in fish and transfer from food contact materials, less is known about food processing as a potential pathway, Webster said. Higgins pointed out that dietary exposure pathways are likely complex; farmlands can be contaminated from the use of biosolids as fertilizer or from the use of contaminated water sources. Participants also noted the need to understand inhalation and dermal exposures, for example, through personal care products. “We need more work on inhalation and dermal exposures, and we need to really be doing exposure studies of the newer PFAS,” said Webster. Reflecting on the gaps related to sources and exposure pathways, Thomas Burke, Johns Hopkins University, emphasized the need for a systems approach to assessing human exposure, going beyond biomonitoring to listening to communities to understand how exposures may occur.

Expanding Research Capabilities

> “This is a very complex issue...so the ability to work collaboratively with a lot of different people, I think, is important.” – Christopher Higgins
>
> “Understanding PFAS is certainly [...] going to require a multidisciplinary team.” – Antonia Calafat

Participants suggested ways to expand capabilities for characterizing human exposure to PFAS and their effects, including providing necessary research funding; developing standards, methods, and models; and enabling collaboration and coordination. Field, Webster, and others called for the development of additional analytical chemistry standards and methods, including methods to analyze new compounds and methods for measuring PFAS in a wider variety of substances. George Daston, Proctor & Gamble, suggested that computational methods could be valuable for identifying compounds for which standards are lacking via unsupervised chemical analysis approaches. Webster and Focazio highlighted the importance of developing models that link PFAS exposures in humans with sources and routes of exposure because existing models do not always apply to PFAS. For example, existing bioaccumulation models, which are based on Kow (the octanol and water partition coefficient), do not work when applied to PFAS, Webster noted.

Field, Higgins, and Calafat stressed that the complexity of the research questions necessitates a collaborative, interdisciplinary approach augmented by data-sharing and cross-sector dialogue. “One of the things that I think has been most encouraging is there has been some effort toward large scale collaborative efforts,” said Higgins. “The more of that—where you can bring people in with different sorts of expertise [...]—the better.” Field suggested that funding agencies can help support this approach by incentivizing collaboration rather than competition through their grant awards. Samet and others expressed support for holistic approaches, such as a total exposure study or integrative exposure assessment, and Williams and Samet noted that it would be valuable for such efforts to be informed by an understanding of the specific types of exposure research that would best enable decision-making.

ADDRESSING PFAS CONTAMINATION

Where PFAS are present in the environment, what can be done to contain them, destroy them, or limit people’s exposure? The workshop’s second panel focused on current practices and opportunities for improving the treatment of PFAS-contaminated media, such as water and soil. In this panel and throughout the workshop, participants also considered how to communicate with communities who are affected by PFAS contamination.

Current State of Knowledge

Rula Deeb, Geosyntec Consultants, gave an overview of approaches to dealing with PFAS-contaminated media. PFAS contamination is a complex challenge because PFAS are often present as mixtures, can transform into different compounds, and can be present in high volumes in a variety of environmental media. Most technologies are designed to remove PFAS (e.g., from water) or contain them in place (e.g., in soil); incineration is currently the only approach used to destroy them. For PFAS removal, Deeb noted that available technologies are often not able to remove PFAS completely compared to other contaminants. Although destruction would be ideal, PFAS are inherently difficult to destroy. “These compounds are meant to put out fires and to be stable under very extreme conditions, so it’s going to take very extreme conditions to break them down,” said Deeb. “There are no destruction methods that are fully demonstrated in the field yet [as] capable of addressing PFAS impacted media.” She added that treatment efforts are hindered by a lack of a federal maximum contaminant level (MCL) for PFAS or other mechanisms to require cleanup.

Potential Actions to Improve Treatment Capabilities

Samet and Philip Johnson, The Heinz Endowments, moderated a discussion of strategies to improve treatment capabilities. Deeb was joined by panelists Jason Dadakis, Orange County Water District; Detlef Knappe, North Carolina

State University; Linda Lee, Purdue University; Andrea Leeson, U.S. Department of Defense and Kurt Pennell, Brown University.

Monitoring Contamination

PFAS contamination is found in a variety of environmental media but is most actively monitored and treated in drinking water. Although Higgins, Martha Rudolph, Colorado Department of Public Health & Environment, and others cautioned against focusing on PFAS in drinking water at the expense of examining the full range of exposure sources, other participants offered concrete suggestions for improving water monitoring. In particular, they suggested three water sources—public water systems, private wells, and source water—should be regularly tested for PFAS.

Because most Americans consume water from public water systems, testing could provide valuable information on how well current water treatment systems protect the public from PFAS exposures. However, Lee and Schaider cautioned that such assessments can be biased if they only test for a limited number of PFAS; in addition, tests that are only focused on testing finished (drinkable) water do not necessarily help to identify the source of the PFAS. Focazio underscored the importance of private wells, which represent the water supply for about 40 million Americans, but acknowledged that well water is difficult to monitor and test as it is hard to track private well use.

Other participants, including Knappe and Burke, stressed the need for monitoring PFAS "upstream" in addition to drinking water supplies. Doing so can help inform treatment approaches and also yield insights on sources of PFAS contamination and how PFAS behave in various media. Specifically, Lee, Pennell, and Knappe stressed the need to investigate PFAS sources, including potential emissions from the technologies used to remove or destroy PFAS; how compounds might interact; how long PFAS persist in various media; and how they move. "We may be spending a lot of money installing a treatment technology that removes some PFAS, but if the water source isn't well characterized, we may be missing another part of the problem," said Knappe.

"Technologies that we're relying upon right now for dealing with PFAS impacted media [...] are just merely removing PFAS from one environmental stream [and] concentrating it into another, so we have to still deal with that concentrated stream." – Rula Deeb

"It may be 10 years before we come up with [destruction] technologies that are effective and safe [...] and in the meantime, we'll do containment. We'll do pump and treat, dig and haul [...] the idea there is to protect the public and reduce the exposure." – Kurt Pennell

"It seemed like the news from the treatment session was kind of dismal. I would say it's not. We've made a tremendous amount of progress, I think, in a very short term." – Andrea Leeson

Containing Contaminants

Participants discussed the importance of protecting the public when PFAS contamination is discovered. Knappe and Pennell emphasized that it is crucial to keep the PFAS from spreading, perhaps, through such strategies as treating polluted water or moving polluted soil to a facility, like a lined landfill, from which it (and any byproducts of containment strategies) cannot migrate back into the environment. Others focused on ways to reduce human exposure to contaminated media. Deeb noted that the EPA has not set a MCL for PFAS in water, despite its authority to do so under the Safe Drinking Water Act. She suggested that better coordination and guidance among state governments would be helpful for informing mitigation activities while waiting for EPA to set a MCL. Lee argued for a dual strategy of containment (to address known problems now) and destruction (for which it will take time to develop technologies).

Destroying PFAS

To enable actual removal of PFAS from the environment, rather than only containing or moving them, many participants stressed the need for better methods to destroy PFAS. Although incineration is a common method of destruction, Lee and Knappe noted that little is known about the chemical interactions that occur during incineration of

"The practice of doing incineration without knowing exactly what we're doing is very concerning. [...] We don't fully understand all of the reaction products and byproducts that are formed." – Detlef Knappe

"[We need to] make sure that whatever we come up with, we're not making the problem worse by developing these other byproducts that could be toxic, that we don't know anything about." – Kurt Pennell

"It's not just [...] getting to the destructive technologies, but also developing the tools to correctly and accurately identify the byproducts and the mechanisms that are involved before we can fully validate the technology and stamp it as safe." – Rula Deeb

PFAS or what risks they may pose. Knappe suggested that incineration may be a viable destruction technology but urged that it should be done carefully with appropriate pollution control measures. Leeson and Deeb expressed optimism about alternatives to incineration that are being developed, although Deeb, Knappe, and Pennell stressed the importance of identifying and mitigating the byproducts of any such technology.

Expanding Treatment Capabilities

Participants discussed who would pay for research and technology development to enhance treatment capabilities and options for funding cleanup efforts. In terms of cleanup, Knappe posited that rate payers will likely bear the cost burden in the short term. Dadakis suggested manufacturers could be held financially and legally responsible, and Deeb suggested the government should be responsible for ensuring access to clean water when the polluter cannot be identified. For both cleanup and technology development, Pennell suggested that philanthropic organizations that have an interest in specific areas, such as water, could be a source of funding. For research funding, participants pointed to agencies, such as EPA, National Science Foundation, and National Institutes of Health, in particular the National Institute of Environmental Health Sciences (NIEHS). Leeson noted that the U.S. Department of Defense is investing heavily in PFAS remediation solutions, with a total funding level of close to $75 million. Dadakis suggested that quantifying potential co-benefits of PFAS remediation could help bolster research support and inform the selection of approaches. Leeson and Andrea Amico, Testing for Pease, underscored the need for coordination among funding organizations to avoid duplication of efforts and to make progress, and Leeson and Linda Birnbaum, former NIEHS director, said there have been efforts to facilitate cross-talk among federal agencies that are funding work to advance methods for PFAS remediation.

> "It's really important for the organizations doing the funding to be talking [to each other]." – Andrea Leeson

Communicating with Communities

A number of participants stressed the need to take action and communicate with communities based on available information, even if it is incomplete. "While everybody determines more studies and more science to do, communities aren't getting the action that they need, and I feel like we know a lot and we should see a lot more action," said Amico. Pennell and Rudolph said that exposed communities remain frustrated with the lack of answers as to how they can protect themselves and their families. For instance, granular activated carbon water filters are often mentioned as a solution that residents can implement, but Lee, Knappe, and Pennell expressed uncertainty about the effectiveness of this expensive short-term solution.

> "I don't think we have a good answer yet for the homeowner on how to treat their water or where to live." – Andrea Leeson

Burke urged that the communication should go both ways, with scientists working to educate the public on what is known about PFAS exposures, health effects, and treatment and listening to communities about their experiences and concerns. From the community perspective, Spaniola said, "It's really critical for the scientific community to engage in an ongoing and proactive dialogue with community members [...] Help us understand where you, in the scientific community, have issues. And allow us to help you find solutions."

Participants explored the public's role in three main areas: monitoring water, monitoring PFAS exposure in the body, and increasing transparency regarding PFAS content in consumer products. Pennell suggested that people would benefit from access to "some type of system where they can get their water tested." Dadakis underscored the importance of being transparent with water customers and noted that professional associations have useful guidance for utilities; Johnson argued that homeowners should also be provided with guidance on actions they can take. Lee cautioned that it is important to convey the limitations of water monitoring when communicating with the public, as "the maps can be misleading," for example, by giving the impression that PFAS contamination is not present in places where it simply has not been assessed.

A second issue is access to tests to detect PFAS exposure at an individual level. Providing a public perspective, Amico described limitations in testing access. Steve Korzeniowski, FluoroCouncil, American Chemistry Council (ACC), also described how it is "basically impossible" for people to know the level of PFAS in their own blood because testing is expensive and largely inaccessible, and Birnbaum noted the challenge of knowing what to test for given the many compounds in this chemical class.

> "They were exposed...without their consent and now they have to fight tooth and nail to get a blood test result to know how much exposure they had? It just seems incredibly wrong [...] We don't have all the answers yet, but not testing them is not the right answer." – Andrea Amico

Amico implored for more access to testing despite the knowledge gaps regarding the interpretation of test results, as this testing would at least allow people to compare their levels with others in highly exposed communities. Birnbaum agreed that relative exposure understanding has value and said that testing could potentially highlight some "options for what they could do to reduce their exposure going forward." Representing a different public health view, Lynn Goldman, George Washington University, who previously served as Assistant Administrator for Toxic Substances at the EPA, argued that the value of testing is diminished in the absence of information about health effects or clear guidelines regarding how people can protect themselves. Testing without this context could do "more harm than good," she suggested, with test results merely raising concern without offering helpful guidance.

PREVENTING PFAS EXPOSURE

In light of the difficulty of remediating persistent chemicals once they are in the environment, another approach to reducing exposures is to prevent the release of these chemicals in the first place. To this end, the workshop's third session focused on strategies to reduce PFAS use. Carla Ng, University of Pittsburgh, and Holly Davies, Washington State Department of Health, provided an overview to frame the discussion. They were joined by panelists Mike Belliveau, Environmental Health Strategy Center; Elizabeth Harriman, Toxics Use Reduction Institute; Steve Korzeniowski, FluoroCouncil, ACC; and Meredith Williams, California Department of Toxic Substances Control, for a discussion moderated by Jonathan Samet, Colorado School of Public Health, and Patricia Mabry, HealthPartners Institute.

> "We can work on developing ways to try and get rid of [PFAS]...but unless we...stop putting it into our environment, the levels in our environment will continue to go up and this problem will be around not only for our children and our grandchildren, but for their grandchildren." – Linda Birnbaum
>
> "I think the priorities should be to not produce these chemicals in the first place because we end up with this conundrum. Once we have it, all solutions seem to be somewhat imperfect." – Detlef Knappe
>
> "We need to [...] understand the true cost of letting this get so out of control. [...] The cost of cleaning this stuff up or dealing with it once it's out in the environment is exponentially more than the cost of controlling it in the beginning." – Workshop participant

Current State of Knowledge

Ng offered criteria for identifying and prioritizing opportunities to eliminate PFAS from products. She outlined two critical distinctions: first, whether the product is essential for health and safety and the functioning of society; and second, whether there are alternatives to PFAS that are technically and economically feasible. On the basis of those factors, the use of PFAS in a product can be categorized as either nonessential, essential, or substitutable.[15] Ng said PFAS can be "easily" omitted from nonessential uses—what she called "the low-hanging fruit"—and replaced with alternatives where it is substitutable. Although eliminating PFAS from essential products with no alternatives is harder, she noted that "essentiality is not permanent" as alternatives continue to be discovered and developed.

Davies outlined how alternatives assessments can be used to identify, compare, and select safer alternatives to PFAS for new products. As opposed to risk assessment, which focuses on quantifying hazards associated with exposures, "the idea of alternatives assessment is to reduce risk by reducing intrinsic hazard," Davies said. Many tools are available for informing alternatives assessments.[16,17,18] Determining whether PFAS are necessary, as discussed by Ng, is integral to this process. Key considerations in an alternatives assessment include performance, cost, availability, and exposure, although manufacturers, purchasers, and regulators may consider different factors and have different priorities. The process

> "We have to identify when the functionality is actually critical, and when it's just a 'nice to have.' I think that's an important conversation." – Carla Ng
>
> "We should [ensure] that the benefits that we're getting from [a] particular product [...] outweigh the cost—not just the money, but the cost." – Martha Rudolph
>
> "Manufacturers can make, and people can buy, other products that might be just as bad—and that's just a challenge we have of encouraging the use of safer alternatives." – Holly Davies

[15] Cousins, I. T., G. Goldenman, D. Herzke, R. Lohmann, M. Miller, C. A. Ng, S. Patton, M. Scheringer, X. Trier, L. Vierke, Z. Wang and J. C. DeWitt. 2019. The concept of essential use for determining when uses of PFASs can be phased out. *Environmental Sci: Processes Impacts* 21:1803-1815.

[16] National Research Council. 2014. A Framework to Guide Selection of Chemical Alternatives. Washington, DC: The National Academies Press. https://doi.org/10.17226/18872.

[17] Interstate Chemicals Clearinghouse. IC2 Alternatives Assessment Guide. Available at http://theic2.org/alternatives_assessment_guide.

[18] Association for the Advancement of Alternatives Assessment. Available at https://www.saferalternatives.org.

may identify preferred alternatives, or it may determine that the alternatives are no safer than PFAS. Davies added that there are also likely to be unknowns, especially given how large and diverse the PFAS class of chemicals is and the lack of hazard information for many compounds. Finally, the feasibility of alternatives may vary for different places or for different goals, for example, in accordance with a locality's practices and rules for waste disposal, fire codes, or energy efficiency.

Potential Actions to Prevent PFAS Exposure

Participants discussed opportunities to address challenges related to identifying where PFAS are used, determining where they may be eliminated, and adopting safer alternatives. Participants also explored the drivers behind PFAS use and suggested ways to address these drivers through both regulatory and non-regulatory means.

> "I understand [proprietary information] protects information about competitors. The problem is it doesn't protect the public." – Jennifer Field
>
> "Which exact chemicals are being used, how much is being used, what is the concentration? [...] It's hard to [detect] [...] specific compounds when we don't know which compounds to look for." – Holly Davies

Understanding PFAS Production and Use

Because the exact chemical composition of products is often protected as confidential business information, retailers, consumers, and researchers typically lack information about PFAS use and potential sources of environmental contamination. "We don't have the information of how [many] organoflourines are being produced each year, and where they're going," said Birnbaum. "[It] is important for us to understand the size of the problem and the scope of the problem, because these chemicals essentially will never go away." Several participants pointed out that greater transparency and data sharing related to PFAS production and use would have the dual benefit of enabling exposure research and facilitating efforts to reduce human exposures. Field and Davies underscored the challenge of conducting analytical chemistry on a target that is unclear and constantly changing. "Product compositions seem to change faster than we can get research done," said Davies. Field, Webster, and Lohmann emphasized that data on PFAS production are critical to both measuring human exposures and assessing PFAS in the environment.

Field pointed out that researchers could potentially take a "reverse engineering" approach to determine products' chemistry composition or reconstruct historical PFAS use, but she said that such studies would likely be expensive and noted that they would ultimately be paid for by taxpayers. Birnbaum, Daston, Harriman, and others pointed to the role of industry in providing information on PFAS production and its use in materials and products. "Some sort of extraordinary measures in terms of transparency is necessary," Harriman said. Referencing the ACC's long-range planning, Daston noted that "this idea of inventorying production and use of chemicals [...] is at the top of their agenda. It will be a difficult task, but [...] the chemical industry is the right player because of their knowledge of what is produced and how it is used." He urged companies to prioritize PFAS chemicals in such efforts. Pointing to a January 2019 webinar organized by the Interstate Chemicals Clearinghouse,[19] Korzeniowski said industry is "certainly willing to help point folks in the right direction about what's used" and referenced efforts the chemical industry has made to describe general uses of PFAS, for example, as surfactants. However, he noted that although some data is available on historical PFAS use and on global manufacturing for some compounds, "what we don't have is current use, because producers don't share that." He added that actual data for individual end uses is "basically impossible to get."

Mechanisms for Disclosure of PFAS Use

> "We really have to take a life cycle view to understand what's going on during production and what's being released, [as well as] what's [in] the waste streams being released." – Carla Ng

Participants discussed regulatory and non-regulatory mechanisms for encouraging or requiring the disclosure of details about PFAS production and use. Several participants suggested state and federal governments could exercise their authority to force disclosure, and Davies and Belliveau noted that policymakers have the power to mandate disclosure and labeling. For example, Goldman noted the EPA could obtain information on production and use under the Lautenberg Chemical Safety Act. Williams said that California's Safer Consumer Products program may provide relevant authority, and Belliveau, Davies, and Mark Rossi, Clean Production Action, added that relevant legislation is also being considered or enacted in other states. Ng, Belliveau, Williams, and Harriman stressed that transparency should extend through the entire life cycle, reflecting the use of PFAS in the manufacturing process and in the final product, and Burke, Rudolph, and Ng added that it is also important to consider waste management for PFAS-containing products. Williams said

[19] See http://theic2.org/ic2_webinar_the_pfas_universe (accessed July 30, 2020).

that manufacturers can face barriers in understanding their full supply chains and suggested that a consortium approach could help reduce these barriers. Highlighting the role of retailers, Belliveau suggested a REACH-like[20] approach in which information is required to be sent both up and down the supply chain, and noted that a rule pending in Maine advances this idea by requiring manufacturers to disclose their use of certain PFAS chemicals in consumer products sold in the state.[21]

> "What do labels and warning statements really accomplish? What we've labeled as 'right to know' has not been a success. What we have to have is a 'right to understand.'" – George Daston

Davies added that companies in Europe are required to provide information on products that contain substances deemed to be of "very high concern" when requested. However, other participants cautioned that simply allowing consumers to know when PFAS are in a product is not necessarily sufficient to help them make informed decisions. Spaniola emphasized that "when consumers are buying products, they need to know what's in them and what the impacts are." Rather than simply a "right to know" what is in a product, Daston argued that consumers should have a "right to understand" the full array of benefits and risks it brings.

Mechanisms for Limiting PFAS

Participants discussed regulatory and non-regulatory mechanisms for limiting PFAS use or environmental contamination. At the federal level, Harriman said PFAS "are unregulated at this point." Although EPA has proposed a Significant New Use Rule (SNUR) pertinent to PFAS in new products, Korzeniowski noted that the SNUR does not address imported products, and Belliveau added that it only requires notification, rather than actually restricting use. Davies noted that Washington State has a new law to encourage the use of safer alternatives, one of several state efforts that could lead to reductions in PFAS use, or at least increase disclosure. Deeb urged more coordinated guidance for states and said that the uneven regulatory landscape across the states "really complicates treatment, and it complicates taking information from one system in one state and extrapolating it to another." On the other hand, in the context of incentivizing the use of alternatives, Davies noted that "one size does not fit all," given that there are local differences in rules relevant to PFAS-containing products, such as fire codes and waste disposal.

> "If we set a firm direction that this is where we need to go, and government says 'we're presuming we're going to get there,' this will unleash [...] the best competitive instincts in American business to solve these problems and get those products on to market." – Mike Belliveau

Actions can affect the use of PFAS in products produced in the United States, but Lee, Korzeniowski, Belliveau, and others noted that manufacturers in China and other countries are still likely to continue using these chemicals. "This is a global problem," said Lee, urging that "we have to do something to prevent products being imported into the [United States]."[22]

Even without actual PFAS bans, Belliveau suggested a "firm direction" from governments could nudge industry to develop and adopt alternatives. In addition, nongovernmental organizations, including standard setting and certification bodies, can and have played a leading role in reducing PFAS use. For instance, Belliveau noted that one of the leading organizations that promotes composting now restricts residual organofluorine content in compostable products they certify, thus driving manufacturers to remove PFAS from their compostable food packaging.[23] This precedent, he suggested, could set an example for other industries.

> "Basically there is nothing in life that has no risk. But I think what we need to be looking at is balancing the benefits from the risk." – Linda Birnbaum
>
> "We have learned the lesson the hard way about persistent substances over and over again, and what I hope is that we can start to not make similar mistakes." – George Daston
>
> "We have these brands that imply good things, because that's what companies do to sell products. [...] People don't understand, in fact, that these properties [...] come with a cost of exposure of people and the environment." – Jonathan Samet

[20] Registration, Evaluation, Authorisation and Restriction of Chemicals. See https://ec.europa.eu/environment/chemicals/reach/reach_en.htm (accessed July 30, 2020).

[21] Maine Department of Environmental Protection, Chapter 890, Designation of PFOS as a Priority Chemical. See https://www.maine.gov/dep/rules/#2072687 (accessed July 30, 2020).

[22] On February 20, 2020, EPA proposed a supplemental Significant New Use Rule that would require notifying the EPA before importing long-chain PFAS as part of surface coatings on articles. See https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/prepublication-version-proposed-supplemental-significant (accessed July 30, 2020).

[23] Biodegradable Products Institute, Fluorinated Chemicals, see https://bpiworld.org/Fluorinated-Chemicals (accessed July 30, 2020).

Advancing Alternatives

Several participants posited that people may come to different conclusions regarding when PFAS are essential or which alternatives are feasible. “Who decides what’s essential?” Korzeniowski asked; “Is it the market, or it is us, as scientists?” Williams said that such decisions should incorporate a wide range of viewpoints, including retailers, regulators, and communities affected by PFAS contamination, and added that considerations of functionality should include the function of the PFAS in both the end product and the manufacturing process.

> “We need to effectuate an orderly transition away from extremely persistent chemicals, and the chemistries that create them.” – Mike Belliveau

Participants discussed the roles of materials manufacturers, product manufacturers, retailers, and consumers in driving demand for PFAS-containing products (or the adoption of alternatives). Belliveau argued that “the customer is queen” in a market economy and predicted that consumers will create an “increasing market incentive to move toward safer alternatives.” On the other hand, Ng cautioned against overemphasizing the role of consumer demand, given that consumers lack the chemistry knowledge to understand the properties that give products their functionality and the potential downsides. Samet underscored the importance of effective public outreach to help consumers consider what is “essential” as they weigh the costs of PFAS use and exposure against the messages they receive from brands about product functionality.

Korzeniowski said that many manufacturers “have responded to the consumers,” but stressed that performance and functionality matter. “It’s perfectly acceptable to do alternative assessments [...] but [...] some of these chemistries provide very significant benefits, and we should acknowledge that,” he said. For example, what level of risk is acceptable if firefighting foams are less effective without PFAS? Davies stressed the value of partnerships between industry and users, such as firefighters, to understand the performance requirements. Similarly, Goldman suggested bringing “the pollution prevention community together with the public health and medical community” to facilitate productive exchange around PFAS-containing medical waste and the feasibility of alternatives in medical products.

Defining safer alternatives presents another challenge. Rossi suggested seeking ways to “help elevate and get more alignment on how we define what a safer alternative is.” Birnbaum suggested that alternatives should be selected on the basis of their ability to degrade in the environment into harmless byproducts. Another participant stressed the need to consider equity of potential impacts as PFAS are phased out or alternatives are adopted. Participants also discussed some specific alternatives, in particular fluoropolymers. While acknowledging that they are persistent because they are designed to be durable, Korzeniowski said fluoropolymers have the right properties for a number of applications. However, Belliveau, Ng, and Birnbaum cautioned that polymers can also potentially degrade and release chemicals of concern into the environment.

Encouraging Innovation

Ng, Williams, and Belliveau underscored the need to perform alternatives assessments and drive the discovery or development of effective PFAS replacements. As part of this, Belliveau urged a major initiative to invest in “green manufacturing” with environmentally sustainable materials. Darrell Boverhof, the Dow Chemical Company, said there is a need for sustainable processes at every stage of the life cycle, from developing PFAS-free product ideas to managing PFAS-containing production waste. Williams suggested that policymakers should partner with economists to develop “a very thorough economic analysis of the markets and the incentives and disincentives” for green manufacturing. Davies and Belliveau suggested states should expand economic development programs with grants aimed at enabling and incentivizing businesses to switch their production methods to being PFAS free. Belliveau added that federal government leadership will be required to scale these efforts.

SUMMARY

Throughout the two-day workshop, attendees from industry, government, academia, and PFAS-affected communities discussed gaps and opportunities in understanding and addressing PFAS chemicals. Participants surfaced numerous ideas for better understanding PFAS production, use, and exposure through expanded research efforts, as well as action on the part of industry and governments. They also identified opportunities to address PFAS contamination where it is already present in the environment and strategies to curtail future PFAS exposures by limiting the production and use of these chemicals. Those potential actions, which are presented in the preceding text, are summarized in Table 1.

TABLE 1 Potential Actions Suggested By Individual Workshop Participants to Understand and Address PFAS Chemicals

Area of Focus	Potential Actions	Possible Actors[a]
Understanding PFAS production and use	Collect and share information on PFAS production and use, including the types and amounts of PFAS in materials and products extending across the full life cycle from supply chain through waste disposal	Researchers Industry Retailers Government
	Exercise authority to require disclosure of PFAS production and use	Government (state authorities and U.S. EPA)
	Use a "reverse engineering" approach to determine products' chemistry composition or reconstruct historical PFAS use	Researchers
Characterizing human exposures	Conduct biomonitoring studies, such as untargeted studies of total organoflourine exposure and targeted studies to characterize exposure to specific compounds	Researchers Industry Research Funders
	Conduct a comprehensive study to systematically examine exposure in populations at different times and places	Researchers
Identifying sources and routes of exposure	Conduct environmental monitoring studies, especially for newer PFAS compounds	Researchers
	Test public water, private wells, and water sources	Utilities Researchers Communities
	Investigate non-water routes of exposure, especially dietary and dermal exposures	Researchers
	Characterize PFAS sources, including potential emissions from treatment strategies	Researchers
	Characterize how compounds interact, how long PFAS persist in various media, and how it moves	Researchers
	Listen to communities to understand how exposures may occur	Researchers Communities
Expanding exposure research capabilities	Provide funding for studies and tool development	Research funders (government and philanthropic)
	Develop standards, methods, and models for characterizing human exposures and linking them with sources and routes of exposure	Researchers Standards-setting bodies Model developers Technology developers
	Facilitate and incentivize collaboration and coordination to support holistic, interdisciplinary research	Researchers Research funders
Addressing contamination	Reduce exposure to contaminated media	Responsible Industry Government
	Use containment strategies to keep PFAS from spreading	Industry Government
	Coordinate exposure guidance among states	State governments Federal government
	Establish a maximum contaminant level (MCL) for PFAS	U.S. EPA
	Establish and validate methods to characterize and mitigate byproducts of any PFAS destruction technology	Researchers
	Investigate PFAS incineration byproducts and develop appropriate controls to prevent the release of harmful byproducts	Researchers
	Develop safer alternatives to incineration	Researchers
Expanding mitigation capabilities	Provide funding for studies and tool development	Research funders (philanthropic and government, specifically DOD, NIH/NIEHS, NSF, EPA)
	Coordinate research investments	Government
	Provide funding for cleanup of contaminated media	Industry Government Philanthropic organizations
Communicating with communities	Facilitate two-way communication between researchers and communities	Non-Governmental Organizations
	Share information on PFAS contamination, along with guidance on actions homeowners can take	Utilities State governments
	Communicate about PFAS content in products and the full array of benefits and risks	Industry (e.g., consumer product) Government
Reducing PFAS use	Differentiate between essential, nonessential, and substitutable PFAS uses in products and manufacturing processes	Communities Retailers Regulators
	Engage in productive exchange to understand performance requirements and benefits and risks of PFAS and proposed alternatives	Industry Users (e.g., firefighters, medical community) Pollution prevention community
	Engage in productive exchange to establish criteria for assessing alternatives	Industry Researchers Government Consumers
	Create bottom-up incentives to develop and adopt safer alternatives	Consumers
	Assess markets and incentives for green manufacturing	Economists Policymakers
	Invest in green manufacturing through economic development programs and grants	States Federal government Foundations
	Set standards for PFAS content in products	Government Non-governmental standard setting and certification bodies
	Set a firm direction for reducing PFAS use and adopting alternatives	Government
	Establish rules regarding imports of PFAS-containing products	Government

[a]Actors have been inferred where attendees did not explicitly identify actors.

Note: This table lists potential actions attributed to individual workshop participants in the text above, grouped by similarity, as topics were discussed from different angles at different points during the workshop. This table does not include all actions mentioned by participants. These actions are not consensus conclusions or recommendations of the National Academies.

DISCLAIMER: This Proceedings of a Workshop—in Brief was prepared by Anne Johnson, Marilee Shelton-Davenport, and Ellen Mantus as a factual summary of what occurred at the workshop. The statements recorded here are those of the individual workshop participants and do not necessarily represent the views of all participants, the committee, or the National Academies.

REVIEWERS: To ensure that this Proceedings of a Workshop—in Brief meets institutional standards of quality and objectivity, it was reviewed in draft form by **Darrell Boverhof**, The Dow Chemical Company; **Rula Deeb**, Geosyntec Consultants; **Rainer Lohmann**, The University of Rhode Island; **Jonathan Samet**, Colorado School of Public Health; **Tom Webster**, Boston University School of Public Health; and **Xiaoying Zhou**, California Environmental Protection Agency. The review comments and draft manuscript remain confidential to protect the integrity of the process.

PFAS workshop planning committee members are **Jonathan M. Samet** (*Chair*), Colorado School of Public Health; **John L. Adgate**, Colorado School of Public Health; **Rula Deeb**, Geosyntec Consultants; **Elizabeth Harriman**, University of Massachusetts, Lowell; **Philip R. Johnson**, The Heinz Endowments; **Patricia L. Mabry**, HealthPartners Institute; and **Elsie Sunderland**, Harvard University.

ABOUT THE ENVIRONMENTAL HEALTH MATTERS INITIATIVE

From the air we breathe to the water we drink, our health is defined by our natural environment. Environmental health issues like air and water pollution affect everything from our quality of life to the prevalence of a variety of illnesses. We bring together leaders from various sectors to share their insights on how to solve our most pressing environmental health challenges. Our goal is to have experts leave our convening events with new ideas, connections, and partnerships so they may be better equipped to innovate and develop environmental health solutions in their respective fields.

The Environmental Health Matters Initiative was supported by the Centers for Disease Control and Prevention; U.S. Environmental Protection Agency; ExxonMobil; Gordon and Betty Moore Foundation; National Institutes of Health/National Institute for Environmental Health Sciences; Target Corporation; Walmart Foundation; the National Academy of Sciences Cecil and Ida Green Fund; and the National Academy of Sciences George and Cynthia Mitchell Endowment for Sustainability Sciences. Any opinions, findings, conclusions, or recommendations expressed in this publication do not necessarily reflect the views of any organization or agency that provided support for the project.

Suggested citation: National Academies of Sciences, Engineering, and Medicine. 2020. *Understanding, Controlling, and Preventing Exposure to PFAS: Proceedings of a Workshop—in Brief.* Washington, DC: The National Academies Press. https://doi.org/10.17226/25856.

Division on Earth and Life Studies

The National Academies of
SCIENCES • ENGINEERING • MEDICINE

The nation turns to the National Academies of Sciences, Engineering, and Medicine for independent, objective advice on issues that affect people's lives worldwide.
www.nationalacademies.org

THE ENVIRONMENTAL HEALTH MATTERS INITIATIVE