Cover Story

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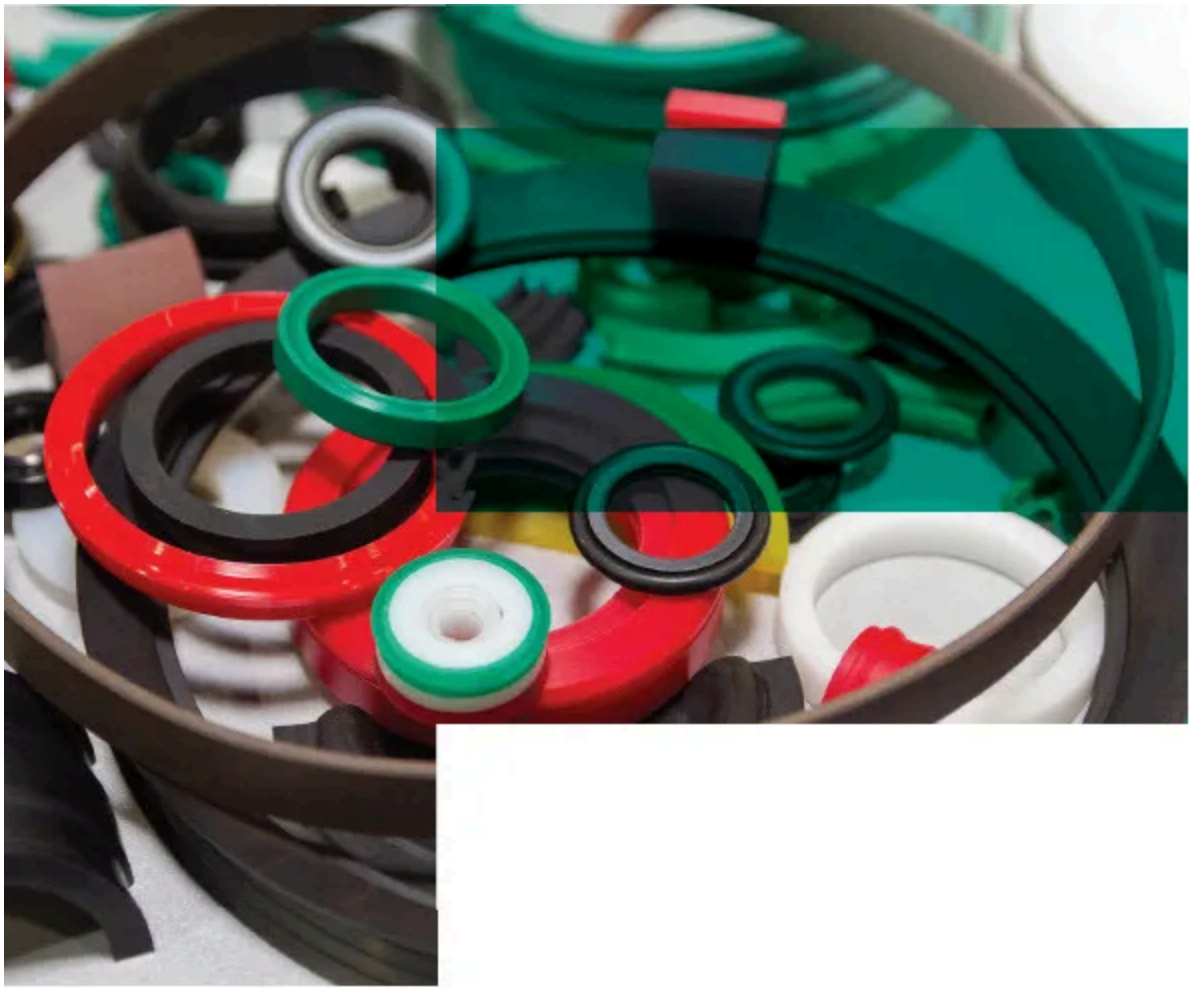
The End Of PFAS



With the current phasing out and probable end of most PFAS applications, time is running out to come up with replacement lubricants and associated products.

KEY CONCEPTS

Materials containing PFAS have been damaging the environment for more than 80 years and, because they are highly persistent, they continue to accumulate in soil and waterways.

Restrictions on the introduction of new products containing PFAS are tightening in the U.S. and EU.

Because PFAS have a combination of properties that are especially beneficial for lubricants, suitable replacements will be difficult to develop.

PFAS are perfluoroalkyl and polyfluoralkyl substances that refer to a wide range of organic and inorganic chemicals containing at least one fully fluorinated carbon atom and that have radically different physical, chemical and biological characteristics. Due to their distinct chemical profile and desirable properties, such as high thermal stability, low surface tension and resistance to degradation, PFAS have been extensively used in the lubricants industry.1

PFAS have proliferated since they were introduced in the 1940s. There are now up to 10,000 different PFAS, more than 200 primary usage categories and countless subcategories.

In addition to industrial applications such as lubricants, seals and elastomers, textile treatments, firefighting foam and electroplating, consumer use categories include PFAS in ammunition, climbing ropes, guitar strings, artificial turf and soil remediation.2 PFAS are present in some form in virtually all industries and a wide range of consumer goods.

They are everywhere, and they aren't going anywhere.

However, recent regulatory scrutiny in the U.S. and Europe and resulting/ pending revisions that limit the use of PFAS in a variety of applications, including lubricants, are a result of growing public awareness of the harmful effects that highly persistent PFAS have on the environment and human health. There also is a lack of understanding about the characteristics, applications and toxicological profiles of many PFAS.

While PFAS could simply be removed from non-essential applications without the need to first locate suitable replacements, regulation becomes complicated and substitution difficult for some crucial applications—such as health and safety—with no alternative formulations. This makes a blanket ban on all PFAS unrealistic.

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Despite this, the lubricants industry will be impacted by these regulatory developments; alternatives that address environmental issues while delivering similar or better performance will be required—and soon.

Environmental impact

PFAS have long been an environment concern because they do not break down in the environment, they can migrate through soil and contaminate sources used for drinking water *(see PFAS Contamination in Water on page 58),* and they bioaccumulate in fish and wildlife.

Uncertainty surrounds the consequences of PFAS exposure at low ambient concentrations on human health. Some PFAS may have an impact on growth and development, according to studies done on lab animals who received high doses of PFAS. These animal studies also suggest PFAS may harm the liver and have an impact on immune system, thyroid and reproductive functions.3

STLE member Dr. Amanda W. Stubbs, scientist group leader of tribology and industrial specialty greases, Nye Lubricants, Inc. (member of the FUCHS Group), explains, "Many of the alternatives we are considering are based upon existing PFAS-free technologies with known profiles offering improved sustainability and environmental responsibility over traditional PFAS-containing solutions. When evaluating novel technologies, we partner closely with our product stewardship team to

do a thorough review of regulatory profiles to ensure that we are moving in a more sustainable and environmentally friendly direction."

Stubbs adds that, when working to develop alternative technologies meeting the most challenging technical requirements (for example, a lubricant with vacuum stability, high temperature performance and chemical inertness), the risk of making a lateral move in terms of sustainability and environmental friendliness is higher, due to the inherent nature of lubricant solutions that have these properties. "For example, materials that are chemically inert are going to be resistant to degradation and will pose a risk for bioaccumulation," she says.

Monitoring and restriction

STLE member Khalid Malik, CLS, OMA I and II, lead auditor general, nuclear oversight, Ontario Power Generation, observes that there is currently legislation and regulatory activities that are ongoing in the U.S. at a state and national level, and in the Euro pean Union through REACH4 to classify fluoroelastomers as PFAS (polyfluoroalkyl) compounds. This would include fluorocarbon (FKM), fluorosilicone (FVMQ), TFE/P and perfluoroelastomer (FFKM). "These are the famous seal materials used in varieties of sealing technologies," he points out *(see Fluoroelastomer Seals and the Concept of Essential Use on page 56).*

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In addition to monitoring existing PFAS contamination, the U.S. Environmental Protection Agency (EPA) is currently reviewing and restricting new formulations and new uses for PFAS.5

The following is a summation of the EPA's goals for restriction:6

• Utilize and coordinate efforts under all applicable legal provisions in order to minimize exposure to PFAS during consumer and industrial applications and to manage and prevent PFAS contamination.

• Assign manufacturers, processors, distributors, importers, industrial and other important users, dischargers and treatment and disposal facilities responsibilities for reducing exposures and managing PFAS dangers.

• Create programs that are voluntary to decrease the usage and release of PFAS.

• Regardless of socioeconomic status, racial identity or linguistic obstacles, prevent or reduce PFAS discharges and emissions in all communities.

The Netherlands, Germany, Sweden, Norway and Denmark are the authors and submitters of the REACH restriction proposal in Europe, which is designed to address the production, marketing (including import) and use of PFAS, including as constituents in other substances, mixtures and articles above a certain concentration in the EU.

With two different restriction options, the limitation proposal has a relatively broad scope (encompassing more than 10,000 PFAS chemicals). The two restriction options are:

1. A full ban after a transition period of 18 months.
2. Some instances of a phased ban, with specific time-restricted derogations applying for particular uses. This option also includes some time-unlimited derogations for exceptional cases. This is the preferred option and the most likely to be adopted.7

Jonatan Kleimark, senior chemicals and business advisor, ChemSec, The International Chemical Secretariat, clarifies, “So the proposal is comprehensive and covers all persistent PFAS substances, for all uses. There also are some general exemptions concerning pharmaceuticals, biocides and plant protection products. In addition, there are some derogations (time-limited exemptions) for specific uses, such as semiconductor manufacturing. For non-derogated uses, the transition time is 18 months, and for derogations it is either 6.5 or 13.5 years.”

Kleimark says that the discussion, which ended Sept. 25, has been an opportunity for stakeholders to submit information about PFAS uses, derogations, alternatives, etc. He adds, “After that, the European Chemicals Agency (ECHA) and its scientific committees form their opinion, which should be finished mid-2024. After that, the proposal will be on the Commission’s table, with a decision sometime during 2025, hopefully, but it might be 2026. In summary, the restriction suggests a complete phase-out of PFAS over time.”

Affected applications

There are many applications that could be impacted by PFAS regulation changes. Two important applications Malik cites are:

• Fluoroelastomers that are successfully used in phosphate ester (fire-resistant fluid) and fuel applications. Due to the fluoropolymer’s ability to resist fire, weather, temperature and chemicals, these are the preferred elastomer and synthetic rubber compounds. Malik adds that other types of elastomers cannot withstand these conditions and have failed in service.

• Fluoroelastomers that are widely used in environmental qualifications (EQ) applications of nuclear plants. EQ is a procedure used to make sure that equipment will be able to survive any potential environmental conditions that may arise when it is actually required to carry out the intended function in accident-related circumstances. It often starts with testing that models design-based accident scenarios like loss of coolant accidents (LOCA), high energy line breaks (HELB) and severe accidents (SA). The testing then incorporates accelerated aging (thermal, radiation, vibration, mechanical) tests. The testing also must cover any other condition or combination of conditions that the component may have to operate in during design and beyond-design circumstances. “Many studies have been conducted on fluoroelastomer performance under severe thermal and radiation testing, and they have been proven much better than the other types of elastomers materials,” Malik says.

Impact on the lubricants industry

Since the lubricants industry encompasses many other industries, industrial as well as consumer products, it will be important for this industry to identify alternatives and understand performance requirements at an early stage, Kleimark advises *(see The Urgent Need for PFAS Substitutes on page 59).*

"Especially important will be the understanding of performance requirements, since the PFAS-containing lubricants in many cases have much higher performance than is necessary for the use," he notes. "At the current time I don't see any readily available alternative for PFAS. I am not aware of any new emerging technologies, at least in my field. In fact, the industry is currently not prepared with any possible alternative. It might take some time to come up with suitable solutions, or there may be limited use of PFAS under strict criteria. The change should be scrutinized and not pose risks and problems to applications."

Dr. Lou A. Honary, president, Environmental Lubricants Manufacturing, Inc., explains that as a biobased grease and lubricant manufacturer, most of the issues with PFAS he deals with are related to the additives they use for performance enhancers in their products.

The importance of developing PFAS-free replacements varies by industry and application.

"Since vegetable oils, which we use as base oils for our products, have shown to be free of per- and polyfluoroalkyl substances, the most important requirement within our industry is the ability of additive manufacturers to reduce or remove PFAS from their additives," he says. "Our concern is with the presence of PFAS in the additives we purchase to enhance the performance of our biobased grease and lubricants. But, since we are certain vegetable oils do not contain PFAS in their natural forms, we have to rely on the expertise of the additive manufacturers to find replacements for PFAS in their products."

Stubbs adds that the importance of developing PFAS-free replacements varies by industry and application. “In some cases, a suitable PFAS-free solution is already available; customers moving to this technology will impact relative levels of demand, which may put a strain on the supply chain,” she cautions. “In exploring new technologies to satisfy more technically challenging applications, I anticipate that new lubricants with novel properties will be innovated; some will satisfy existing PFAS-containing technology replacements, while others may enable us to accomplish things that were previously unattainable.”

PFAS replacements

The advantages of PFAS materials in lubricants have been thoroughly studied, and certain studies have determined that the performance of PFAS-free technology can sometimes be equal to or even better than conventional technology, especially when it comes to low temperature characteristics, stick-slip behavior and wear resistance.

While the elimination of PFAS does provide certain technological hurdles in applications demanding high temperatures, chemical inertness and vacuum conditions, developers are now working on next-generation technologies.

“It is important to emphasize that requirements vary by application; one of our key strategies in developing alternative technologies is ensuring that we have a thorough understanding of customer applications and are utilizing appropriate test methods to screen for these properties in the lab,” Stubbs says. “Field trials are and will continue to be a key part of our development process as well. As we explore alternative technologies, we are leveraging our supplier relationships.”

Honary believes that, in principle, finding replacements for different types of per- and polyfluoroalkyl or fluorinated substances will not be difficult. But, he cautions, to replace all of the different fluorinated

substances in a diverse array of products will require a long time as well as significant cost.

Stubbs explains, “While the regulatory landscape remains uncertain, we have been preparing for elimination of PFAS-containing lubricants. We recognize how challenging and costly (in time, energy, resources and funds) it can be for some customers, particularly OEMs, to change the identity of the lubricant in their application. Because of this, we are continuing to offer our existing PFAS-containing products but have made the decision to not formulate new products with fluorinated raw materials. Additionally, some customers looking to spec in new lubricants are actively choosing not to evaluate PFAS-containing options in the interest of avoiding future headaches if regulations ultimately limit the use of these products.”

She continues, “We acknowledge that PFAS-free technologies will likely not be a one-size-fits-all solution. As we develop alternative technologies, we are performing extensive screening at the bench level, beginning with basic properties and going so far as to use custom application simulation test rigs that we have built in house. We are partnering closely with our product management team to ensure we have a thorough understanding of the variety of applications in which our products are used, so that we can perform appropriate testing and target the most informative field trials for our new technologies.”

Summary

Honary believes that the presence of PFAS in everyday products is so pervasive that it will require many years to even partially eliminate the chemical. “The polarity of vegetable oils is such that in many applications they bond to metal surfaces and lubricate without the need for antiwear or extreme pressure additives,” he says. “As such the biobased lubricants industry has a starting advantage due to the use of renewable oils. While additives that contain PFAS are currently in use, it is likely that economical alternatives will be available. The cost to replace

existing additive formulations and qualify products with the new PFAS-free additives will be expensive and could require decades to accomplish."

Stubbs summarizes, "This is an exciting time to be in the R&D field of the lubrication industry. Various challenges over the last few years, including the global COVID-19 pandemic, supply chain disruption and regulatory flux, have spurred exploration of new technologies and adoption of agile strategy. While the times have been challenging, I think in the long run we are going to benefit from what we have learned, and we will continue to learn over this period."

Kleimark concludes, "Since there may be a complete phase-out, all industry sectors will have to ensure that their supply chain is on top of this. The main obstacle for companies is to understand whether they are using PFAS, and how the potential uses can be identified. This is especially difficult for industrial uses, for example for the industrial use of lubricants."

The U.S. EPA also maintains a resource library for PFAS information and compliance. 8 Other resources are available through individual companies, trade organizations and action groups.9, 10

Fluoroelastomer seals and the concept of essential use

Khalid Malik, CLS, OMA I and II, lead auditor general, nuclear oversight, Ontario Power Generation, explains, "The notable advancement over the years in seal materials is in the use of fluoropolymer compounds. We tried different materials in the past, but none of them performed nearly as well as fluoropolymers. As far as I know, at the present time, there are no PFAS alternatives in the marketplace that offer the same high-performance levels and levels of safety."

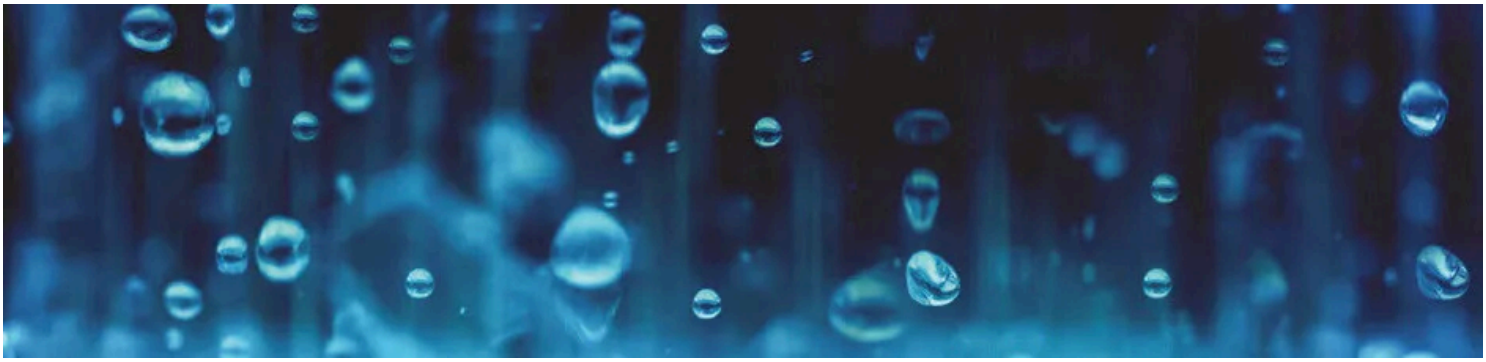
Even though PFAS-containing fluoroelastomer seals are crucial to many industries, there are currently no alternatives in widespread use. These

seals and other lubricant-related PFAS applications could be deemed by regulatory agencies “an essential use” meaning they may not be subject to the same regulatory scrutiny as other applications. The two qualifying elements of an essential use are:

1. That a use is necessary for health, safety or is critical for the functioning of society.
2. That there are no available technically and economically feasible alternatives.A

“There is need for a detailed study on new materials and their risks and challenges to applications and products in the long run,” Malik says. “There should be some classification, specifying and naming hazardous and non-hazardous chemicals to support the seal industry.”

A. Cousins, I.T., Goldenman, G., Herzke, D., Lohmann, R., Miller, M., Ng, C.A., Patton, S., Scheringer, M., Trier, X., Vierke, L., Wang, Z. and DeWitt, J.C. (2019), “The concept of essential use for determining when uses of PFASs can be phased out,” *Environmental Science: Processes and Impact,* **11**. Available at: **https://pubs.rsc.org/en/content/articlelanding/2019/em/c9em00163h**.



PFAS contamination in water

Dr. Lou A. Honary, president, Environmental Lubricants Manufacturing, Inc., observes that since one of the most troubling aspects of PFAS in human health is related to their presence in drinking water, the

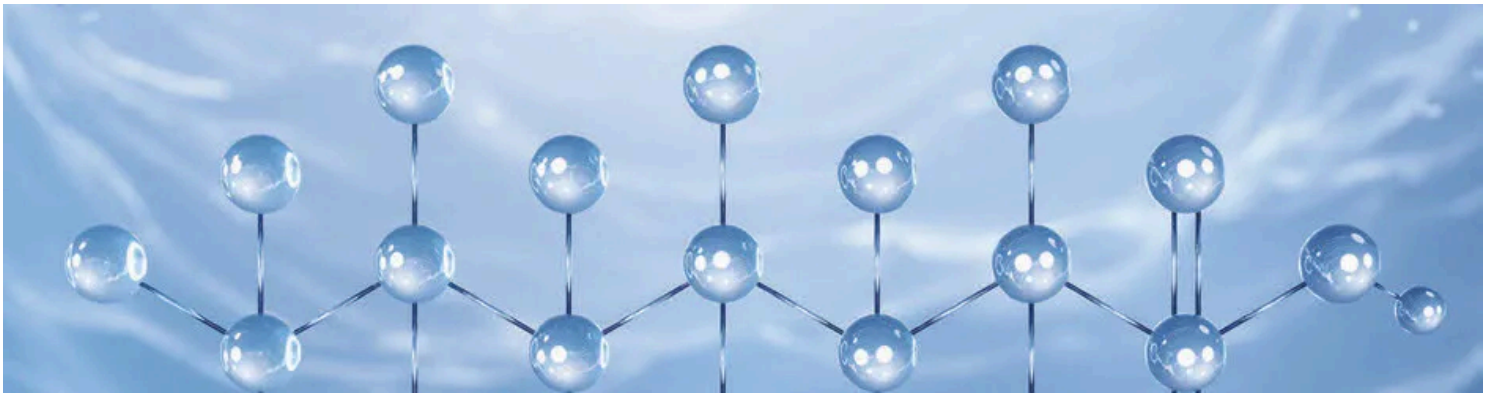
assumption would be that all applications near or on waterways or close to aquifers would require more immediate actions than others. He cites applications such as drilling where drill rod grease is introduced into the ground and wire ropes used in cranes or equipment for dredging.

According to a recent NPR blog post, there are several PFAS that are of particular concern in drinking water.A Research that includes a USGS studyB has connected exposure to specific PFAS to harmful health effects in people, including an increased chance of developing certain malignancies, an increased risk of obesity and high cholesterol, a decreased ability to conceive children and developmental issues such as low birth weight.

The USGS study is the first to compare PFAS in tap water across the entire U.S. from both public and private sources.

A. Treisman, R. (July 6, 2023), "'Forever chemicals' could be in nearly half of U.S. tap water, a federal study finds." Available at: **www.npr.org/2023/07/06/1186230007/drinking-water-forever-chemicals-pfas-study**.

B. Smalling, K.L., Romanok, K.M., Bradley, P.M., Morriss, M.C., Gray, J.L., Kanagy, L.K., Gordon, S.E., Williams, B.M., Breitmeyer, S.E., Jones, D.K., DeCicco, L.A., Eagles-Smith, C.A. and Wagner, T. (2023), "Per- and polyfluoroalkyl substances (PFAS) in United States tapwater: Comparison of underserved private-well and public-supply exposures and associated health implications," *Environment International*, **178,** 108033, **https://doi.org/10.1016/j.envint.2023.108033**.



The urgent need for PFAS substitutesA

The EU has started reviewing the new proposal for REACHB restriction of all perand polyfluoroalkyl substances (PFAS). Following are four reasons to take action on PFAS substitutes now.

1. There is a significant number of formulations. According to a broad interpretation of the European Chemicals Agency (ECHA), PFAS affect more than 10,000 chemicals.

2. Because of new and pending regulation, time is running out. The limitation could ban the import and production of PFAS in Europe within 18 months of its implementation.

3. Markets, including the lubricants market, have already been affected. Massive changes have been announced by major stakeholders, and production methods for fluoropolymers (such as polytetrafluoroethylene, PTFE) have already been disrupted. Some companies are ceasing PFAS production as soon as 2025.

4. End-users are actively looking for PFAS alternatives. In recent months, PFASfree materials have risen to the top five most sought-after additives.

A. Stoyanova, A. (June 6, 2023), "4 reasons why you must speed up the offering of PFAS substitutes," SpecialChem blog post. Available at **http://bit.ly/43jizTk**.

B. Registration, Evaluation, Authorisation and Restriction of Chemicals.

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1. Buck, R.C., Franklin, J., Berger, U., Conder, J.M., Cousins, I.T., de Voogt, P., Jensen, A.A., Kannan, K., Mabury, S.A. and van Leeuwen, S.P. (Oct. 2011), "Perfluoroalkyl and polyfluoroalkyl substances in the environment: terminology, classification, and origins," *Integr Environ Assess Manag,* **7** (4), pp. 513-41. doi: 10.1002/ieam.258. PMID: 21793199; PMCID: PMC3214619.
2. Glüge, J., Scheringer, M., Cousins, I.T., DeWitt, J.C., Goldenman, G., Herzke, D., Lohmann, R., Ng, C.A., Trier, X. and Wang, Z. (2020), "An overview of the uses of perand polyfluoroalkyl substances (PFAS)," *Environ Sci Process Impacts,* **22** (12), pp. 2345-2373. doi: 10.1039/d0em00291g. Epub 2020 Oct 30. PMID: 33125022; PMCID: PMC7784712.
3. From CDC Fact Sheet: Per- and polyfluorinated substances (PFAS). Available at **www.cdc.gov/biomonitoring/PFAS_FactSheet.html#print**.
4. Registration, Evaluation, Authorisation and Restriction of Chemicals.
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6. From "PFAS strategic roadmap: EPA's commitments to action 2021-2024." Available at **www.epa.gov/system/files/documents/2021-10/pfas-roadmap_final-508.pdf**.
7. From "EU REACH: How to prepare for the proposed PFAS restriction." Available at **bit.ly/3pFFXg9**.
8. EPA PFAS resource repository available at **www.epa.gov/pfas/pfas-resources-data-and-tools**.
9. The ChemSec PFAS Guide is available at **https://pfas.chemsec.org/**.
10. Information on the PFAS Movement is available at **http://chemsec.org/pfas**.