2025 Edition Report

The Rising Threat of HFOs and TFA to Health and the Environment

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ATMO Report

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Originally published in July 2025.

ATMO sphere

Let's Stop Playing Russian Roulette

Commenting in regard to the risk of nuclear war, the mathematician and cryptologist Martin Hellman has written, "The only way to survive Russian roulette is to stop playing."

That metaphor can also be applied to PFAS (per- and polyfluorinated substances), the notorious group of chemical pollutants that has gained much attention over the past two decades as their presence in the environment and grave harm to human health have been documented. Known mostly for keeping food from sticking to packaging or cookware and making clothes and carpets resistant to stains, PFAS have been used in many other applications, including refrigeration, cooling and heat pumps.

The scientifically accepted definition of PFAS comprises those with at least one fully fluorinated carbon atom, such as many HFO and HFC refrigerants and their atmospheric degradation byproduct, trifluoroacetic acid (TFA). In this report – the second one ATMOsphere has published on the topic – we look at the global impact of these refrigerants and TFA. We make the case that the risk associated with these chemicals is too high, especially when there are commercially available natural refrigerant alternatives for virtually every HVAC&R application.

In Europe, the PFAS risk is being taken very seriously. It was just reported that executives at a chemical plant in Italy were sentenced to jail terms of up to 17 years and fined millions of euros for PFAS pollution of water used by hundreds of thousands of people.

And the EU, through the European Chemicals Agency (ECHA), is well into its consideration of a "Universal PFAS Restriction" proposal – originally made by Denmark, Germany, the Netherlands, Norway and Sweden – to restrict PFAS as a class under REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals), the EU's chemicals regulation. This restriction would cover thousands of PFAS, including f-gases and TFA, making it perhaps the most important PFAS law in the world.

Over the past year, the ECHA has undertaken a very lengthy and comprehensive consultation process, receiving more than 5,600 comments. There is the clear potential to ban HFOs – which are largely untouched by the EU's F-gas Regulation – in the next decade. This will be in large part because of the availability of credible natural refrigerant alternatives across many segments in Europe today, from refrigeration to air-conditioning and chillers to heat pumps.

A comprehensive PFAS ban will have a huge impact, not just in Europe but globally. Indeed, the world is watching what Europe does, and PFAS manufacturers are feeling the pressure. They are employing their traditional playbook to maintain the status quo, as they did with ozone-depleting refrigerants and global-warming refrigerants, denying the potential risks and gaslighting the marketplace.

But many important players in the HVAC&R industry are tired of this. They don't trust chemical refrigerant manufacturers anymore because of their terrible track record over the last 50 years. Why should the scenario with HFOs and TFA be any different?

In this report we show how TFA has become the most widespread PFAS in the world and the focus of great concern, with a direct link to the HVAC&R industry. This is a fast-evolving issue, and ATMOsphere will continue to report on it in the weeks and months ahead. Don't be surprised if you see a third edition of the report soon.

And remember, we don't need to play Russian roulette with our future. We can put down the PFAS and use natural alternatives.

Marc Chasserot
Founder and Publisher, ATMOsphere

Table of Contents

Executive Summary

When some f-gas refrigerants – particularly HFO-1234yf, used in millions of car air-conditioning systems – escape into the atmosphere, they readily break down into trifluoroacetic acid (TFA). TFA, an ultrashort-chain (two-carbon) chemical, is extremely mobile and water-soluble and is absorbed in rainfall and other precipitation. Once it lands on Earth, TFA spreads throughout the environment and builds up due to its extreme persistence.

HFO-1234yf and many other f-gases fall under the category of chemical pollutants called PFAS (per- and polyfluoroalkyl substances). According to the scientifically approved definition of PFAS, which includes these f-gases and TFA, they have at least one "fully fluorinated carbon atom."

TFA has shown a consistent upward trend in concentrations in surface water and rainwater over the past three decades. It has also been discovered in soil, dust and air, and in many plants and wildlife. TFA ultimately ends up in drinking water, beverages and food.

TFA has also been detected in human blood, raising concerns about its potential health impacts, especially long term. A major new study on TFA characterizes it as a "planetary boundary threat." Transitioning away from TFA and its precursors – such as by adopting natural refrigerant-based systems – "is the most effective way of safeguarding future generations," the study said.

Concerns about TFA were accentuated on May 26 of this year when three German government agencies announced that their assessment of TFA and its trifluoroacetate salts as reproductively toxic, very persistent and very mobile was officially submitted to the European Chemicals Agency (ECHA).

While the U.S. Environmental Protection Agency (EPA) does not regard f-gases and TFA as PFAS, many other U.S. states do, notably Maine and Minnesota. Minnesota has initiated a toxicity review of trifluoroacetate. In Canada, the government is collecting feedback on its proposal to regulate PFAS as a class, excluding fluoropolymers but including HFOs.

The biggest regulatory effort is being undertaken by the EU, as the European Chemical Agency (ECHA) evaluates PFAS proposals from five countries to restrict PFAS as a class, including f-gases and TFA. The ECHA has also started its consultation and expert evaluation of the German proposal to classify TFA as reproductively toxic under the EU's classification, labelling and packaging (CLP) regulation. In addition, several European countries have issued guidelines for acceptable levels of TFA in drinking water and food.

The chemical industry has aggressively defended the use of HFOs like HFO-1234yf and downplayed the threat potentially posed by TFA, though the industry does not have a good safety track record when it comes to other PFAS and previous generations of f-gases.

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Acronyms and Abbreviations

A2L (non-toxic, mildly flammable)
ALT (alanine transaminase)
AR6 (Sixth Assessment Report)
BAuA (German Institute for Occupational Safety and Health)
BfR (German Federal Institute for Risk Assessment)
bw (body weight)
CF3 (trifluoromethyl group)
CFC (chlorofluorocarbon)
CO_2 (carbon dioxide)
COOH (carboxyl group)
dw (dry weight)
ECHA (European Chemicals Agency)
EEAP (Environmental Effects Assessment Panel)
f-gas (fluorinated gas)
GWP (global warming potential)
HCFC (hydrochlorofluorocarbon)
HFC (hydrofluorocarbon)
HFC-134a (1,1,1,2-tetrafluoroethane)
HFO (hydrofluoroolefin)
HFO-1234yf (2,3,3,3-tetrafluoropropene)
HFO-1234ze(E) (1,3,3,3-tetrafluoro-propene)
IPCC (Intergovernmental Panel on Climate Change)
MAC (mobile air-conditioning)
mcg (microgram)
mg (milligram)
ng (nanogram)
NOEC (no observed effect concentration)
ODP (ozone-depleting potential)
OECD (Organisation for Economic Co-operation and Development)
PFAS (per-and polyfluoroalkyl substances)
PFAA (perfluoroalkyl acid)
PFOA (perfluorooctanoic acid)
PFOS (perfluorooctanesulfonic acid)
PNEC (predicted no effect concentration)
R290 (propane)
R717 (ammonia)
R744 (CO_2)
REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals)
TFA (trifluoroacetic acid or trifluoroacetate)
UBA (German Environment Agency)
UNEP (United Nations Environment Programme)
U.S. EPA (United States Environmental Protection Agency)

INTRODUCTION

The Rising Threat of HFOs and TFA to Health and the Environment

Over the past few years, there has been growing evidence of HFO-produced trifluoracetic acid's proliferation in the environment and its potential toxicity, prompting the EU and other governmental bodies to act.

Persistence.

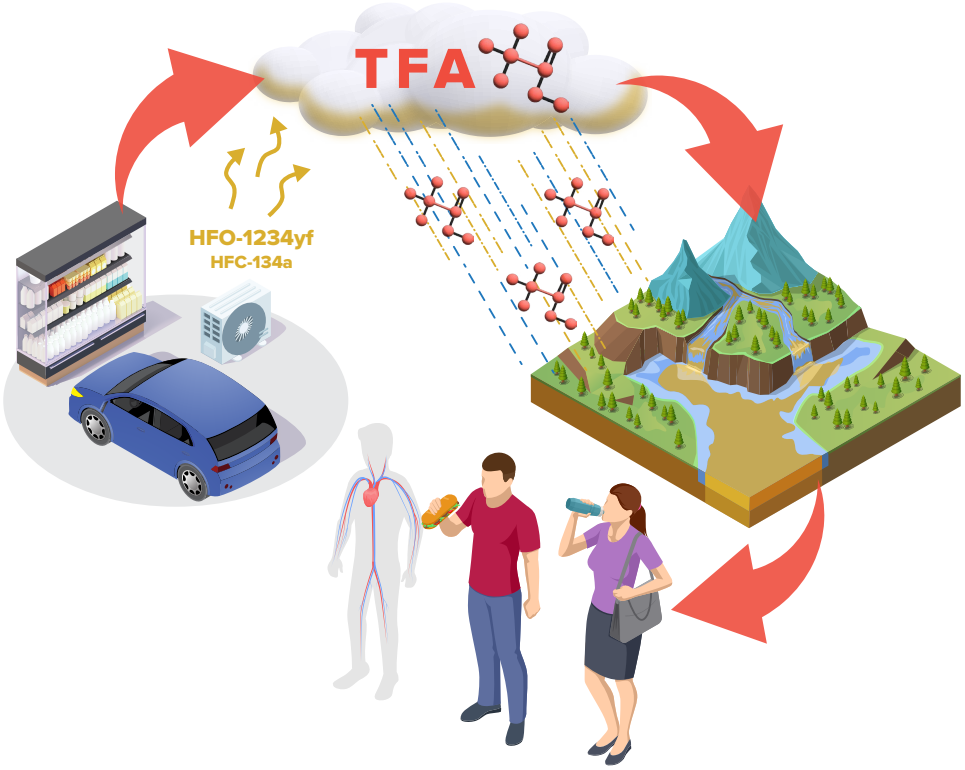
That's often a useful quality but can be highly problematic when it comes to environmental pollution.

Take climate change. The amount of carbon dioxide generated from fossil fuel combustion in 2024 was reported to be 37.4 billion metric tons, a record high, up 0.8% from 2023. That's bad, but what's worse is the persistent presence of carbon dioxide as a heat-trapping greenhouse gas once it's in the atmosphere – 300 to 1,000 years – a problem exacerbated by long-lasting, super-polluting gases like HFC refrigerants and methane.

Over the past 25 years the world has come to learn about another extremely persistent source of pollution, a group of more than 10,000 synthetic compounds called PFAS (per- and polyfluoroalkyl substances), which are so persistent they have been dubbed "forever chemicals." Once they get into the environment, they typically stay there unless removed, which can be expensive and difficult. Worse, some have been linked to a number of adverse health impacts, including testicular and kidney cancer, reproductive issues, developmental problems and immune system effects.

PFAS are distinguished by their carbon-fluorine chemical bond. This is the key feature of a definition established by the Organisation for Economic Co-operation and Development (OECD) and defended by scientists around the world, most recently in the journal *Environmental Science & Technology Letters* (page 35). This definition states that PFAS have at least one "fully fluorinated carbon atom." It's this carbon-fluorine bond that makes PFAS so durable and persistent, which is both its blessing and its curse.

The chemical structure of PFAS has rendered them extremely useful in keeping food from sticking to packaging or cookware, making clothes and carpets resistant to stains and creating more effective firefighting foam. Indeed, after PFAS was discovered in the late 1930s, they became commonplace additions to hundreds of product categories throughout the world.



When they leak into the atmosphere certain refrigerants produce trifluoroacetic acid (TFA), which comes down to Earth in rain. The TFA infiltrates the environment and ends up in food, drinks and ultimately the bloodstream.

But the very property that made PFAS so useful also made them harmful to human health when the chemicals leaked or were dumped into the environment, which was only disclosed thanks to the efforts of U.S. attorney Robert Bilott beginning in the late 1990s.

Bilott, whose work was highlighted in the 2019 film *Dark Waters* and the 2018 documentary *The Devil We Know*, revealed the carcinogenic and other health impacts of two long-chain (eight-carbon) PFAS called PFOA (perfluorooctanoic acid) and PFOS (perfluorooctanesulfonic acid). Moreover, he learned that DuPont and 3M, the manufacturers of the chemicals, while saying publicly that these chemicals were harmless, did not disclose their internal findings that they caused harm to laboratory animals and their own employees.

Bilott was the keynote speaker at the ATMOsphere America conference in 2024 (page 49) and the IIAR 2025 Natural Refrigeration Conference & Heavy Equipment Expo because of the connection between PFAS and f-gas refrigerants. According to the OECD definition, many commonly used f-gases, including HFC-134a and HFO-1234yf, are PFAS.

But the bigger problem with these gases is that when they escape into the atmosphere some break down into another PFAS, trifluoroacetic acid (TFA), which is extremely mobile and water-soluble and is absorbed in rainfall and other precipitation. Once it lands on Earth, TFA, an ultrashort-chain (two-carbon) chemical, spreads throughout the environment and builds up due to its extreme persistence. TFA can also form trifluoroacetate salts by reacting with calcium or sodium minerals, with a similar environmental effect.

TFA ultimately ends up in drinking water, beverages and food. As a result it has been found in the blood serum of people, for whom the effects are not yet fully understood but are deeply concerning.

This report is ATMOsphere's second review of the PFAS issue as it relates to refrigerants – particularly the latest generation, HFOs – and TFA. Since the first report was published in 2022, the issue has spawned a torrent of activity, including research and discussion on the proliferation of TFA and its potential harm to human health and the environment, as well as regulatory efforts in the EU and some U.S. states. All will be covered in this report, based on new developments and articles that have appeared over the past year in NaturalRefrigerants.com, also published by ATMOsphere.

Common history

F-gas refrigerants and PFAS have been linked from their earliest days. In fact, DuPont discovered nonstick PFAS chemicals in 1938 during a failed experiment with fluorinated refrigerants, which were first synthesized a decade earlier.

Both PFAS and f-gases proved wildly successful for several decades. But f-gases hit their first hurdle in the 1970s and 1980s after the discovery that CFCs and HCFCs depleted the Earth's ozone layer, leading to the 1987 Montreal Protocol agreement to phase them out. The impact of CFCs and HCFCs and their replacement gases, HFCs, as super-polluting greenhouse gases led to the planned phase-down of HFCs under the Kigali Amendment to the Montreal Protocol in 2016.

As PFAS's health effects were uncovered in the 2000s, the fact that many f-gases were themselves PFAS and that some changed into TFA started to gain attention.

In pure form, TFA is a strong corrosive acid used in industry that is harmful when inhaled, causes severe skin burns and is classified under the EU's Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) regulation as harmful to aquatic life with long-lasting effects.

In structure TFA is similar to PFOA, which has eight carbons compared to two for TFA; both have the CF3 and COOH moieties. PFOA has been clearly established as harmful to people at extremely low concentrations; TFA has been found harmful in low concentrations to lab animals, sounding alarms about its potential effect on humans, especially over long-term exposure as TFA builds up in the environment.

As early as 1993, the Ford Motor Company studied the TFA formed from the partial (up to 20%) atmospheric degradation of HFC-134a, used as a refrigerant in car air-conditioning. The study concluded, "Remote possibility of fetal toxicity; further research required."

That finding was echoed on May 26 of this year by three German government agencies (page 40) when they announced that their assessment of TFA and its trifluoroacetate salts as reproductively toxic, very persistent and very mobile was officially submitted to the European Chemicals Agency (ECHA). They based this recommendation on studies showing harm done to some rabbit fetuses whose mothers were given 750mg/kg bw/day of TFA for 23 days. For example, 32% of the litters had offspring with multiple folded retinas.

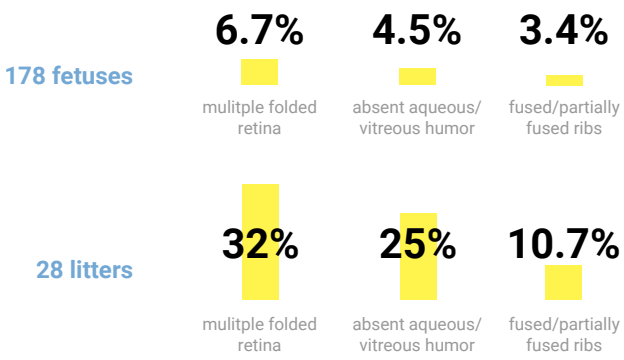
In addition to rabbits, studies of TFA's effects have been done on rats. A German study found that rats exposed to TFA developed an increase of ALT, a marker of liver dysfunction. The Netherlands determined that TFA was 0.002 times as toxic as PFOA in causing rat livers to enlarge. Other evidence of TFA's impact was uncovered in new research on tiny worms called C. Elegans. Scientists at Quinnipiac University determined that micro molar quantities of TFA may cause oxidative stress in the worms and may downregulate their fatty acid metabolism.

In addition, ECHA REACH has listed for TFA a predicted no-effect concentration (PNEC) of 560ng/L for algae and has a no observed effect concentration (NOEC) of 0.83mg/kg in soil for crop plants. Researchers in the late 1990s observed TFA incorporation in biomolecules such as proteins in aquatic organisms.

Impact of TFA on Rabbit Offspring

NaTFA dosage in female rabbits

750mg/kg bw/day
X 23 days



Source: Labcorp Laboratories (2024c)

One of TFA's biggest sources

HFO-1234yf (2,3,3,3-tetrafluoropropene) is a mildly flammable (A2L) refrigerant introduced in 2012 in Europe as a replacement for HFC-134a in car AC systems, and then used as a key ingredient in f-gas blends like R513A and R449A. Over the past dozen years, it has become one of the biggest sources of environmental TFA in the world.

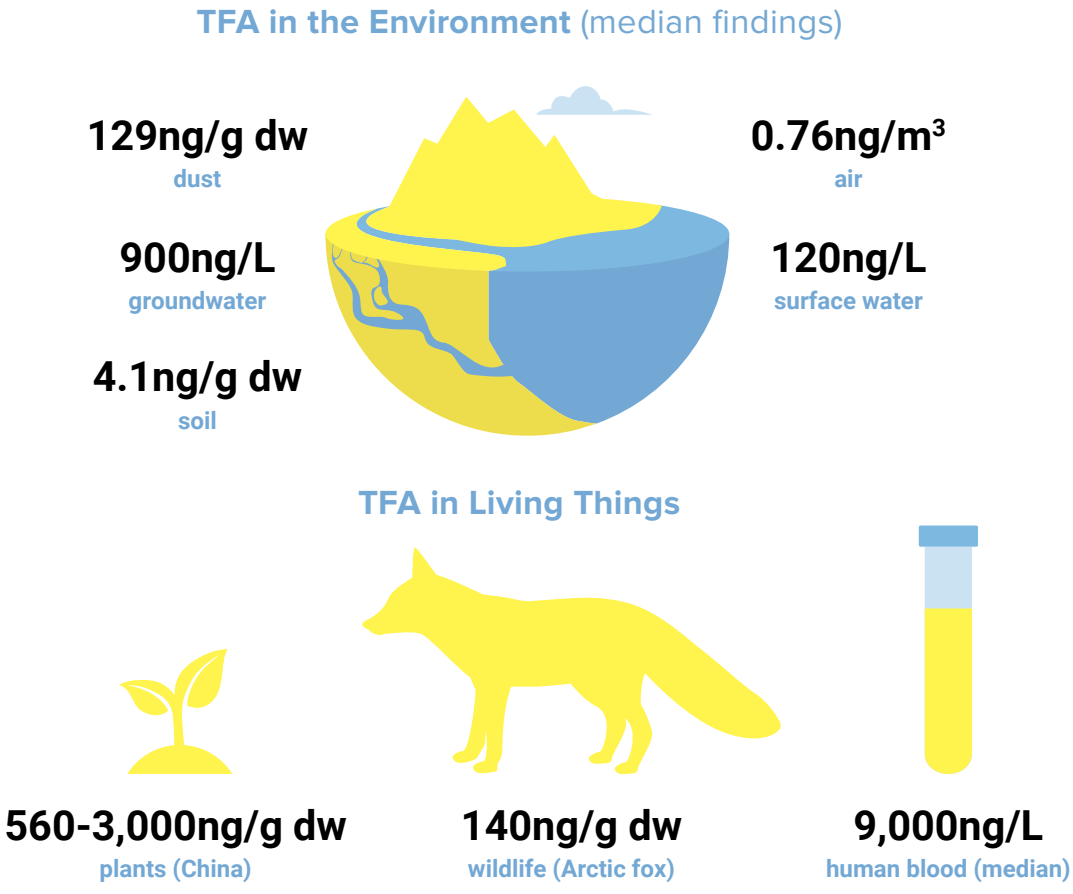
A hydrofluoroolefin, HFO-1234yf has a very low 100-year GWP, 1.81, and an even lower 20-year GWP, 0.501 (both IPCC AR6). But upon release into the atmosphere, 100% of HFO-1234yf turns into TFA via photo-oxidation in just 10 to 14 days. Another common HFO, HFO-1234ze, generates TFA in the atmosphere in 20 days but to a much lower extent (less than 10%).

The effect of photo-oxidation in the atmosphere, triggered by light energy, on converting HFOs and other f-gases into TFA was demonstrated in a 2024 study in which 36 PFAS were detected in surface snow around the Arctic island of Spitsbergen. Samples were collected during January to August 2019, covering a period when there were 24 hours of darkness to one with 24 hours of daylight. The researchers found that TFA concentrations were up to 71 times higher during the sunshine period compared to the darkest days.

While HFO-1234yf and other f-gases are a major contributor to environmental TFA, there are other sources, including the breakdown of certain pesticides, pharmaceuticals and other PFAS, sewage treatment and industrial releases, all adding to the worldwide proliferation of this chemical.

TFA is everywhere

The extent to which TFA has infiltrated the environment in ever-increasing quantities was explored in a 2024 study, "Environmental Occurrence and Biotic Concentrations of Ultrashort-Chain Perfluoroalkyl Acids: Overlooked Global Organofluorine Contaminants" (Zhi et al.). Perfluoroalkyl Acids (PFAAs) are the subgroup of PFAS that include PFOA, PFOA, TFA and other PFAS acids.



Source (2024): Environmental Occurrence and Biotic Concentrations of Ultrashort- Chain Perfluoroalkyl Acids: Overlooked Global Organofluorine Contaminants (Zhang, Zhi et al.)

According to the Zhi study, TFA exhibits environmental concentrations "surpassing other ultrashort-chain PFAAs and often exceeding those of short- and long-chain PFAAs." Furthermore, TFA has shown a consistent upward trend in concentrations in surface water (rivers, streams, lakes and wetlands, as well as ice in arctic regions), rainwater and air over the past three decades. Despite the already elevated concentrations of TFA, its environmental levels are expected to continue to increase over time, the study said.

The Zhi study included data on TFA's presence in multiple environments. For example, in aquatic environments, it is prevalent in North America (600 detections, 100ng/L median) and Europe (900 detections, 100ng/L median). It has shown up in all manner of water, especially surface water (1,240 samples, median 120ng/L) but also groundwater (median 900ng/L), rainwater (median 170ng/L) and ultimately tap water (median 160ng/L) and bottled water.

TFA, added the Zhi study, has also been discovered in soil (median 4.1ng/g dw (dry weight), dust (median 129ng/g dw) and air (median 0.76ng/m3). In living things it has been observed in many plants, with concentrations of 560 to 3,000ng/g dw in China, and wildlife (such as the Arctic fox with 140ng/L).

One of the most recent studies of TFA in surface water comes from Fidra, which on June 16, 2025 published what it called the first nationwide study of TFA in the U.K. It found TFA contamination at 98% of the 54 river sites investigated. The average concentration was 2,211 ng/L, toward the higher end of the range of average concentrations reported from studies in other countries; the highest concentration (78,464 ng/L) was seen for a sample obtained from the River Kelvin in Glasgow, the second highest recorded value of TFA in surface water globally, said Fidra.

In drinking water, a 2024 study by Eurofins of ultrashort-chain PFAS in Sweden and Norway found TFA in nearly all samples at an average concentration of 295ng/L. In the U.S. researchers at the University of Rhode Island recently reported detecting TFA in 66% of 320 drinking water samples collected in the state, with median concentrations of 580ng/L and a maximum concentration of 2,400ng/L (page 22).

There have been findings of TFA in bottled water. For example, in January of 2025, it was reported that Swiss broadcaster RTS had 13 brands of bottled water sold in Switzerland tested for TFA, and found it in 10, with the highest concentration at 800ng/L.

PAN Europe, which has published studies on TFA in surface and drinking water in Europe, has recently published studies of the growth of TFA in wine and bread/cereal products. (Other studies have found TFA in beer and tea.) Notably, TFA was found in the wines and bread/cereal products at much higher levels that than those found in surface water and other parts of the environment. While PAN Europe attributes the TFA in large part to pesticide byproducts, especially in agricultural areas, it also cites f-gases as another major precursor.

TFA in U.K. Rivers

78,464 ng/L
River Kelvin highest concentration

2,211 ng/L
average concentration

98%
of 54 sites investigated

Source (2025): Fidra, Concentrations of Trifluoroacetic Acid (TFA) in UK Surface Waters

Growth in TFA in Wine (10 EU Countries)

0mcg/L	13mcg/L	21mcg/L	40mcg/L	122 mcg/L
before 1988	1988	2010	2015	2021–2024 (average)

Source (2025): Pesticide Action Network Europe, "Message from the bottle: The Rapid Rise of TFA Contamination Across the EU"

In the wine study, which covered 10 EU countries, no TFA was detected in wine dated before 1988, but the amount of TFA progressively grew from 1988 (13mcg/L) to an average of 122mcg/L between 2021 and 2024. A separate Swedish study found microgram levels of TFA in juices and purees, including an average of 34mcg/L ± 20mcg/L in orange juice (page 28).

The increasing amounts of TFA detected over time was also seen in a 2024 study of Danish well water, in which TFA grew from an average of 60ng/L between 1960 and 1980 to an average of 600ng/L between 2000 and the 2020s (page 26).

In the 2025 PAN Europe study of bread and cereal products in Austria, conducted by affiliated group Global 2000, TFA was discovered in, for example, organic rye (13mcg/kg), conventional cereal products (167mcg/kg) and conventional butter biscuits (420mcg/kg); the average concentration across 48 products was 119mcg/kg.

TFA in Bread and Cereal Products in Austria

13mcg/kg	420mcg/kg	119mcg/kg
organic rye	conventional butter biscuits	average concentration 48 products

Source (2025): Global 2000, "The Forever Chemical in Our Daily Bread: The worrying rise of TFA in cereal products"

TFA in blood

Given the many pathways that TFA has for entering the body, it is not surprising that TFA has also been detected in human blood (median 9,000ng/L, based on 17 detections), said the Zhi study. TFA can cross the placental barrier; it was found in 55% of cord serum samples (median concentration: 0.23ng/ml).

The presence of TFA in human blood has raised concerns about its potential health impacts, especially long term. An important 2023 study of Indiana households done at Emory University (page 20) found TFA in human blood at a median concentration of 6.0ng/mL, higher than for PFOA and PFOS; TFA was the only PFAS for which blood concentrations significantly correlated with both dust and water levels.

When it comes to TFA's presence in the body and its potential long-term effects, many scientists invoke the "precautionary principle," meaning that even without scientific certainty, there is sufficient evidence of risk to take preventive steps. On February 13, 2025, the Belgian village of Villers-le-Gambon invoked the precautionary principle in announcing that it was temporarily closing a spring that provides mineral water due to a high level of TFA (page 24).

The World Health Organization (WHO) and ECHA recommend applying "additional uncertainty factors" in setting guidelines for chemical pollution "in cases of major data gaps or suspected serious or irreversible effects, such as fetal malformations," noted PAN Europe in its wine study.

"We've never seen in recent history a chemical [TFA] that's accumulating in so many media at such a high rate," said Hans Peter Arp, Professor at the Norwegian University of Science and Technology and Technical Expert at the Norwegian Geotechnical Institute. "I'm afraid the impact on humans and the environment won't be recognized by scientists until it is too late."

Arp is one of the authors of a major study on TFA that characterizes it as a "planetary boundary threat" (page 43). The study stated that, even at present levels of understanding "there are more than sufficient data to conclude that TFA poses a risk to humans and the environment." What remains less clear, it added, "are the thresholds where irreversible effects on local or global scales occur."

Meanwhile, the study added, the uptake of HFOs could cause emissions of TFA to increase by orders of magnitude in the coming years. Transitioning away from TFA and its precursors – such as by adopting natural refrigerant-based systems – "is the most effective way of safeguarding future generations from this planetary boundary threat," it said.

Regulating f-gases and TFA as PFAS

On the regulatory front, the U.S. Environmental Protection Agency (EPA) has taken the position that f-gases and TFA don't fall under the definition of PFAS, contrary to the findings of the OECD and scientists worldwide. In an email to ATMOsphere, the EPA's Office of Pollution Prevention and Toxics (OPPT) said it wants to "focus on substances most likely to be persistent in the environment, and resemble PFOA, PFOS, and GenX." By that standard, TFA should be included.

However, at the state level, there has been movement to regulate f-gases and TFA as PFAS. Maine has enacted a law banning f-gas refrigerants in 2040, including possible action on TFA in 2032, with exceptions for cases of "currently unavoidable use" (page 57).

Minnesota, which passed one of the most aggressive PFAS laws in the U.S. in 2023, is engaged in rulemaking to establish a process to determine whether PFAS refrigerants and other products are "essential" to avoid prohibition in 2032 (page 59). Minnesota has also initiated a toxicity review of trifluoroacetate (page 61). But in California, the most populous state, the legislature recently decided to exclude f-gases and TFA from its latest PFAS law.

In Canada, the government is collecting feedback on its proposal to regulate PFAS as a class, excluding fluoropolymers but including HFOs (page 63).

The biggest regulatory effort is being undertaken by the EU, as the ECHA evaluates PFAS proposals from five countries to restrict PFAS as a class, including f-gases and TFA (page 66). ECHA is looking at regulating very persistent and mobile substances like TFA for which chronic exposure alone a concern.

ECHA has also started its consultation and expert evaluation of the German proposal to classify TFA as reproductively toxic under the EU's classification, labelling and packaging (CLP) regulation (page 40).

In the meantime, several European countries have issued guidelines for acceptable levels of TFA in drinking water and food. Germany has set a health-based guideline value of 60mcg/L for TFA in drinking water and a "precautionary measure" of 10mcg/L. Denmark has set a TFA drinking water threshold of 9mcg/L while the Netherlands, based on its rats study, has listed the lowest drinking water advisory, 2.2mcg/L, which is the average TFA concentration found in U.K. rivers in the Fidra study.

In the EU as a whole, the recast Drinking Water Directive will limit "PFAS total" (including TFA) in drinking water to 0.5 µg/L as of January 12, 2026; member states can use this or a 0.1mcg/L limit for 20 specific PFAS, not including TFA.

EurEau, which represents Europe's drinking and wastewater sector, stated in a position paper that the EU's PFAS total parameter "is inadequate for TFA" and that "a specific TFA limit value in drinking water should be set based on health-derived criteria." At the same time EurEau noted that if TFA becomes classified as a "relevant metabolite" under the Drinking Water Directive, member states would have to impose a limit of 0.1mcg/L for TFA, which would be difficult for drinking water suppliers to meet.

In other guidelines for TFA ingestion, the Netherlands have come up with an acceptable daily intake (ADI) for TFA of 0.32mcg/kg bw (body weight)/day, and Flanders has one at 2.6mcg/kg bw/day; these are far lower than the ADI of 50mcg/kg bw/day proposed by the European Food Safety Authority (EFSA) in 2014. But all of these are well below the amount of TFA found on average in breads and cereals in the PAN Europe study (119mcg/kg).

The EFSA is reviewing the toxicological values for TFA in cooperation with the ECHA at the request of the European Commission.

Chemical industry arguments

The chemical industry has aggressively defended the use of HFOs like HFO-1234yf and downplayed the threat potentially posed by TFA, though the industry does not have a good safety track record when it comes to other PFAS and previous generations of f-gases.

A frequent claim made by the chemical producers is that TFA is a naturally occurring substance. "TFA has been present in our oceanic environment for thousands of years, and evidence suggests that the majority of TFA comes from natural processes," said a statement recently posted by Refrigerants Australia, an industry group that includes HFO producer Chemours. However, the scientific community has emphatically rejected that claim. For example, a 2021 study by Canadian researchers determined that there are "no compelling scientific arguments" to support the existence of naturally formed TFA.

Even granting the presence of TFA from industrial sources, the chemical industry contends that TFA "does not bioaccumulate, bio-magnify, and is non-toxic at levels seen in the environment," said Refrigerants Australia.

The fluorochemical Industry points to the UN Environment Programme (UNEP) and its 2022 Environmental Effects Assessment Panel (EEAP) report. The report says that TFA is not bioaccumulative, is "not expected to pose significant risk to humans or the environment at the present time" and "is unlikely to cause adverse effects out to 2100." The report does not comment on the contribution of pesticides and other precursors to TFA since they don't fall under the purview of the Montreal Protocol.

The report noted that deposition of TFA from HFOs and HCFOs will result in greater concentrations near the locations of release. "This is unlikely to present a risk to humans or the environment in these locations but changes in concentration in surface water (or soil) would respond rapidly to releases," it said, adding, "Monitoring of the environment for residues of TFA would provide an early warning if trends in concentration indicate rapid increases."

The chemical industry also addressed the environmental deposition of TFA in an October 2021 study funded by the Global Forum for Advanced Climate Technologies (globalFACT), which represents f-gas producers Chemours, Honeywell, Arkema and Koura (and equipment manufacturer Daikin). The

study concluded that "with the current knowledge of the effects of TFA on humans and ecosystems, the projected emissions through 2040 would not be detrimental." But the study also acknowledged that "the major uncertainty in the knowledge of the TFA concentrations and their spatial distributions is due to uncertainties in the future projected emissions."

Scientists respond

The chemical industry's contentions about the safety of TFA have been challenged by the scientific community.

Similarly structured, longer-chain PFAS like PFOA are bioaccumulative in organs like the liver and linked to cancer. TFA may be less bioaccumulative than PFOA in the liver but its presence in the blood over a long period of time still raises red flags, noted Shira Joudan, Assistant Professor of Analytical Environmental Chemistry at the University of Alberta in Edmonton, Canada. "We know that [TFA is] not going to be an acute, short-term exposure. It's going to be one of these long-term exposures at the lower concentrations that need to be studied in toxicity studies" (page 37). Already, Germany's environmental authorities have indicated reproductive toxicity from TFA.

Moreover, bioaccumulation has been seen in various plants, including crops, noted the study calling TFA a "planetary boundary threat." The Emory University study of Indiana households said that TFA was reported to bind to protein fractions and lipids.

Asked about claims that TFA is not bioaccumulative, scientist Michael Kauffeld noted that the half time of TFA in the body is 16 hours. "So until everything is gone, it's like 32 hours. Can you live without drinking or eating for 32 hours? No, you can't, and that's why the concentration in your body is increasing all the time" (page 46).

Mindi Messmer, Senior Research Scientist for MedStar Health and former Member of the New Hampshire House of Representatives, believes TFA could be bioaccumulative. "I think there's enough information to show that your body is not going to discriminate between how many [carbon–fluorine] bonds there are, whether it's a PFOA or a TFA. As long as it has that C–F bond, it appears that the health effects are similar" (page 52).

In Michigan, a 2024 study of rainwater led by the Ecology Center found TFA to be the largest PFAS contributor in two out of three sample locations. TFA's "persistence and mobility and the greatly increasing concentrations found in the environment are all red flags that are enough to put the brakes on," said Gillian Zaharias Miller, Senior Scientist at the Ecology Center.

The Canadian government's assessment of TFA is that "given the potential for TFA to cause adverse effects and its ubiquitous presence in the environment and organisms alongside other PFAS, the potential for TFA to contribute to cumulative effects of PFAS in organisms is of concern" (page 63).

TFA Drinking Water Guidelines

0.5mcg/L EU (2026)

2.2mcg/L Netherlands

9mcg/L Denmark

60mcg/L Germany

10mcg/L Germany

Anna Reade, Senior Scientist and Director of PFAS Advocacy at the Natural Resources Defense Council (NRDC), stated at the 2025 ATMO America conference that there is "initial evidence for liver, immune, developmental, and reproductive effects for ultra-short chain PFAS like TFA and PFPrA [perfluoropropionic acid]."

Regarding whether TFA is bioaccumulative, "the problem is that there is a lot of TFA all around us all the time, and so we're being chronically exposed," Reade said. "What we found out is, when you expose animals to long term chronic exposure, that we find the same health effects as the long-chain [PFAS]. So [the absence of] bioaccumulation is not actually a protective factor anymore."

"We've never really come across a PFAS that we have studied well that has been shown to be safe," she said.

Eliminate TFA precursors

In assessing Germany's determination that TFA can be classified for reproductive toxicity, Andreas Hensel, President of its Federal Institute for Risk Assessment (BfR), noted, "The toxicological effect was only demonstrated in animal models at TFA concentrations significantly higher than those found in the environment." Rabbits in the toxicology studies were given 750mg/kg bw/day for 23 days; that is more than 6,000 times as much TFA found on average in bread and cereal products in the PAN Europe study (119mcg/kg), assuming one portion per day.

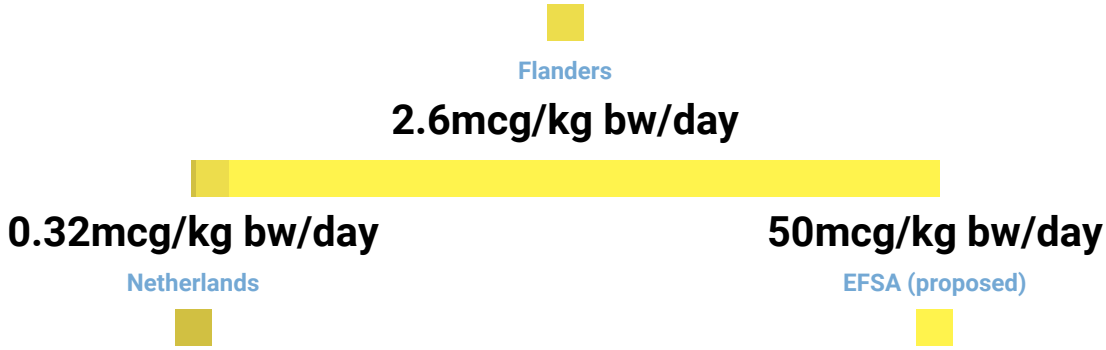
"Therefore, health impairments are currently not expected from consuming water or food contaminated with TFA," Hensel said. However, he added, "The new classification is an important step in preparing further measures to ensure this remains the case in the future."

In light of the evidence of potential harm from the growing proliferation of TFA worldwide, it's clear that a global effort is needed to eliminate, where possible, the precursors of TFA like HFO-1234yf and other f-gases, as well as TFA-generating pesticides and pharmaceuticals. Effective alternatives to these precursors, such as natural refrigerants, are widely available.

In addition, a number of other steps are needed for TFA, including continuous environmental monitoring, detection improvements, toxicological studies, water treatment research and regulatory limits on TFA. Polluters should be required to pay for clean-up.

The following articles provide an overview of other recent developments in the understanding and regulation of TFA and its HFO precursors.

TFA Acceptable Daily Intake



Source (2025): Global 2000, "The Forever Chemical in Our Daily Bread: The worrying rise of TFA in cereal products"

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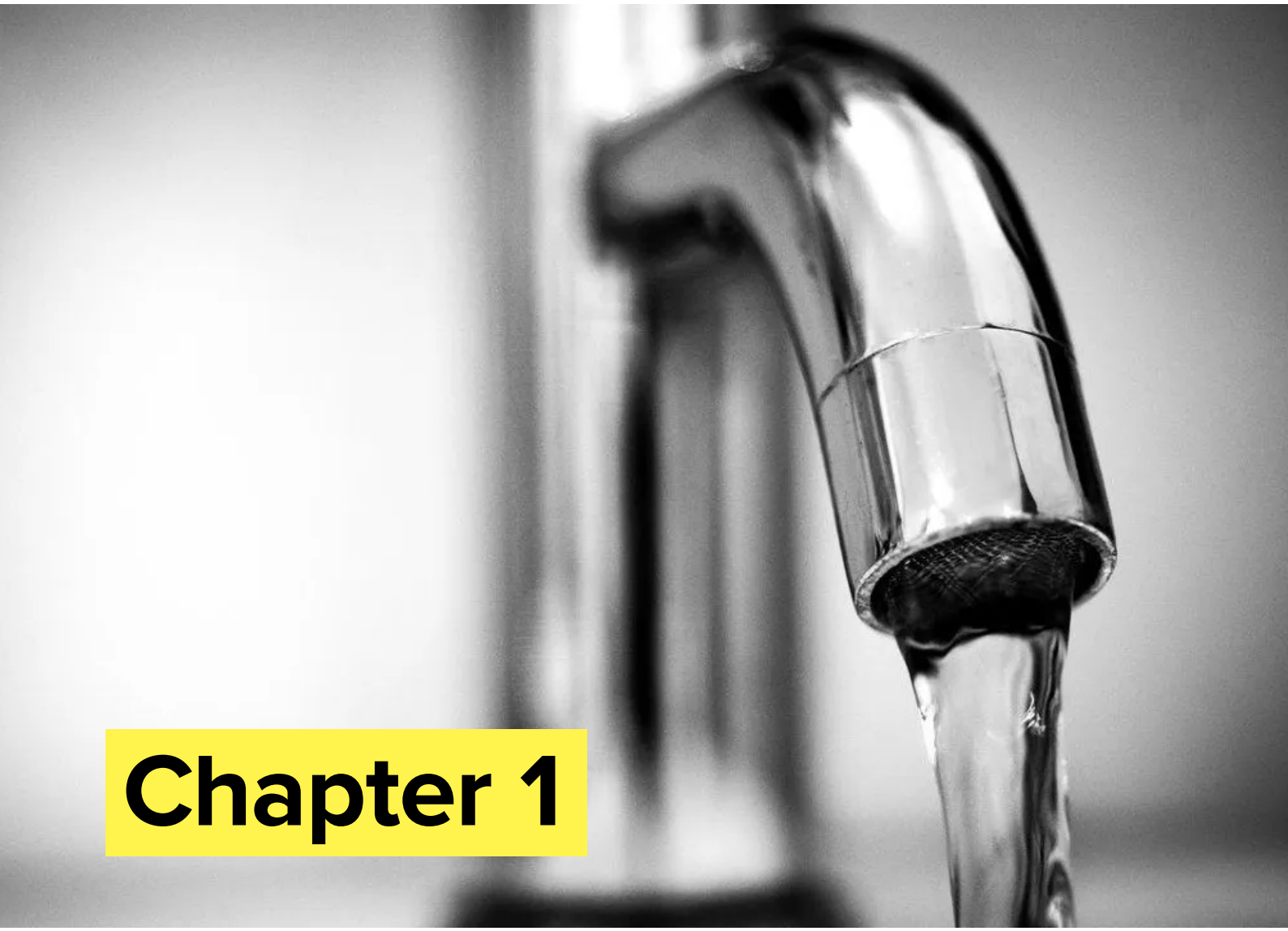


Chapter 1

The Presence of HFOs and TFA in the Environment

Study Finds HFO Byproduct TFA in Dust, Drinking Water and Blood in U.S. Households

Researchers from U.S. and China say TFA is abundant in the indoor environment and in humans and this warrants further research on potential adverse health effects.

A 2023 study of households in the U.S. state of Indiana found TFA in samples of dust, drinking water, human blood serum, and, to a lesser degree, urine.

The study said it was the first to report "a substantial prevalence" of TFA and another similar substance in the U.S. indoor environment and the general population and possibly the first to correlate the presence of TFA in drinking water with TFA in blood samples.

The study, "Elevated Levels of Ultrashort- and Short-Chain Perfluoroalkyl Acids in US Homes and People," was published by the American Chemical Society in *Environmental Science & Technology*. Its author is Stephanie M. Eick of the Gangarosa Department of Environmental Health, Rollins School of Public Health at Emory University in Atlanta, Georgia; its co-authors are Amina Salamova, Eick's colleague at Emory University, and Guomao Zheng of the School of Environmental Science and Engineering, Southern University of Science and Technology in Shenzhen, China.

The study characterized TFA as being part of PFAS. In particular, TFA is described as an ultrashort-chain PFAA (perfluoroalkyl acid), with two carbon atoms (one fully fluorinated). Longer (eight-carbon) PFAA include PFOA and PFOS, two of the most regulated PFAS in the world.

In this study, 47 PFAAs and their precursors were measured in paired samples (324 in total) of dust, drinking water, blood and urine collected in 2020 from 81 Indiana residents. Ultrashort- (with two or three carbons) and short-chain (with four to seven carbons) PFAAs were found to be the most abundant and constituted on average 69–100% of the total PFAA concentrations.

In particular, TFA and another ultrashort-chain PFAA, perfluoropropanoic acid (PFPrA) were the predominant PFAAs in dust, drinking water and blood. Moreover, a significant positive correlation was found between TFA in dust or water and that in blood, "suggesting dust ingestion and/or drinking water consumption as important exposure pathways."

This study concludes that "ultrashort- and short-chain PFAAs are now abundant in the indoor environment and in humans and warrants further research on potential adverse health effects of these exposures."

The most abundant PFAA

The study found TFA in 84% of the dust samples. It was "by far the most abundant PFAA" with a median concentration of 220 ng/g, contributing 75% to the total PFAA concentration in dust.

These findings were similar to those from a study from China (with sampling in 2017) that reported TFA and PFPrA as the predominant PFAAs in indoor dust with concentrations of 116–470 ng/g and 35–152 ng/g, respectively.

In drinking water TFA was also found to be the predominant PFAA (median concentration of 79 ng/L) with a detection frequency of 95% and an 84% contribution to the total PFAA concentration. The levels of TFA in drinking water were consistent with those detected in drinking water from the United States collected in 1994–1995 (41–150 ng/L), but lower than those reported from China in 2012 (median 155 ng/L).

The study cited HCFCs and HFCs, as well as fluorinated pesticides and pharmaceuticals, some plastics (such as polytetrafluoroethylene) and aqueous film-forming foams as precursors of TFA in the environment that "may at least partially explain the abundance of TFA in dust and drinking water found in the current study." However, the study added that consumption of drinking water and dust intake contributed only about 20% to the total PFAA levels in blood, "suggesting other exposure pathways for these compounds."

As with the dust and drinking water samples, TFA was the predominant PFAA in blood serum samples (detection frequency 74%, median of 6.0 ng/ml) and constituted 57% of the PFAA concentration. These findings were consistent with those from the China study, which reported TFA and PFPrA in serum at median concentrations of 8.5 and 0.48 ng/mL, respectively.

The study noted that protein binding affinity – TFA was reported to bind to proteinaceous fractions and lipids in biota – "could be a driving force behind the bioaccumulation mechanism of the ultrashort- and short-chain PFAAs in human blood."

In urine TFA was detected in only 31% of the samples but was found at high concentrations in some of the samples, with its maximum concentration reaching 290 ng/ml.

Notably, TFA was the only PFAA for which the blood serum concentrations significantly correlated with both dust and water levels. "To the best of our knowledge, this is the first report of significant correlations between the concentrations of the ultrashort- and short-chain PFAAs in drinking water and serum samples collected from the general population of the United States," the study said. "These associations suggest that consumption of drinking water may be a significant exposure pathway for these shorter-chain PFAAs, even in the general population with no known PFAS-contaminated sites nearby."

The study called the high abundance of ultrashort- and short-chain PFAAs in drinking water from municipal sources "a potential environmental health problem that should be taken into consideration in assessing the risk of exposure to PFAS in the general population."

In addition, a significant positive relationship between the TFA concentrations in dust and those in serum "indicates that dust intake could also be an important exposure pathway for this compound." By one estimate, two-thirds of household dust comes from outdoors.

The authors acknowledged "several limitations," including a small sample size and a cohort limited in diversity and geographic coverage, adding, "We were not able to determine the contribution of diet or biotransformation of PFAA precursors or fluorinated pharmaceuticals to the total body burden of ultrashort- and short-chain PFAAs." Thus, it adds, the reported levels of PFAS "should be interpreted with caution."

Nonetheless, the study said that its findings "warrant urgent research focused on the ultrashort-chain PFAAs to elucidate their sources, potential human exposure pathways, and the effects of these exposures on human health."

'Pretty significant'

Heidi Pickard, a PFAS scientist and Lead Consultant at environmental consultancy Ramboll, who spoke in June 2023 at ATMOsphere America about TFA in the environment, called the TFA study's findings "pretty significant," adding that it will be more useful "once additional studies replicate these findings to confirm these levels of TFA are found in other human serum to make sure that it's not an artifact of contamination or analytical limitations."

But she agreed with the study that its findings increases the need to "assess potential human health impacts from the ultra-short chain PFAS. If they're being detected in serum at these levels, then they must have some affinity for binding to proteins or lipids, which means there's potential for them to have impacts."

"A request for comment from Honeywell about the Emory University study did not receive a response."

Heidi Pickard, PFAS scientist

Rainer Lohmann, Professor at the University of Rhode Island, speaking at the ATMOsphere America Summit 2025.

ATMO America: Researchers Find TFA in Two-Thirds of Drinking Water Samples in Rhode Island

TFA, a byproduct of f-gases, was the dominant PFAS with concentrations up to 2.4mcg/L among five ultrashort-chain chemicals.

Researchers at the University of Rhode Island have detected TFA in 66% of 320 drinking water samples collected in the U.S. state, with median concentrations of 580ng/L and a maximum concentration of 2,400ng/L (2.4mcg/L).

The findings were reported by Rainer Lohmann, Professor at the University of Rhode Island's Graduate School of Oceanography and Director of the University's Superfund research program STEEP (Sources, Transport, Exposure & Effects of PFAS). Lohmann was a member of the U.S. Environmental Protection Agency (EPA) Board of Scientific Counselors from 2017 to 2023 and serves as editor of the *Environmental Toxicology* and *Chemistry Journal*.

Lohmann shared the research findings during a panel discussion on PFAS at the ATMOsphere (ATMO) America Summit 2025, held June 11 and 12, 2025, in Atlanta, Georgia. The conference was organized by ATMOsphere, publisher of this report.

While exposure to long-chain PFAS like perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS) have been linked to cancer and other adverse health effects, the toxicity of ultrashort-chain PFAS like TFA is "unclear," said Lohmann. But the finding of hundreds of nanograms per liter of TFA was "a large number – enough to cause health concerns if it was PFOA or PFOS."

> *"It is a concerning trend if everything is going up."*
>
> ***Rainer Lohmann, Professor at the University of Rhode Island's Graduate School of Oceanography***

In addition to TFA, Lohmann and his team looked for the presence of other ultrashort-chain PFAS, including perfluoropropionic acid (PFPrA), trifluoromethanesulfonic acid (TFMS), perfluoroethanesulfonic acid (PFEtS) and perfluoropropanesulfonic acid (PFPrS). All but PFPrS were detected, though TFA had by far the highest concentrations.

Lohmann attributed the source of TFA in Rhode Island drinking water to "mostly f-gases" that form TFA in the atmosphere as well as to direct production and the breakdown of polyfluorinated alkyl substances such as fluorinated pharmaceuticals. It also comes from the breakdown of certain fluorinated pesticides and other sources. Still, he said that additional work on TFA would include identifying "potential point sources" and links to other PFAS. It's also not apparent where the other ultrashort-chain PFAS in the samples originated.

TFA dominates

While TFA had a median concentration of 580ng/L in 66% of the 320 samples, the second most detected chemical, PFPrA (similar to TFA except with one additional fluorinated carbon atom), had a median concentration of 11ng/L in 35% of the samples. TFMS's median was just 2.8ng/L in 40% of samples, while PFEtS was seen in only 1%.

The highest concentration for TFA, 2,400ng/L, dwarfed the next-highest maximum concentration, 96ng/L for PFPrA. Lohmann concluded that "TFA dominates PFAS in water in the mcg/L range," adding that the EPA targets long-chain PFAS like PFOA and PFOS at 4ng/L. He noted that ultrashort-chain PFAS are found in water sources around the world, but TFA "is always the highest concentration."

Lohmann pointed out that the range of TFA in Rhode Island drinking water (no detection to 2,400ng/L) was similar to that found in surface or ground water elsewhere in the world, such as the San Francisco Bay Area (290 to 2,800ng/L), Denmark (0 to 1,500ng/L) and Germany (300 to 3,000ng/L).

He also referenced data showing "a strong increase in TFA in different matrices" – not just water but biological sources like plants, adding, "it is a concerning trend if everything is going up." Another study, of Denmark groundwater, underscored this trend by finding that "the younger the groundwater, the higher the TFA," he said.

The 320 drinking water samples analyzed by Lohmann and his team came from a variety of water sources in Rhode Island collected between April 2024 and February 2025. These range from "the really big drinking water providers of Providence to small wells that serve schools somewhere in the not-so-urban areas of the state" and from Massachusetts rivers, he said. The researchers analyzed the samples in a SCIEX X500 QToF liquid chromatography mass spectrometry system.

Government-supplied samples

The samples were provided by Rhode Island government agencies. "We asked them whether there was a chance they could share with us some of the drinking water samples that Rhode Island collects to measure PFAS, and it turns out that they were more than happy [to do so]," Lohmann said.

Rhode Island, the smallest U.S. state in geographic area, has a shallow aquifer in most places, with recharge times of typically a year or so, but there are also some much deeper wells, said Lohmann. The state tests for PFAS because of its own rules and because the EPA "likes these samples on a fairly regular basis," he said.

However, given that the human effects at this level of TFA are not known, Lohman does not expect the Rhode Island government "to lead the charge on regulating it, just based on the history of my small state." On the other hand, he added, if enough other New England states push something forward, Rhode Island could follow them. "That's what typically seems to happen."

Lohmann was part of a group of 20 PFAS scientists who recently published a statement supporting the OECD definition of PFAS that includes f-gases and TFA and refuting an effort to change that definition. That definition says that with a few exceptions, any chemical with at least one perfluorinated methyl group (–CF3) or one perfluorinated methylene group (–CF2–) is a PFAS. This includes thousands of compounds, hundreds that are produced and around 10 that are monitored.

TFA has been detected in other parts of the U.S. A 2024 study of PFAS in rainwater in Michigan found TFA to be the largest contributor in two out of three sample locations and one of the largest in the third location. A 2023 study of households in Indiana found TFA in samples of dust, drinking water, human blood serum and, to a lesser degree, urine.

Villers-le-Gambon, Belgium; image by Jean-Pol Grandmont, via Wikimedia Commons

Belgian Village Shuts Down Mineral-Water Spring Due to High TFA Level

Villers-le-Gambon is one of the first governmental authorities to act on TFA, a byproduct of certain f-gases and pesticides.

The Belgian village of Villers-le-Gambon announced on February 13, 2025, that it was temporarily closing a spring that provides mineral water due to a high level of TFA.

This is one of the first times that a governmental authority has shut down a water supply due to the presence of TFA, which has been proliferating globally in surface and drinking water, soil, crops, beverages and human blood.

"In accordance with the application of the precautionary principle, we have taken the decision to temporarily close the spring of Villers-le-Gambon (Fontaine de Moisny)," the village said in a statement. During the closure the village plans to "carry out additional analyses to identify the origin and impact of the TFA" and "assess the measures to be put in place to ensure water quality."

The village stressed that drinking water distributed by the public network of Villers-le-Gambon "does not exceed the threshold [for TFA] and can be consumed safely."

Villers-le-Gambon is part of the municipality of Philippeville in the Walloon (French-speaking) part of Belgium.

An analysis of mineral water from groundwater and deep aquifers in Europe revealed that Villers-le-Gambon had the highest TFA concentration, 3.4mcg/L (3,400ng/L), which exceeded a limit (2.2mcg/L) set by a local authority, the Belgian Independent Scientific Committee (ISC). The analysis was done by the Pesticide Action Network (PAN) Europe, which has also found TFA in surface water and in drinking water throughout Europe.

PAN Europe targeted for analysis mineral water at 19 locations in Europe. TFA measurements were taken during the summer and the fall of 2024, with the latter results confirming the former in all cases. The samples encompassed two mineral water brands from France, four from Belgium, one from the Netherlands, one from Luxembourg, one from Hungary and the five best-selling mineral water brands from Austria. The Bund für Umwelt und

Naturschutz Deutschland (BUND) also provided PAN Europe with the analysis results of five mineral and spring waters from Germany.

Nine of the locations (including two that provide spring water) did not contain quantifiable TFA residues, but the others showed TFA levels ranging from 52 to 470ng/L, except for Villers-le-Gambon, which had by far the highest levels at 3,400ng/L in the fall reading and 3,200 in the summer. In its latest publication PAN Europe identified most of the mineral water companies associated with each measurement, which was not done in the original publication.

Message from the bottler

The upper limit for total PFAS, including TFA, of 0.5mcg/L (500ng/L) proposed in the EU Drinking Water Directive is due to come into force in 2026, although it will not be implemented by all Member States. But PAN Europe stated that, each of the mineral waters tested – including the one at Villers-le-Gambon with the highest measured contamination of 3,200/3,400ng/L – "complies with most of the current human health guideline values set by various authorities in the EU, even with a high daily consumption of 2L [0.5gal] calculated for a 60kg [132lb] adult."

Village authorities met with Villers Monopole, the local bottler of mineral water in Villers-le-Gambon, on February 17, and released a message from the company reassuring residents that its mineral water is "fit for human consumption." (There is no TFA standard for bottled water in Belgium, according to the French-speaking public broadcaster RTBF.)

The company said it supports measures to establish a standardized methodology to measure the presence of TFA and participates in the analyses and scientific work carried out by the trade group Natural Mineral Waters Europe "to share and deepen knowledge on this emerging topic."

In addition, Villers Monopole said it "supports the request of the European bottled water industry for the reduction and gradual elimination of TFA-based products and applications, to protect and preserve the quality of water resources."

Another study of TFA in Belgian drinking water found it the Dutch-speaking northern Belgium region of Flanders, according to a report in the Dutch-speaking public broadcaster VRT last November. De Watergroep, the largest drinking water company in Flanders, recorded in TFA levels of 8.3mcg/L in Zillebeke and more than 7mcg/L in Dikkebus, De Blankaart and Roksem, as well as in lower concentrations elsewhere. Those levels were below the recently established health advisory value of 15.6mcg/L for drinking water. An earlier study revealed TFA in the drinking water in Belgium's capital city of Brussels.

De Watergroep assured its customers that "we continue to strictly monitor the amount of TFA in drinking water and ensure that it remains below the maximum standard at all times." The company offers customers the opportunity to view the origin and composition of their drinking water, with TFA expected to be added to the analysis in the spring of 2025.

Meanwhile, PAN Europe calls for a ban on PFAS pesticides, f-gases and other precursor substances that create TFA in the environment.

To that end, the NGO believes "it is essential to break the silence surrounding TFA and make all information – even if it includes uncomfortable truths – publicly accessible," adding, "Collecting facts, critically evaluating them according to scientific principles, and transparently informing the public are the most significant contributions we, as independent environmental organizations, can make to addressing and reducing global TFA contamination."

> *"In accordance with the application of the precautionary principle, we have taken the decision to temporarily close the spring of Villers-le-Gambon."*
>
> ***Announcement by Villers-le-Gambon, Belgium***

Image by Mabel Amber, from Pixabay

Researchers Find Growing Levels of TFA in Danish Groundwater Over 60 Years

The study looked at concentrations of TFA – linked to f-gas degradation – in 113 Danish groundwater-monitoring wells.

Researchers identified increasing concentrations of trifluoroacetate in Denmark's groundwater over the last 60 years, according to a 2024 study.

The study – "A 60-Year Increase in the Ultrashort-Chain PFAS Trifluoroacetate and Its Suitability as a Tracer for Groundwater Age" – was published on September 4 in *Environmental Science & Technology Letters*. It received funding from the Danish Environmental Protection Agency and the Danish Groundwater Monitoring Program.

Trifluoroacetate (abbreviated as TFA in the study and in this article) is formed when the highly acidic trifluoroacetic acid (also abbreviated as TFA elsewhere) mixes with water.

In this study, the researchers – Christian Albers, Senior Research Scientist for the Geological Survey of Denmark and Greenland; and Jürgen Sültenfuss, Research Scientist at the University of Bremen, Germany – tied the concentrations of TFA to different time periods across 113 Danish groundwater-monitoring wells, a source of drinking water. The time periods were derived from the tritium-helium dating method, which used the half-life of tritium (about 12.3 years) to estimate the age of samples. (Tritium is a radioactive isotope of hydrogen.)

"Here, we show that the concentration of TFA in 113 Danish groundwater-monitoring wells is strongly correlated to the groundwater recharge year, as derived from the tritium-helium dating method," said the study abstract.

The recharge year is the estimated year when groundwater was last replenished in an aquifer, calculated by measuring the amount of tritium and helium-3 present in a water sample. The researchers suggest that the TFA level by itself could be a simpler way of estimating the age of groundwater.

According to the abstract, TFA was not detected in tritium-free groundwater recharged before 1960, while it was detected at low concentrations in most samples recharged between 1960 and 1980. Groundwater recharged after 1980 had at least 0.1 mcg/L of TFA, and the concentration increased with time.

More details on the study were provided in an article in *SciTechDaily*. According to the article, the following TFA levels were found in the wells:

- From 1960 to 1980: 0.06 ppb (0.06mcg/L) on average.
- From 1980 to 2000: 0.24 ppb (0.24mcg/L) on average.
- From 2000 to the 2020s: 0.6 ppb (0.6mcg/L) on average.

The study suggests that the growth in TFA in groundwater could be linked to the increasing use of HFO-1234yf in recent years as a substitute for HFCs. "Oxidation of certain fluorinated gases in the atmosphere is considered the primary source of TFA in the terrestrial environment, and the combined change in gas type and increased usage would therefore expectedly lead to an increased TFA burden over the last few decades," said the study abstract.

The European Partnership for Energy and the Environment (EPEE), which includes chemical producers among its members, did not respond to a request for comment on the groundwater study.

"Oxidation of certain fluorinated gases in the atmosphere is considered the primary source of TFA in the terrestrial environment, and the combined change in gas type and increased usage would therefore expectedly lead to an increased TFA burden over the last few decades."

From the study "A 60-Year Increase in the Ultrashort-Chain PFAS Trifluoroacetate and Its Suitability as a Tracer for Groundwater Age"

Image by Bruno from Pixabay

Swedish Researchers Find Elevated Levels of TFA in Juices and Kids' Purées

Health impacts are uncertain, but data suggest children's intake of orange juice and some purées could result in 'significant exposure' to TFA.

Swedish researchers in 2024 found "elevated levels" of trifluoroacetic acid (TFA), an HFO byproduct, in juices and drinks – especially orange juice and some hand-squeezed oranges – as well as in fruit purées for small children.

The researchers did not draw any conclusions in regard to potential health impacts. But the levels detected often exceeded drinking water limits for TFA in some European countries and intake calculations for children suggest orange juice and some purées could result in "significant exposure."

The results were reported in a white paper – "Trifluoroacetic acid (TFA) and trifluoromethane sulphonic acid (TFMS) in juice and fruit/vegetable purées," – authored by Patrick van Hees, Patrik Karlsson, Ludmila Bucuricova and Helena Olsman of the PFAS Competence Centre, which is part of Eurofins Food & Feed Testing in Lidköping, Sweden, and Leo Yeung, Researcher in Chemistry at the Man-Technology-Environment (MTM) Research Centre, Örebro University in Sweden.

The researchers believe their work provides the first overview of TFA and TFMS in juice-based drinks and fruit purées for children.

The paper regards TFA as belonging to the category of PFAS, so-called "forever chemicals" that are used in consumer products and in some cases have been linked to cancer and other diseases. The researchers use the scientifically accepted PFAS definition established by the OECD, which encompasses substances that have at least one fully fluorinated methyl or methylene carbon atom, such as TFA. The paper also studied trifluoromethane sulphonic acid, another "ultrashort PFAS," used in lithium-ion batteries.

The paper noted that "one important source" of TFA is phototransformation (hydrolysis in the atmosphere) of refrigerants such as HFO-1234yf, followed by absorption in rainfall. Other sources include the combustion of fluoropolymers, effluents from landfills and treatment plants and the degradation of some pesticides.

Study findings

The Swedish study looked at 37 samples of fruit and vegetable-based juices and drinks and nine samples of fruit/vegetable purées for small children. Both conventional and organic products were analyzed, with organic items having TFA levels sometimes comparable to conventional ones. The products were purchased at local supermarkets in Lidköping from February through July of 2024; the country of origin of the fruit included Brazil, Italy, Spain and Greece for orange juice and Poland and Greece for apple juice.

The highest concentrations of TFA were observed in orange juice (including freshly squeezed oranges) with significant levels (greater than the limit of quantification) found in 13 out of 21 samples. The average of the 13 was 34mcg/L ± 20mcg/L. For apple juice, significant levels were discovered in nine samples with an average of 6.2mcg/L ± 2mcg/L. The tomato juice showed a value between that of apple and orange juice, as did the mixed-fruit juice.

Among the purées, significant levels of TFA were found in two samples: an organic mix of apple, pear, banana and lemon (approximately 30mcg/L) and a conventional mix of peach, apple, banana and lemon (approximately 28mcg/L). "It is not clear why two samples had significantly higher TFA levels than the others, which warrants further investigation," the paper said. No analysis of pure ingredients was performed on the purées, so no conclusions of relative contributions from the different fruits and vegetables could be made.

"I wasn't surprised that we found TFA in juice and purée, as we have found the substance everywhere when we have analyzed water, even in drinking water," said Yeung in an article on Örebro University's website on September 5. "I was somewhat surprised that the average [orange juice] levels were at 34,000 ng/L [3.4mcg/L], with some samples reaching over 80,000 ng/L [8mcg/L], which was higher than my expectations." The paper noted that these TFA levels are "realistic given the increased knowledge of TFA contamination and uptake into plants."

The Netherlands, Denmark and Germany have all set drinking water limits for TFA. All product samples in the Swedish study with measurable TFA concentrations exceeded the drinking water limit set by the Netherlands (2.2mcg/L), and many surpassed the Denmark limit (9mcg/L); one freshly squeezed orange juice with 84mcg/L passed the German limit (60mcg/L). The paper cited a Dutch methodology whereby a child weighing 10kg (22lbs) could drink 92ml (3.1oz) of orange juice (with an average TFA concentration of 34mcg/L) or about one pouch of the highest TFA purée (30mcg/L) per day to reach the tolerable daily intake limit.

These findings "may imply potential health effects," said Yeung. "As parents, we don't need to be overly concerned about the results just yet. However, to better understand the situation, we should demand more information about baby food."

The European Fluorocarbons Technical Committee (EFCTC), which represents f-gas producers in Europe, did not respond to a request for comment on the Swedish study.

"As parents, we don't need to be overly concerned about the results just yet. However, to better understand the situation, we should demand more information about baby food."

Leo Yeung, Researcher in Chemistry, Örebro University

The Danube River, a source of drinking water, in Bratislava, Slovakia. Image by Marc Ryckaert (MJJR), CC BY 3.0, via Wikimedia Commons.

Study Puts Annual Cost of Removing PFAS from the Environment in Europe, Including TFA, at €100 Billion

The Forever Lobbying Project looks at two remediation options – a legacy scenario and an emerging scenario that includes f-gas byproduct TFA.

The cost of removing PFAS from the environment in Europe, including "emerging" PFAS like f-gas byproduct TFA, would be €100 billion ($108 billion) per year, or €2 trillion ($2.2 trillion) after 20 years, according to the Forever Pollution Project published by a group of journalists and scientists.

The Forever Pollution Project, which was launched in 2022 to track the proliferation of PFAS across Europe, comprises two parts: the Map of Forever Pollution (published in February 2023) and the Forever Lobbying Project (published in January 2025). The latter describes lobbying strategies employed by the chemical industry to exempt PFAS from regulations and provides the data on PFAS remediation costs across all 27 EU countries and four non-EU countries (U.K., Norway, Switzerland and Iceland).

The Forever Lobbying Project was initiated in 2024 by Stéphane Horel of French newspaper *Le Monde*; Luc Martinon, a data journalist in France and Germany; and Sarah Pilz, a freelance journalist in Germany. PFAS remediation cost estimates were handled by Ali Ling, Assistant Professor of Civil Engineering at the University of St. Thomas in St. Paul, Minnesota; Hans Peter Arp, Professor of Environmental Chemistry at the Norwegian University of Science and Technology (NTNU), Raphaëlle Aubert, Data Journalist with *Le Monde*; and Eurydice Bersi, Investigative Journalist with Reporters United. Arp is also one of the authors of a study describing TFA as a planetary boundary threat.

> *"It's meant to say [removing PFAS from the environment] costs too much; therefore, we should be reducing it upstream."*
>
> ***Ali Ling, the University of St. Thomas***

The Forever Lobbying team did two cost estimates for PFAS remediation in Europe. In the "legacy" scenario, PFAS emissions cease immediately, and only legacy PFAS – long-chain PFAS such as PFOS and PFOA that have already been regulated – are removed, for an estimated cost of about €4.8 billion ($5.2 billion) per year, or €96 billion ($104 billion) over 20 years.

In the "emerging" scenario, emissions continue, and remediation efforts also address short-chain and ultra-short chain PFAS like TFA, which are difficult to remove from the environment. Estimated costs then rise to over €100 billion annually, or around €2 trillion over 20 years, though these costs could theoretically extend "in perpetuity," said the Forever Lobbying Project. "These calculations do not include a wide variety of unknown costs due to a lack of knowledge and data sources, meaning they are underestimated," the Project noted. "Ongoing innovations have the potential to lower the remediation costs, but the most economical option is to lower [PFAS] emissions."

The emerging scenario is thus meant to reflect ongoing, annual remediation costs "in the case that effective restrictions and source control are not implemented," particularly for the more challenging to remediate emerging PFAS. This estimate considers costs to remove ultra-mobile TFA and other short and ultra-short chain PFAS from drinking water and other media such as soil, which is technically possible (via reverse osmosis, followed by supercritical water oxidation of brine, for example) but comes at a high price. (Researchers from the University of Illinois, Urbana-Champaign have developed an electrochemical process designed to economically remove up to 86% of TFA as well as long-chain PFAS from water intended for human consumption.)

Because TFA removal and destruction have not been widely studied or proven for landfill leachate or wastewater effluent, the estimated costs reflect "targeted" TFA removal, not "guaranteed" TFA removal in these media, the Project said.

Generational decision

The European Fluorocarbons Technical Committee (EFCTC), which represents f-gas producers, did not respond to a request for comment on the PFAS Lobbying Project.

Ling of the University of St. Thomas has done two previous cost estimates for PFAS remediation. One was for the Minnesota Pollution Control Agency in 2023, which determined the cost of removing six long-chain PFAS to be "millions of dollars per pound of PFAS," she said in a LinkedIn post. The other was a global estimate in 2024, which concluded that the current costs to remove and destroy the total PFAS mass released annually into the environment would likely exceed the global GDP of $106 trillion (€98 trillion). The latter estimate did not look specifically at TFA.

Regarding the European remediation analysis, Ling wrote on LinkedIn that the key difference between the two cost scenarios is "what this generation decides to do about PFAS." The emerging option would be to "continue to make, use, and emit PFAS, passing down whatever legacy they hold (and potentially €100 billion/year in cleanup costs) to future generations." Alternatively, Europeans could enact policies and support industries to phase out as much PFAS as possible. "In that case, we can pay the cheaper, legacy cost for cleanup, plus the costs of phasing out PFAS. (These have yet to be estimated, but I'm pretty sure they are less than €100 billion/year)."

The €100 billion annual PFAS remediation estimate – which could theoretically continue without pause – is intended more as a warning, explained Ling in an interview with NaturalRefrigerants.com. "It's meant to say it costs too much; therefore, we should be reducing it upstream."

The European Chemicals Agency (ECHA) is, in fact, considering class-wide restrictions, with certain exemptions on PFAS, including f-gas applications and their TFA degradation product. "If the EU acts now, we can prevent concentrations of emerging PFAS like TFA from reaching harmful levels in our drinking water," said the PFAS Lobbying Project.

TFA in blood

Ling believes that TFA should be taken seriously as a potentially harmful PFAS. "I hear a lot of people saying that TFA is not toxic because it's not bioaccumulative," she said. "But I think that's missing the fact that the concentrations of TFA in environmental media are getting so high now that it doesn't actually need to bioaccumulate at all to have

really high levels of TFA in your blood serum. It's not like an exposure that happens once, and then you clear it."

But given the high cost of eliminating TFA from the environment, Ling described such an effort as "a fool's game." Acknowledging that "we target places where there's a health risk," she thinks that "talking about removing PFAS from environmental media is distracting from the need to phase it out and phase out the precursors."

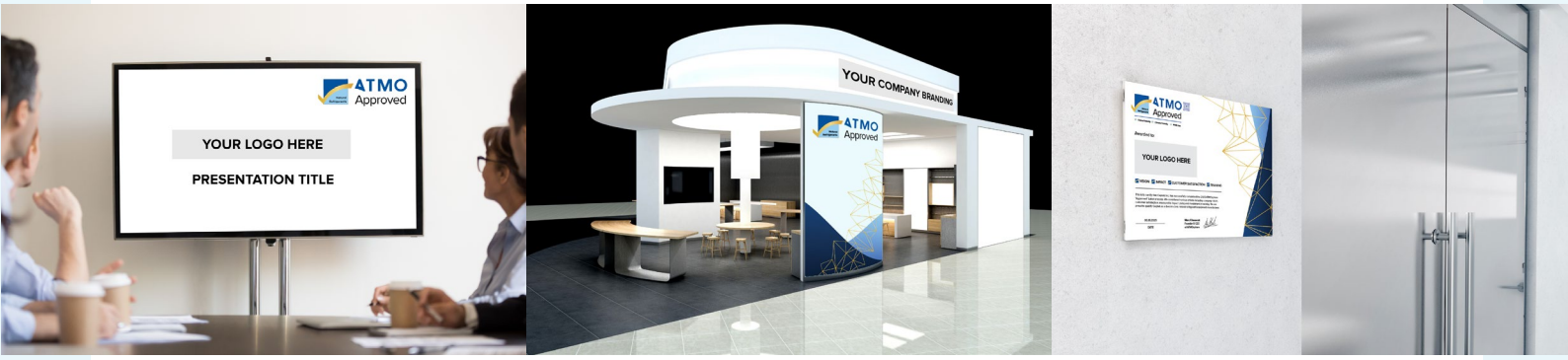
Another reason to restrict or ban PFAS at the source is that the cost of removing PFAS from the environment is often borne by governments and taxpayers. "If you remove it at the source, then the companies [that manufacture it] pay," she said, adding that some of those costs may be passed on to consumers. Last year in the U.S., PFOA and PFOS were designated hazardous substances subject to CERCLA (the Comprehensive Environmental Response, Compensation, and Liability Act) – known as Superfund – requiring polluters and not taxpayers to pay for clean up.

The Forever Lobbying Project's study of PFAS remediation costs throughout Europe, she added, is likely the first of its kind. "I think there have been some studies by consultants that have estimated costs for the U.K. or other places, but I don't think there's been a scientific study on it."

ATMOsphere Natural Refrigerants Label

ATMOsphere launched a label to meet growing market demand for a globally recognized quality label for the natural refrigerant industry that qualifies and celebrates the best natural refrigerant companies and products.

Aimed at natural refrigerant manufacturers (both system and component) and contractors, our custom process considers company vision, customer satisfaction, measurable impact, and investment in training.



atmosphere.cool/natural-refrigerants-label

Chapter 2

Image by Dmytro Tkachuk from Pixabay

HFOs and TFA: Evidence of a Potential Threat to Human Health and the Environment

Scientists Publish Statement Defending PFAS Definition That Includes F-Gases and TFA

The science-based OECD definition of PFAS pollutants is being challenged by the International Union of Pure and Applied Chemistry, an industry-backed group.

Twenty scientists with expertise in per- and polyfluoroalkyl substances (PFAS) have published a statement supporting a definition of PFAS that includes f-gases and f-gas byproduct TFA and refuting an effort to change that definition.

The "Scientists' Statement on the Chemical Definition of PFASs," was published June 10, 2025, in *Environmental Science & Technology Letters*. (PFASs are the same as PFAS.) The corresponding author is Gabriel Sigmund, Assistant Professor, Environmental Technology at Wageningen University in the Netherlands. Other authors include Shira Joudan, Assistant Professor of Analytical Environmental Chemistry at the University of Alberta in Edmonton, Alberta; Cora Young, Professor, Department of Chemistry at York University in Toronto, Ontario; and Rainer Lohmann, Professor at the University of Rhode Island's Graduate School of Oceanography in Narragansett, Rhode Island.

The statement asserts that the definition of PFAS established in 2021 by the Organisation for Economic Co-operation and Development (OECD) – which says that a PFAS contains at least one fully fluorinated carbon atom – "is scientifically grounded, unambiguous, and well suited to identify these chemicals" and does not "prescribe how [PFAS] should be regulated."

But, the statement notes, "We are concerned that some individuals and organizations are seeking a redefinition of [PFAS] endorsed by the International Union of Pure and Applied Chemistry (IUPAC) to exclude certain fluorinated chemical subgroups from the scope of the existing definition. We are concerned that this effort is politically and/or economically, rather than scientifically, motivated."

Changing the OECD definition of PFAS "will also cause substantial ambiguity and confusion in international discussions and could lead to unnecessary jurisdictional inconsistencies and contradictions in PFAS regulations and action," the statement said.

The IUPAC is a U.S.-based organization consisting of chemical societies, national academies of science and chemical company representatives, among others.

> *"We are concerned that this effort is politically and/or economically, rather than scientifically, motivated."*
>
> ***Scientists' statement published in***
> **Environmental Science & Technology Letters**

The OECD definition of PFAS includes all molecules that contain at least one fully fluorinated methyl or methylene carbon, including f-gases, pesticides, and pharmaceuticals, many of which can degrade to form TFA, an extremely persistent two-carbon PFAS.

The widely used f-gas HFO-1234yf, when leaked into the atmosphere, changes entirely to TFA within a few weeks. The TFA is then absorbed in rainfall and has been found in water sources and soil globally as well as in human blood. Germany recently made an official proposal to the EU to categorize TFA a being reproductively toxic.

Many jurisdictions, including the EU, have adopted the OECD definition of PFAS. The EU is engaged in evaluating the extent to which f-gases would be regulated as PFAS as part of a universal PFAS restriction proposal. In the U.S., while the Environmental Protection Agency (EPA) does not use the OECD definition, many states do. Maine has enacted legislation calling for bans of PFAS f-gases in 2040.

But efforts to create alternative definitions of PFAS may exclude f-gases, TFA and/or polymers, the scientists' statement said. An IUPAC-endorsed

and potentially narrower PFAS definition "could confer undue legitimacy from the endorsement by a recognized global scientific organization and, thereby, influence regulatory bodies and others to adopt less protective policies," the statement added.

The International Panel on Chemical Pollution (IPCP) is conducting a campaign to collect public signatories in support of the scientists' statement. As of June 25, 2025, nearly 350 scientists and practitioners from 45 countries had added their names and affiliations as signatories.

ATMO America comment

The scientists' statement came up on June 12, 2025, at the ATMOsphere (ATMO) America conference in Atlanta, Georgia, organized by ATMOsphere (publisher of this report). "We just said, 'OECD had a big, long discussion. Industry was present. Government was present. Scientists were present. They came up with a very logical chemical definition [of PFAS],'" said Lohmann of the University of Rhode Island and one of authors of the statement, in his PFAS panel presentation at the conference. "There's no chemical need to change that. There might be regulatory needs, but that's a different story."

The message to the IUPAC, added Lohmann, is that "whatever your group is doing is not chemistry-based. So just stick to the chemistry, please."

Lohmann's point distinguishing between scientific and governmental aims is underscored in the scientists' statement. "Governmental and intergovernmental bodies as well as other interested parties should continue to use the unambiguous and effective chemical definition of [PFAS] provided by the OECD to identify [PFAS]," the statement said. "It is a separate question as to what is and is not included by jurisdictions for specific regulatory or policy-making purposes." As an example, pesticides, pharmaceuticals and f-gases have been regulated or managed separately from other PFAS in many jurisdictions. "This does not exempt them from meeting the chemical definition of [PFAS]," the statement said.

On its website, the IUPAC has listed a project called "Terminology and Classification of Per- and Poly-Fluoroalkyl Substances (PFAS)," which was launched in June 2024. The objective of the project is to "collect, and critically analyze existing information, providing a rigorous definition for PFAS, and standardizing terminology, classification, and nomenclature," says the IUPAC, adding, "These findings are expected to help national and global regulation and policy decisions, by filling information gaps and allowing targeted education campaigns."

The IUPAC did not respond to a request for comment on the scientists' statement.

Last year, more than 150 PFAS scientists from around the world co-signed a similar statement urging governmental bodies to adopt a science-based "at least one fully fluorinated carbon atom" definition of PFAS.

Shira Joudan, Assistant Professor of Analytical Environmental Chemistry at the University of Alberta in Edmonton, Canada; photo by Dawn Graves, University of Alberta

How Harmful Is TFA?

Trifluoroacetic acid, an atmospheric byproduct of certain f-gases, has been found in human blood. Environmental chemist Shira Joudan shares her thoughts on what this means.

A large and growing number of studies have reported the rapid proliferation in the environment of TFA, a byproduct of certain f-gases in the atmosphere (notably HFO-1234yf) as well as the breakdown of certain pharmaceuticals, pesticides and other chemicals.

This raises the question: How harmful is TFA to human beings?

TFA is an ultrashort-chain (two-carbon) example of PFAS (per- and polyfluoroalkyl substances), a category of chemical pollutants, according to the scientifically accepted definition of PFAS. Similarly structured, longer-chain PFAS, like eight-carbon PFOA (perfluorooctanoic acid), are bioaccumulative in organs like the liver and cancer-causing. However, TFA is not considered toxic by the chemical industry, which cites certain studies to back its claims.

But some researchers believe that TFA, which continues to accumulate in water supplies and food, could pose a threat to human health over time. That is particularly because TFA has been found in human blood, usually at levels higher than that of longer-chain PFAS.

To gain further insight into the potential toxicity of TFA, NaturalRefrigerants.com spoke to Shira Joudan, Assistant Professor of Analytical Environmental Chemistry at the University of Alberta in Edmonton, Canada. Her research group studies the environmental fate of PFAS, halogenated contaminants, and other organic chemicals in the environment, including TFA. She was part of a study debunking the claim that TFA is found naturally in the environment, published a paper exploring the degradation of the drug fluoxetine (Prozac) into TFA, and another looking at the presence of TFA in the atmosphere. She is currently studying how the breakdown of pesticides contributes to environmental TFA and how certain fluoropolymers can leach TFA into aqueous systems.

The following interview was edited for brevity and clarity.

NaturalRefrigerants.com: We know that TFA is persistent, accumulating and ubiquitous in the environment, it's absorbed by people through drinking water, food and air, and turns up in blood serum. Do you agree that it's a planetary boundary threat?

Shira Joudan: If we are emitting a chemical into the environment – whether that's directly or via many other chemicals that are useful but then form it – and it has no way to break down, and it keeps increasing, that's concerning. Because the idea is that we may reach a concentration that has major harmful effect, and then we can't deal with it.

The chemical industry and some studies contend that TFA is not bioaccumulative and therefore does not harm humans at current environmental levels and is not a threat in the future. What is your view on the degree of toxicity represented by TFA, given that it's present in the blood?

It's one thing to say a chemical accumulates in the body. That's concerning because it can provide a higher exposure concentration compared to what's in the environment. TFA is not really like that, but it has a high concentration in the body because it's also high in the environment. Ultimately, the concern is we don't want potentially harmful chemicals in high concentrations in our body. To me, if you make a measurement, you have the answer. So the question about whether TFA bioaccumulates or builds up in your organs is sort of irrelevant if you've made a measurement of TFA, and you know its concentration.

You mean the concentration of TFA in the blood?

Yes. Let's say that the TFA concentration in blood is exactly the same as what's in the drinking water. But what's in the drinking water is 100 times higher than some other contaminant or PFAS, then that's bad.

Of course, if TFA is in the blood, then it travels throughout the body and through all of the organs, even crossing the placenta in pregnant women. But critics would argue that it is not getting into, say, the liver like PFOA or PFOS.

I don't think that's true. It's not going to be 100 times higher, let's say, in your liver, like the longer PFAS building up there. It's more like TFA is in a balance with drinking water or your blood or your liver, whereas the longer chain PFAS like PFOS will be highest in the liver but lower in the drinking water and in the blood.

So you're saying there still might be some TFA that gets into the organs because it's in the bloodstream and has every opportunity to infiltrate the liver and every other organ?

Exactly. What people usually are trying to say about TFA is that it doesn't build up [in biota], it doesn't accumulate [in organs]. That means they're saying the ratio is not higher. For example, in [the Emory University study of TFA in Indiana households] they measured it in urine, and they measured it in blood. So the urine means it's leaving the body, but if it's a high concentration in the blood, it's still there. And that's not a question of whether it's accumulating [in organs]. It's just there. If that's the blood concentration every day of this person's life, does it matter if it's accumulating or not [in organs]?

And given the fact that TFA continues to be building up in the environment, the level in the blood could build up as well.

Exactly.

So, ultimately, even if TFA is not bioaccumulative in the sense that PFOA is, it's still concerning from a health impact.

We're still being exposed to it, and it's still in our bodies. As context, people are used to contaminants that do bioaccumulate and build up in our bodies, such as those described in the Stockholm Convention on Persistent Organic Pollutants. And so the idea of being exposed to something every day – and maybe it's building up in the environment, so we're exposed more – that's not what people think about all the time. And that sort of paradigm is hard for people to change, I think, even in my field.

TFA is not at this point widely considered to be harmful to human health the way PFOA and PFOS are, but the German Federal Office for Chemicals has proposed to the EU linking TFA to reproductive toxicity. That link was found in rabbit studies.

I'm not a toxicologist, but I do follow the literature, and it seems that historically people thought TFA doesn't behave like a traditional contaminant that accumulates in the body, so it was not prioritized for toxicological studies. But now we know it is in the body, so it doesn't matter if it accumulates or not. I think that's why there's more of a push for research now. We know that it's not going to be an acute, short-term exposure. It's going to be one of these long term exposures at the lower concentrations that need to be studied in toxicity studies.

Over the past 30 years, toxicologists have learned more about how to do those studies of chronic low

dose exposure, and so that needs to be done for TFA. Way back, they did some TFA tests, but they were not like what we would do now, based on everything that's been learned about related chemicals.

I would prefer that TFA be harmless, given how much of it is out there.

For me, anything that doesn't degrade and we keep putting more and more of that into the environment – it's not a positive feeling if we don't have all the information. It's unsettling.

Some European countries – Germany, Denmark and the Netherlands – have started to establish drinking water limits for TFA, so there is already a sense that it is hazardous. And then there's the precautionary principle – if you don't look at it, and it truly is harmful, then it's a much worse problem.

Yes, that's what I think, because that's the reality of our exposure [that we should consider the precautionary principle].

And the chemical industry does not exactly have a good track record when it comes to PFAS and other chemical pollutants.

Another thing about TFA that's different than most of the other chemicals we think of as PFAS is that it doesn't come from just one product; it forms in the environment from other things. There are a lot of different industries that are involved, and not one is entirely responsible. It seems that a lot of the environmental TFA comes from refrigerants, but that's not all of it. Some of it's from burning fluoropolymers. Some of my work is trying to figure out how much TFA comes from pharmaceuticals and pesticides, but right now we don't know.

I think when it's not one group's responsibility, that makes it easy to push it off. The refrigerant people were saying, "It's naturally occurring, and we're polluting just a small percentage." And then when we tried to debunk them on that claim – that there is no evidence for it – they said, "Well, maybe it's coming from all the pesticides." Being able to blame other people for TFA is very different than, say, PFOA, where someone made that, and now it's in the environment.

"Ultimately, the concern is we don't want potentially harmful chemicals in high concentrations in our body."

Shira Joudan, Assistant Professor of Analytical Environmental Chemistry, the University of Alberta

The Neckar River in Heidelberg, Germany. TFA was detected in the drinking water of the Neckar region in 2016. Photo credit: Laura Stanley for Pexels

Germany's Linkage of TFA to Reproductive Toxicity Officially Submitted to EU

The submission includes the public release of two 105-page dossiers detailing Germany's assessment of TFA, an f-gas byproduct, with a call for stakeholder comment.

Three German government agencies – the Federal Institute for Occupational Safety and Health (BAuA), the Federal Institute for Risk Assessment (BfR) and the Federal Environment Agency (UBA) – announced on May 26, 2025, that their assessment of trifluoroacetic acid (TFA) and its trifluoroacetate salts as reproductively toxic, very persistent and very mobile was officially submitted to the European Chemicals Agency (ECHA).

The announcement includes the public release of two 105-page dossiers detailing Germany's TFA assessment, with a call for stakeholder comment. The assessment was provided to ECHA for consideration under the EU's CLP (classification, labelling and packaging) Regulation. This regulation calls for hazardous chemicals to be properly classified and labelled on behalf of workers and consumers – what's called harmonized classification.

The May 26 announcement was a significant step in a process that began in early 2024 when the BAuA's Federal Office for Chemicals (BfC) informed ECHA of its intention to propose linking reproductive toxicity TFA. This was followed later in 2024 when the BfC initially submitted its proposal.

Consultation and expert evaluation of the German TFA proposal are currently underway. Until July 25, stakeholders can comment on the TFA assessment here and the TFA salts assessment here. Summaries of the proposed changes are available here and here, with the dossiers available here and here.

> *"With our proposal, we are creating an important foundation for reducing the release of this persistent and hazardous chemical into the environment and the associated risks."*
>
> ***Dr. Kerstin Heesche-Wagner, Head of Germany's Federal Office for Chemicals***

ECHA's Scientific Committee for Risk Assessment (RAC) will then discuss the dossiers and the comments received. Within 18 months, the RAC's opinion will be submitted to the EU Commission, which will then propose a corresponding draft regulation to update the CLP Regulation. ECHA is also evaluating regulations for TFA and f-gases as PFAS under a proposed universal PFAS regulation. The EU is not expected to finalize its universal PFAS and CLP regulations for several years.

"With our proposal, we are creating an important foundation for reducing the release of this persistent and hazardous chemical into the environment and the associated risks," said Dr. Kerstin Heesche-Wagner, Head of the BfC. "The harmonized classification is an important tool in hazard communication and a basis for risk management."

In Germany, TFA was detected in the drinking water of the Neckar region in 2016 and has been found in German waters for years, said the agencies, adding that "the trend is increasing." Moreover, they said, drinking water treatment can only remove such substances with considerable technical effort.

"The number and quantities of chemicals that degrade to TFA are constantly increasing," said UBA President Dirk Messner. "Environmental discharges must be reduced as quickly as possible to ensure sustainable protection of the environment and drinking water resources."

TFA emissions from refrigerants could be reduced quickly, as market-ready alternatives such as hydrocarbons, carbon dioxide, ammonia or air are already available, the agencies said. TFA emissions from agriculture could be significantly reduced if approvals of TFA-forming pesticides are removed.

Based on animal models

In particular, the German authorities, based on TFA's potential to cause adverse effects in animal models (particularly rabbits), are proposing to classify TFA and its salts as toxic to reproduction, Category 1B with the hazard statements H360Df: "May harm the unborn child. Suspected of damaging fertility." Germany is the first country to connect TFA with reproductive toxicity in humans.

But the agencies stressed that this hazard classification "does not initially indicate any actual health risks as the amount of the substance ingested is also crucial for this."

Added BfR President Andreas Hensel, "The toxicological effect was only demonstrated in animal models at TFA concentrations significantly higher than those found in the environment. Therefore, health impairments are currently not expected from consuming water or food contaminated with TFA."

However, "the new classification is an important step in preparing further measures to ensure this remains the case in the future," Hensel said.

In addition, the German proposal categorizes TFA and its inorganic salts under hazard classes PMT (persistent, mobile and toxic) and vPvM (very persistent, very mobile). TFA and its salts are tied to PMT EUH450 (can cause long-lasting and diffuse contamination of water resources) and vPvM EUH451 (can cause very long-lasting and diffuse contamination of water resources).

It would also change TFA's current classification of Acute Toxicity 4 H332 (harmful if inhaled) to Acute Toxicity 3 H331 (toxic if inhaled), adding proposed specific concentration limits of 5mg/L (vapor) for inhalation ATE (acute toxicity estimate).

Under the proposal, TFA continues to be classified as Aquatic Chronic 3, H412 (harmful to aquatic life with long-lasting effects) and Skin Corrosion 1A, H314 (causes severe skin burns and eye damage).

According to the UN's Globally Harmonized System (GHS) of Classification and Labelling of Chemicals, which the EU follows, reproductive toxicity refers to "adverse effects of a chemical substance/mixture on sexual function and fertility in adult males and females, as well as developmental toxicity in the offspring." Developmental toxicity pertains to adverse toxic effects in developing embryos or fetuses. Under the GHS, Category 1B refers to presumed human reproductive toxicants, largely based on animal studies. (Category 1A refers to known human reproductive toxicants based on evidence from humans.)

The GHS also lists the minimum concentration for a hazardous substance to trigger the classification of a mixture containing it. For the reproductive toxicity classification 1B, the minimum concentration is 0.1% in the U.S. and Canada and 0.3% in the EU, Japan, Australia and other countries.

The GHS says that if a reproductive toxicant is present in a mixture as an ingredient at a concentration between 0.1 and 0.3%, every regulatory authority would require information on the safety data sheet (SDS) for that ingredient; a label would be optional. However, if the concentration is equal to or greater than 0.3%, both SDS information and a label would generally be expected.

An invisible threat

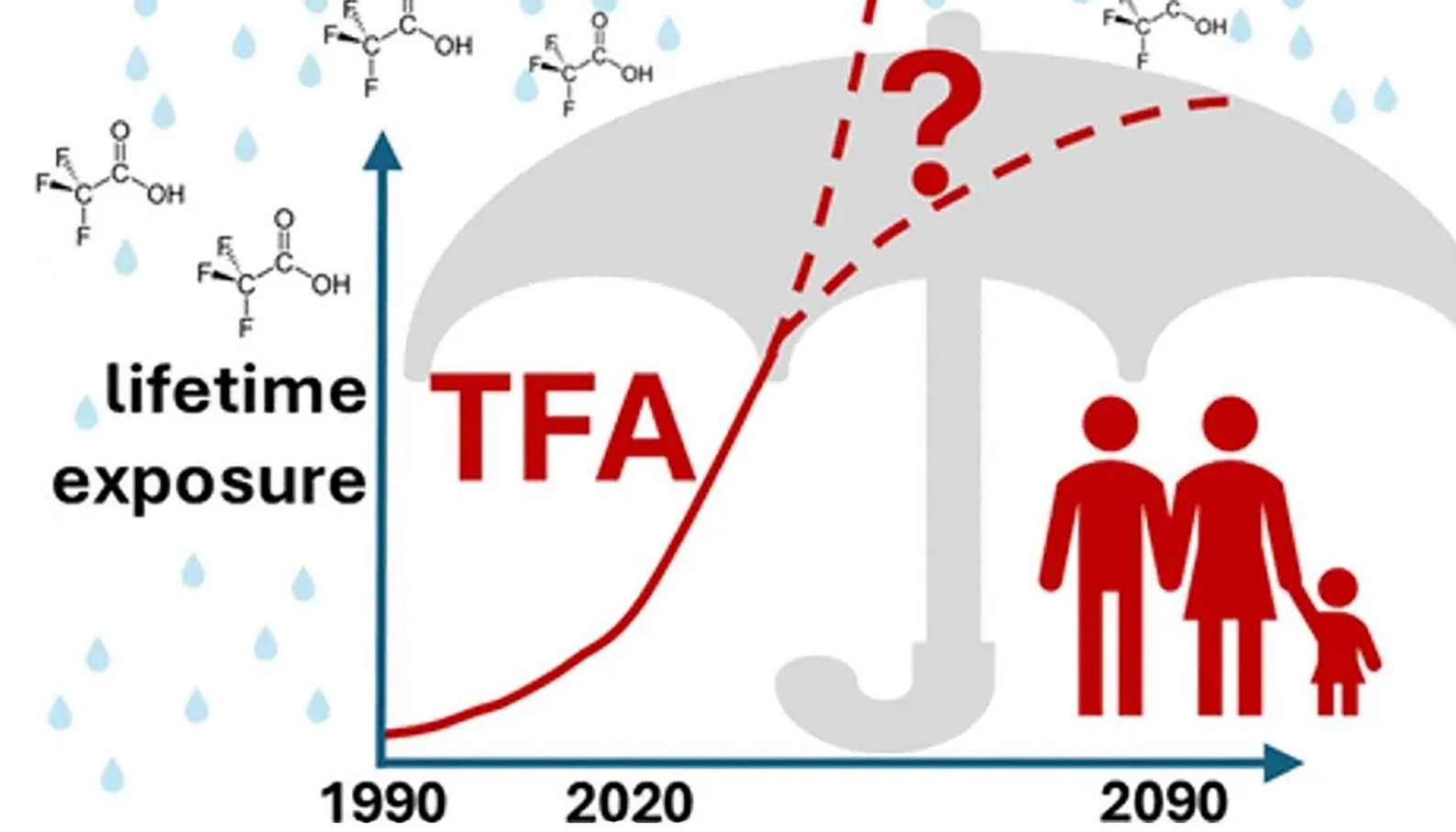
NGOs welcomed news of Germany's public TFA assessment.

"The perennial chemical TFA is an invisible threat to our health," said Jürgen Resch, Federal Director of the German Environmental Aid (DUH). "It is irresponsible that TFA precursor substances such as pesticides and refrigerants, for example, in car air-conditioning systems, are still widely used – especially since more environmentally friendly alternatives have long been available. We call on the federal government to strictly restrict fluorinated refrigerants and TFA-forming pesticides."

"We hope this is the first step towards a ban on TFA and all PFAS," said Hanna Holmquist, Toxicologist at ChemSec, in a LinkedIn statement.

The UBA has already set a human health-based guideline value of 60µg/L for TFA in drinking water and a "precautionary measure" of 10µg/L. This guideline value is based "a dose-dependent activation of the enzyme ALT [alanin-amino-transferase], which is an indicator of possible liver toxicity," said Dr. Alexander Eckhardt, Researcher for the UBA's Department of Toxicology of Drinking Water and Swimming Pool Water. In 2020, UBA published a study showing the link between TFA and ALT in rats.

In response to a query about the German agencies' TFA announcement, Angelica Candido, Sector Manager for the European Chemical Industry Council (CEFTIC), said, "EFCTC [European Fluorocarbons Technical Committee] and/or CEFIC are not planning to respond to any press release. The process is still ongoing."



Graphic from "The Global Threat from the Irreversible Accumulation of Trifluoroacetic Acid (TFA)," Environmental Science and Technology.

Study Calls F-Gas Byproduct TFA a 'Planetary Boundary Threat'

Produced in the atmosphere from HFO-1234yf and other f-gases, trifluoroacetic acid is an omnipresent PFAS with potentially irreversible disruptive effects, the study says.

A 2024 study makes the case that TFA meets the criteria of a "planetary boundary threat" because of increasing planetary-scale exposure, where "potential irreversible disruptive impacts on vital earth system processes could occur."

The study, "The Global Threat from the Irreversible Accumulation of Trifluoroacetic Acid (TFA)," was published October 30 in the journal *Environmental Science & Technology*. Its authors are Hans Peter H. Arp and Andrea Gredelj of the Norwegian Geotechnical Institute; Juliane Glüge and Martin Scheringer of the Institute of Biogeochemistry and Pollutant Dynamics, ETH Zurich; and Ian Cousins of the Department of Environmental Science, Stockholm University. The study received funding from ZeroPM and ARAGORN EU.

The TFA study reviewed 43 studies from the late 1990s to the 2020s that reported on TFA concentrations, concluding that "collectively, these data indicate that TFA exposure is widespread and is increasing."

It found that none of the current studies "considered actual long-term exposure to TFA, which would be more relevant given its ubiquitous and increasing presence over long time scales." Even so, "there are more than sufficient data to conclude that TFA poses a risk to humans and the environment."

The rational response to this global threat, the TFA study said, "is to act swiftly before irreversible impacts are manifested at a global scale to humans and the environment. Transitioning away from TFA and its precursors is the most effective way of safeguarding future generations from this planetary boundary threat."

While several f-gases degrade to TFA in the atmosphere, HFO-1234yf, used globally in millions of car air-conditioning systems and in commercial refrigerant blends, undergoes 100% transformation to TFA within a few weeks; the TFA then comes down to Earth in rainfall. The uptake of HFOs "could cause emissions of TFA to increase by orders of magnitude in the coming years," said the TFA study. It pointed to several sources in addition to f-gases that generate TFA as a byproduct, including pesticides,

pharmaceuticals, fluoropolymers and other PFAS, as well as to the direct release of industrially produced TFA and TFA emitted from wastewater treatment plants and landfills.

As a consequence, TFA has been proliferating throughout the environment in rain, surface water, soil, human blood serum, plants, plant-based foods and drinking water. In fact, noted the study, TFA concentrations are "orders of magnitude higher" than those of other PFAS while ongoing emission concentrations are "increasing irreversibly."

"What remains less clear are the thresholds where irreversible effects on local or global scales occur," the TFA study said. "There are indications from mammalian toxicity studies that TFA is toxic to reproduction and that it exhibits liver toxicity. [But] ecotoxicity data are scarce, with most data being for aquatic systems; fewer data are available for terrestrial plants, where TFA bioaccumulates most readily."

> *"Transitioning away from TFA and its precursors is the most effective way of safeguarding future generations from this planetary boundary threat."*
>
> ***"The Global Threat from the Irreversible Accumulation of Trifluoroacetic Acid (TFA)," Environmental Science and Technology***

In a LinkedIn post, study co-author Arp wrote, "#TFA is now the most abundant #PFAS in drinking water, the most abundant #PFAS in your blood, the most abundant #PFAS in your juice, your wine, your tea, your beer, the trees outside your window, the snow falling down in the Arctic, the groundwater wells, the soils."

"Some have said, so what? It's not toxic," Arp continued, "which is another way of saying, pump up the TFA in my blood, plants and water for the rest of my life, all good." He added, "We are ignorant of where the biggest impacts of TFA on the global scale will be realized, but we know that when they are, they are irreversible."

The American Chemistry Council and the European Fluorocarbons Technical Committee (EFCTC), which represent HFO producers, both declined to comment on the study.

Meeting three conditions

TFA study co-author Cousins contributed to a 2013 study, "Confronting Unknown Planetary Boundary Threats from Chemical Pollution," which identified three conditions that must be simultaneously met for chemical pollution to pose a planetary boundary threat. In the TFA study, the authors contend that TFA meets these conditions:

- Condition 1: The pollution has a disruptive effect on a vital earth system process of which we are ignorant.
- Condition 2: The disruptive effect is not discovered until the associated impacts are, or inevitably will be, manifested at a global scale.
- Condition 3: The impacts are poorly reversible because the level of pollution in the global environment cannot be readily reduced.

Condition 1 is met based on "the many [TFA] thresholds that could be exceeded of which we are ignorant," the study said. This includes surface water concentrations that may exceed the predicted no-effect concentration (PNEC) for algae of 560mcg/L set by the European Chemicals Agency (ECHA), soil concentrations that may exceed the lowest established no observed effect concentration (NOEC) for crop plants of 0.83mg/kg of soil, according to the ECHA, and indications of human toxicity that have led to precautionary thresholds in drinking water in the Netherlands (2.2mcg/L), Denmark (9mcg/L) and Germany (health guideline of 60mcg/L and advisory level of 10mcg/L).

Although TFA does not currently have health advisories or regulatory limits that are as well-established as those for other acid-based PFAS like PFOA, "it is likely that new advisories/limits will be introduced in the coming years when more research on the impacts of TFA emerges," the study said.

Condition 2 is fulfilled as "TFA is already present globally in all environmental media, such as its ongoing bioaccumulation in vascular plants, the accumulation in arctic regions, its ubiquity in groundwater, and the global occurrence of industrial sites that are TFA hotspots where impacts are most likely; therefore, when impacts are discovered, they would be global." Condition 3 is satisfied "due to TFA's extreme persistence and mobility coupled with emissions from multiple sources."

The TFA study cited many other studies and reports in defense of its description of TFA as a planetary boundary threat:

- Many findings of TFA levels in drinking water have exceeded the EU's "total PFAS" (including TFA) limit of 0.5mcg/L, set to begin in 2026. Moreover, the most effective way to remove TFA from water – reverse osmosis (RO) – is expensive, requires a substantial amount of energy and typically results in 50% water loss.
- Because of growing water and soil concentrations, TFA has been accumulating in plants like conifer needles, maize, leaves of various tree species and some wetland species. Consequently, high concentrations of TFA in plant-based foods and plant-based beverages such as juice, beer and tea have been reported, indicating that the ingestion of such foods and beverages could be a substantial route for human (and animal) exposure.
- In another study the concentrations of TFA in the blood serum of nonoccupationally exposed citizens in Indiana (U.S.) households are similar to the concentrations of bioaccumulative long-chain PFAS measured in the serum of occupationally exposed workers in a University of North Carolina study.
- Recently investigations by German researchers have shown the effects of TFA on soil pH, microbial respiration, bacterial abundance and litter (dead leaves) decomposition; litter decomposition – a process that adds nutrients to the soil – is affected at concentrations similar to current TFA concentrations in soil at contamination hotspots (0.0013–2.4mg/kgdw).
- U.S. water researchers showed the incorporation of TFA into cells by microbial communities in freshwater surface sediments after also demonstrating TFA incorporation in biomolecules such as proteins in aquatic organisms. TFA concentrations overlap with those currently observed in waters worldwide, ranging from 2.2 to 43mcg/L, and resulted in significant cell incorporation of TFA.

The TFA study also challenged the conclusions of some TFA investigations:

- Studies of chronic exposure to TFA are still relatively scarce, with chronic data from standardized tests being limited in time of exposure to, for example, 35 days in fish, 21 days in Daphnia, 90 days in rats and 36 days in crop plants. These are insufficient in their extrapolation to potential impacts from lifetime exposure to TFA.
- Earlier studies have regarded TFA as less hazardous and bioaccumulative than longer-chain PFAS, but these reports don't consider TFA's ubiquitous accumulation in the environment, in particular its observed accumulation in water resources and bioaccumulation in various plants, including crops.
- Some recent studies have concluded the risk of TFA to humans and the environment is negligible based on a projected concentration of TFA in the ocean and current levels in blood serum. However, the TFA study rejected this conclusion because it ignores terrestrial environments, assumes that the lowest measured environmental effect levels are known despite the lack of long-term chronic exposure data for other species and does not consider diverse human exposure pathways in diet and potential unknown adverse effects such as on embryo development.

Action urged

With the projected exponential increase in TFA concentrations in the environment, food and in humans, "the question is not if TFA can exceed a planetary boundary, but which irreversible health or Earth system impacts would be first observed at a planetary scale, and where thresholds of TFA emissions should be set to limit the severity of such impacts," the study said.

The study calls for stakeholders to immediately start discussing "policy, industry, and innovation actions toward the phase-out of high-volume substances that lead to increasing TFA accumulation" such as HFOs like HFO-1234yf and pesticides such as flufenacet. Other pharmaceuticals, veterinary products and industrial chemicals that release TFA via transformation processes should also be considered for phase out or substitutions, the study said.

"[TFA] can be put on the list of accumulating persistent substances we know are [causing] or can cause planetary harm, like greenhouse gases, nutrients causing eutrophication, and ozone-depleting substances," wrote Arp on LinkedIn.

Michael Kauffeld, Professor at the Karlsruhe University of Applied Sciences, delivering the keynote address at ATMOsphere Europe 2024

ATMO Europe: Natural Refrigerants Expert Kauffeld Predicts HFOs Have 8 Years Left

Because of the widespread pollution caused by their byproduct TFA, HFOs will be replaced by natural refrigerants, he argued in his keynote address.

In eight years – by the end of 2032 – HFOs, the latest generation of fluorinated refrigerants, will no longer be a viable refrigerant option, following their predecessors HFCs, HCFCs and CFCs into the dustbin of history, predicted Michael Kauffeld, Professor at the Karlsruhe University of Applied Sciences, Institute of Refrigeration, Air-Conditioning and Environmental Engineering in Germany.

Kauffeld made this prognostication during his keynote address on November 26, 2024, at the ATMOsphere (ATMO) Europe Summit 2024 on natural refrigerant-based cooling and heating, held in Prague, Czech Republic, November 25–26.

"It's eight years left before HFOs will disappear," he said in his keynote, titled "PFAS – a growing concern in the HVACR industry." He attributed this largely to the proliferation of the HFO degradation product TFA, which is "polluting our soil and groundwater." HFOs will be replaced, not by another generation of f-gases, but by natural refrigerants such as CO_2 (R744), hydrocarbons such as propane (R290), ammonia (R717), water, air and other substances that don't harm the environment, he said.

In fact, given the increasing severity of the TFA issue, "we shouldn't wait eight more years," said Kauffeld. "The politicians should have banned HFOs and the fluorinated pesticides yesterday, rather than tomorrow, but not in eight years."

A longtime expert on natural refrigerants, Kauffeld was named Person of the Year at the ATMO Europe Summit, which was organized by ATMOsphere, publisher of this report. In addition to writing more than 100 scientific papers, he is the co-editor of *Natural Refrigerants: Applications and Practical Guidelines*, which offers a comprehensive and practical guide to working with natural refrigerants. Most recently, he was part of a team of researchers that found that in a commercial reversible heat pump using R410A refrigerant, the amount of PFAS components by weight was less than 1%.

> *"This is, in my eyes, a much bigger environmental scandal than what we ever had before."*
>
> ***Michael Kauffeld, Professor at Karlsruhe University***

Kauffeld offered his original forecast about the longevity of HFOs in 2017 at the EuroShop trade show in Düsseldorf, Germany, giving the gases 15 years at that time. At EuroShop and again at the ATMO Europe Summit, he noted that it took roughly 60 years (1930 to 1990) "to find out that CFCs damage the ozone layer." It then took about half as long, 30 years (1990 to 2020), to fully acknowledge that HFCs contribute noticeably to global warming and would take half as long again, 15 years, "to accept that HFOs are harmful to the local environment – technician's health and terminal water bodies."

Kauffeld, a member since 1997 of the UNEP (United Nations Environment Programme) Refrigeration, Air-Conditioning and Heat Pumps Technical Options Committee (RTOC), does not expect the transition away from HFOs to be smooth or easy. "We had a very tough fight in the [RTOC] at the end of the 1990s to get HFCs included in the report. We have the exact same fight now again, getting TFA included in the report."

The European Chemicals Agency (ECHA), an EU body, is considering a proposal to regulate PFAS as a category, including f-gases and TFA, under REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals), the EU's chemicals regulation, with rules expected to be enforced before the end of the decade. Also in the EU, a new organization, the Coalition for PFAS Free Cooling & Heating, has been launched, with ATMOsphere as a founding member.

The chemical industry is strongly opposed to regulating HFOs or TFA, especially because there will be no subsequent generation of f-gases, and therefore no more f-gas business, once HFOs are gone, Kauffeld said, citing research conducted by his former colleague Mark O. McLinden, Research Chemical Engineer, National Institute of Standards and Technology (NIST), Boulder, Colorado. "He analyzed 60 million different chemicals and said there's no fifth generation after HFOs, Kauffeld noted. "After HFOs, only natural fluids are left."

Kauffeld added that natural refrigerants are the best choice anyway because they have the highest energy efficiency and produce the least CO_2e emissions during production.

'TFA is a forever chemical'

"The real problem is the TFA because, once it's in the water, it will stay there for thousands of years," said Kauffeld. "So TFA is a forever chemical." He added that TFA, an ultrashort-chain PFAS with two carbon atoms, is the smallest member of the subgroup of PFAS that includes eight-carbon PFOA (perfluorooctanoic acid), a well-known carcinogenic chemical. "If you remove the middle part [of PFOA], it's exactly TFA."

"This is, in my eyes, a much bigger environmental scandal than what we ever had before," said Kauffeld. Even if water filters ultimately protect humans from TFA, animals and plants will remain vulnerable, he noted.

Some reports, such as UNEP's Environmental Effects Assessment Panel (EEAP) 2022 assessment, say that TFA is not bioaccumulative. Asked about that, Kauffeld referred to a U.S. study of Indiana households that found TFA in blood serum and to a much lesser extent in urine, suggesting that the TFA "stays in the body." He also noted that the half time of TFA in the body is 16 hours. "So until everything is gone, it's like 32 hours. Can you live without drinking or eating for 32 hours? No, you can't, and that's why the concentration in your body is increasing all the time." In addition, he mentioned studies showing the accumulation over time of TFA in plants and the leaves and needles of trees.

European studies

In his keynote. Kauffeld reviewed a number of studies indicating the proliferation and source of TFA in Europe. One 2021 study in Switzerland showed that in the Zurich area, where many cars are emitting refrigerant and many refrigeration systems are used, a great deal of HFO-1234yf was found in the atmosphere, while much less was seen in the far less populated Jungfraujoch area. He also cited a recent study of groundwater in Switzerland that found greater than 10mcg/L of TFA near the city of Basel and another 2021 study that detected 0.25mcg/L–0.91mcg/L in Swiss lakes and 0.25–0.80mcg/L in Swiss drinking water.

A 2022 German study mentioned by Kauffeld traced TFA in 2020 largely and equally to emissions of HFC-134a and HFO-1234yf, the legacy and new-generation refrigerants for car air-conditioning, respectively. (Between 7 and 20% of HFC-134a converts to TFA over 13–14 years.) In December 2023, the German Environment Agency published TFA data showing a maximum of more than 30mcg/L in rivers and groundwater in Germany. The agency also reported that compared to 1995–96 there were three to five times higher TFA concentrations in rainwater in 2018–2020.

Kauffeld cited a 2024 study from the European Pesticide Action Network (PAN Europe) that found TFA in 34 of 36 European tap-water samples from 11 EU countries and in 12 of 19 bottled mineral and spring waters. Several of the samples exceed the 0.5mcg/L drinking water limit for total PFAS set by the EU for January 2026. "We have to filter our water because we can simply not drink the water from the first layer of the groundwater any longer," he said.

TFA is also now "in the beer we drink," said Kauffeld, citing a study showing that 104 beer samples in 23 countries had "rather high" TFA concentrations. "It's no longer water, hops and barley, but it's water, hops, barley and TFA," he said.

PFAS in heat pumps

Kauffeld also described a project in which he participated that looked at the PFAS components in an 800kg (1,763lbs) air-to-water heat pump using R410A refrigerant. Designed for use in multi-family buildings, the heat pump has a capacity of 30kW (8.5TR) and was manufactured by Swiss OEM Heim AG Heizsysteme.

The 22kg of R410A refrigerant includes 11kg of HFC-125, a PFAS, about 1.4% of the total weight of the heat pump; about 400g consist of solid PFAS parts, including the coating of the evaporator, power electronics, the O-rings and some gaskets, such as the shaft seal of the expansion valve. "We also looked at the production process, and you can see here where there are different processes where PFAs are involved."

"Are [heat pumps] really clean heating technologies?" he asked. "Because we do have problems with f-gases and maybe also with some components."

However natural refrigerant and component options exist that PFAS-free, he noted. "If you want to replace your O-rings or whatever in your product, then talk with your suppliers, and get this shifted," he said. "If you're uncertain or your supplier cannot guarantee that it's PFAS free, there are ways of analyzing it, such as at the University of Applied Sciences of Eastern Switzerland. They have the equipment to check pure material if there's PFAS inside or not."

In regard to O-rings, he said, one possible PFAS-free option are paper gaskets or using a supplier like OLAB, which won the Innovation of the Year/ Refrigeration award at ATMOsphere Europe for its PFAS-free O-ring gaskets in CO_2 components.

As for the refrigerants in heat pumps, Kauffeld predicts home heat pumps will follow the path of home fridges, which converted within three years in the 1990s from HFC-134a to a hydrocarbon, isobutane (R600a). "I foresee the exact same happening with the heat pump industry, except they will not use isobutane but propane for the residential heat pumps."

Attorney Robert Bilott delivering the keynote at ATMO America 2024 in Washington, D.C.

ATMO America: Famed PFAS Lawyer Bilott Sees 'History Repeating Itself' with F-Gas Refrigerants

'We're hearing the same arguments – that there's not sufficient science to say we should regulate this,' he said in his keynote.

Robert Bilott, the award-winning and widely profiled environmental attorney whose lawsuits over a two-decade period first exposed the environmental and health threat of PFAS, sees "history repeating itself" in the way the chemical industry is characterizing refrigerants.

Bilott told the story of his involvement in the PFAS issue – and provided lessons that could be applied to the refrigerants issue – in a keynote speech on June 10, 2024, at the ATMOsphere (ATMO) America Summit 2024 on natural refrigerant-based HVAC&R in Washington, D.C. He received a standing ovation at the end of his keynote from the more than 350 attendees. The conference, held June 10–11, was organized by ATMOsphere, publisher of this report.

Bilott, whose work was the basis for the 2019 film *Dark Waters* and the 2018 documentary *The Devil We Know*, revealed the carcinogenic and other health impacts of two prevalent PFAS called PFOA (perfluorooctanoic acid) and PFOS (perfluorooctanesulfonic acid), which contain eight carbon atoms (known as C8s). Moreover, he learned that DuPont and 3M, the manufacturers of the chemicals, did not disclose their internal findings that these chemicals caused harm to laboratory animals and their own employees and publicly said that they were harmless.

"I think what we've learned here is we're seeing this whole story repeat itself," said Bilott. "We're hearing the same arguments we heard on C8s 20 to 30 years ago – that there's not sufficient science to say we should regulate this."

Bilott noted the effort to define PFAS in a way that excludes ultrashort-chain chemicals like f-gases and TFA. "Things are being removed from the definition – anything that's got less than a certain number of carbons. So the public is seeing this thinking, 'Oh, there's no PFAS in it.' It's simply a different definition." He also cautioned to be cognizant of

the detection levels that are established for various PFAS. "As we've all learned, those detection levels change over time. And they get a lot more sensitive."

The chemical industry has downplayed the connection between PFAS and f-gases/TFA. For example, the Sustainable PFAS Action Network (SPAN), which represents chemical industry interests, says that low-GWP refrigerants such as HFOs "do not show the three characters of greatest concern regarding PFAS, as they are not persistent, bioaccumulative, and toxic" according to a statement on its website. However, HFO degradation product TFA is well-known to be very persistent and mobile (vPvM), and the German government has linked it to reproductive toxicity. A study of Indiana households states that TFA's presence in human blood suggests bioaccumulative properties. (A SPAN representative did not respond to a request for comment on Bilott's remarks.)

Chuck Allgood, Technical Fellow at U.S. HFO manufacturer Chemours, called TFA a "naturally occurring substance" with 95–99% of it "found in low levels throughout the Earth that has been there for hundreds of years, well before the industrial age" on May 1, 2024, at a University of Maryland (UMD) workshop called "Ultra-Low GWP Refrigerants for Refrigeration, Water Heating, and HVAC Applications," sponsored by UMD, Oak Ridge National Laboratory, the U.S. Department of Energy and Guidehouse. However, Canadian researchers have determined that there are "no compelling scientific arguments" to support the existence of naturally formed TFA.

The contention that TFA is naturally occurring parallels a claim made by 3M-supported studies in the 1970s when human blood data was showing evidence of organic fluorine chemicals, which contain a carbon-fluorine bond like PFAS. "3M actually published studies, or had people print published studies, to try to suggest there were natural sources, when there was no evidence of any natural source for this organic fluorine," said Bilott.

The chemical companies continued to influence the publication of studies on this topic. In 2004, Bilott said, all of the published peer-reviewed literature "had been essentially seeded by the companies to say, 'No harm, there's no problem here.'"

Poisoned cows

Bilott's journey battling PFAS began in 1998 when he was approached by West Virginia farmer Wilbur Earl Tennant, who was convinced that a creek on his property had been poisoned by runoff from a nearby DuPont landfill, causing the death of many of his cows. That landfill proved to be a dumping site for PFOA.

The farmer's case revealed that DuPont had covered up evidence that PFAS was harmful, leading to a class-action suit and penalties from the U.S. Environmental Protection Agency (EPA). In a 2004 settlement of the class-action suit, DuPont agreed to pay $70 million (€64.8 million), which was used as an incentive to get nearly 70,000 West Virginians to provide blood samples that scientists could use to study the health effects of PFAS.

In December 2011, the scientists began to release their findings: There was a "probable link" between PFOA and kidney cancer, testicular cancer, thyroid disease, high cholesterol, pre-eclampsia and ulcerative colitis. This sparked more than 3,500 lawsuits, and DuPont ultimately agreed to pay $750 million (€701 million) to settle those suits. (In 2015, DuPont spun off its fluorinated chemicals business to a new independent company, Chemours.)

Finally in April 2024, a quarter-century since Bilott began exposing PFAS, the EPA issued stringent drinking water regulations for six PFAS, including 4ppt limits for PFOA and PFOS. His firm is continuing to represent more than a dozen states and hundreds of water suppliers in the latest lawsuits seeking millions of dollars to remove PFAS from the water supply.

In his 2019 book, *Exposure*, Bilott wrote about the ongoing questions about other PFAS chemicals: "There was growing awareness that the entire class of PFAS chemicals – as many as four thousand related compounds – might be a problem, including the newer replacement chemicals (like GenX) that were being billed as less persistent than PFOA and PFOS. Their structural similarity and some evidence from animal studies suggested they could be toxic or carcinogenic but we were hearing the same familiar argument that nobody had done the extensive science required to reach a firm and actionable conclusion on the human impact of these additional PFAS chemicals."

Bilott echoed those thoughts in his ATMO America keynote: "This campaign [has begun] in the U.S. and overseas by the [chemical] makers to say there's no evidence that they're harmful, there's no evidence yet that any of these cause any problem and they should be carved out from any attempts to regulate this stuff."

Society needs to "learn from what we already know about the C8 debacle here," he said. "Look how long it took us to get to the point where, despite all of these internal studies that had been covered up for decades and all the public representations that there's no evidence of any harm, we finally learned the truth."

The chemical industry, Bilott noted, has argued that regulating PFAS as a class that includes ultrashort-chain chemicals "is going to devastate the economy since thousands of jobs depend on these new related chemicals. And they're instrumental in the transition to the green economy." However, he noted, studies have shown that the impact of PFAS equates to tens of billions of dollars in health care costs and six million deaths. "Staggering, right?" he said.

An alternative would be to adopt the "precautionary approach – prevent the harm before it happens, not wait till people get sick and die," he said.

Chemical interests also argue that there are no alternatives to PFAS refrigerants, but, he likened this to the contention about PFOA and PFOS, for which "there were plenty of alternatives that were quickly found and switched to when these were phased out." Natural refrigerants, including CO_2 (R744), propane (R290), isobutane (R600a) and ammonia (R717), are widely used throughout the world in virtually every HVAC&R application.

Bilott believes "it's critically important" to find ways to present information on the environmental growth and health impacts of ultrashort-chain PFAS to government agencies like the EPA. "The EPA was completely misled for decades, and it took a long time for them to realize that 'wait a minute, [chemical companies] withheld information from us.' So it's incredibly important to find a way to get that information to the agencies presented in a way that it can be understood."

What's also important is "making sure the public understands what's happening," said Bilott. "We can't just assume that if we provide the science and information to the government agencies, they will take care of it all. No, there needs to be public engagement in this. And that's what prompts the change. That's what gets the agencies to respond and to take action."

"This campaign [has begun] in the U.S. and overseas by the [chemical] makers to say there's no evidence that they're harmful, there's no evidence yet that any of these cause any problem and they should be carved out from any attempts to regulate this stuff."

Robert Bilott

The PFAS panel at ATMO America 2024 in Washington, D.C. (from left): Richie Kaur, NRDC; Michael Garry, ATMOsphere; Mindi Messmer, MedStar Health; and Gabriel Salierno, Toxics Use Reduction Institute.

ATMO America: Scientists Address PFAS Implications of HFOs, TFA

TFA is linked to potential health impacts, though the U.S. EPA relies on assurances from NOAA and the Montreal Protocol.

Three scientists considered the potential health and environmental risks of HFOs and their TFA degradation product during a panel discussion of PFAS at the ATMOsphere (ATMO) America Summit 2024 in Washington, D.C.

The conference, which ran June 10–11, 2024, was organized by ATMOsphere, publisher of this report.

The panel discussion, held on June 10, followed a keynote by Robert Bilott, the well-known environmental attorney whose lawsuits over a two-decade period first exposed the environmental and health threat of PFAS. He said that he sees "history repeating itself" in the way the chemical industry is characterizing refrigerants.

The panel agreed with Bilott that the potential hazards associated with refrigerants and TFA are being underplayed, but in a policy discussion on June 11 an Environmental Protection Agency (EPA) representative deferred to a less concerning characterization of TFA by the Montreal Protocol and the National Oceanic and Atmospheric Administration (NOAA).

One of the panelists, Mindi Messmer, Senior Research Scientist for MedStar Health and former Member of the New Hampshire House of Representatives, said she saw a parallel between the health findings for PFOA (perfluorooctanoic acid) and the potential health effects of TFA. "We are seeing a repeat of the PFOA and the GenX issue with respect to TFA," she said.

Bilott's first PFAS client, the West Virginia farmer Wilbur Earl Tennant, complained about the devastating health impact on his cows of what turned out to be PFOA. Messmer noted that German authorities found "almost identical health effects in rabbits associated with TFA exposure: They saw fetal abnormalities. They saw the same eye defects that Mr. Tennant's cows had. They see fertility issues, and they see reproductive and child development issues. So it's history repeating itself again. Do we really want to continue down this road again and in another 40 years understand that we've made a huge mistake?"

Ultrashort-chain PFAS like TFA are often cited as not being very bioaccumulative, though in the Indiana study TFA was reported to bind to protein fractions and lipids. "I absolutely think [TFA] could be bioaccumulative," said Messmer. "I think there's enough information to show that your body is not going to discriminate between how many [carbon–fluorine] bonds there are, whether it's a PFOA or a TFA. As long as it has that C–F bond, it appears that the health effects are similar."

The EPA currently excludes f-gases and TFA from its definition and takes a piecemeal approach to regulating PFAS. Messmer was one of more than 150 PFAS scientists who signed a statement calling for a broader definition of PFAS that includes f-gases and TFA and for government agencies to regulate PFAS chemicals as a class rather than one by one. "There is precedent for this; we did do this in 1980s with PCBs [polychlorinated biphenyls]," she said. "So it's not like it's an outlandish request."

By contrast, the chemical industry prefers to carve out certain types of PFAS so that they are not subject to regulation. When Messmer was working on getting her PFAS bills passed in the New Hampshire legislature, she said, "the American Chemistry Council came and told us that these PFAS chemicals are like berries – some are good for you, and some are bad for you – and we really need to limit that definition down, which is an absurd thing to say." (The American Chemistry Council declined to comment for this article.)

But New Hampshire regulators are not sampling for TFA yet in any water systems, despite the state "[leading] the way in understanding how widespread PFAS was in our water systems."

The essential-use approach

Another PFAS panelist, Richie Kaur, Senior Superpollutant Reduction Advocate for the Natural Resources Defense Council (NRDC), recommended the "essential-use approach" to HFOs in applications like residential heat pumps and air conditioners in the U.S. The HFOs would be used only as long as it took for standards groups like ASHRAE and UL, the EPA and building codes to approve higher charge limits for propane (R290) in those applications. R290 heat pump and ACs are already being used in Europe.

"There is a need for getting to sustainable refrigerant alternatives now, and it's more urgent now than it has ever been because the trade-off shouldn't be that I get cooling, but then I get exposed to this toxic chemical that's going to stay in my body forever as that science becomes clearer and clearer," said Kaur.

However, the transition to non-PFAS refrigerants "is not easy, particularly not for air conditioners and heat pumps, and particularly not here in the U.S.," she noted.

This is where the essential-use approach comes in, dealing with PFAS as a class and not chasing "one compound after the other until we fully elucidated all the effects over a period of 30 years because we'll never get there with 14,000 or potentially 7 million compounds," said Kaur. The essential-use approach would also "expedite the [standards] process and help prevent undue delays."

The essential-use framework offers time-limited exemptions for refrigerants that are deemed critical and essential when no other technically or economically feasible alternatives are available. "Except the burden of proof is on the industry," noted Kaur. "It's not on the government to point out with certainty that something is causing harm. It says we have enough evidence of harm with this class of chemicals that we will put the burden of proof on industry to demonstrate that they can come up with nothing better. It flips the script." The industry has to prove every five years or so that that exemption should still stand.

Kaur also called for more research, development and deployment of the most sustainable alternatives, "without arguing what the definition of PFAS is or why something should be forever exempted from regulations." Also critical is training the workforce on how to safely handle flammable refrigerants like propane in heat pumps and ACs. In the U.S. "the one thing that equipment manufacturers are afraid of is the liability risk of propane," she said.

Kaur pointed out the effort underway by the U.S. Department of Energy regarding the future of refrigerants. "It is talking about looking at the coefficient of performance, analyzing various refrigerant alternatives and figuring out where we need to update the codes and standards and how quickly we can get there," she said.

A third PFAS panelist, Gabriel Salierno, Green Chemist for the Toxics Use Reduction Institute at the University of Massachusetts, Lowell, explained research he conducted showing that under certain

conditions TFA – and another HFO degradation product called TFE (trifluoroacetaldehyde) – can degrade into HFC-23, a potent global warming gas with a 100-year GWP of 14,600 (IPCC, AR6). He also rejected the claim often made by the chemical industry that TFA is naturally occurring. "If anyone tells you that it is naturally occurring, don't believe them," he said.

While TFA is extremely stable, "what I found is if we start factoring in some environmental factors such as visible light and some biological process, we can produce HFC-23," Salierno said. "Actually, if TFA degrades, the product is going to be HFC-23." On the other hand, TFE – formed from the complete atmospheric breakdown of HFO-1234ze(Z) and HFO-1336mzz(Z) – is very reactive and short lived and can either become TFA, the most likely pathway, or through photolysis generate HFC-23.

Because of the high GWP of HFC-23, it only takes a 1.1% HFO conversion into HFC-23 for the effective GWP of the HFO to jump from around 1 to more than 150, the regulatory threshold for most applications in Europe and the U.S., said Salierno.

EPA on TFA

In the policy panel discussion at ATMO America on June 11, 2024, Cindy Newberg, Director of the Stratospheric Protection Division at the EPA's Office of Atmospheric Programs, provided an update on the agency's rollout of the U.S. AIM Act regulating HFCs.

Asked about concerns regarding HFOs' transformation into TFA, she said the EPA has worked closely with NOAA, which monitors the chemical for the U.S., and the Montreal Protocol to determine its stance on TFA. "And every assessment I've seen from them, and the most recent was the 2022 assessment report, they have basically said this is not of concern from their perspective, though we need to continue to monitor and keep a watch on TFA and bioaccumulation."

The EPA is open to new information on TFA when it becomes available, Newberg added. "It's not like we've never changed our minds about something. HFCs is a good example. Because we all know, 30 years ago, that's where we thought everybody was going to go."

> *"I think there's enough information to show that your body is not going to discriminate between how many [carbon–fluorine] bonds there are, whether it's a PFOA or a TFA. As long as it has that C–F bond, it appears that the health effects are similar."*
>
> ***Mindi Messmer, Senior Research Scientist for MedStar Health***

Cindy Newberg of the U.S. EPA presenting at ATMO America 2024.

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Chapter 3

Maine State House, Augusta, Maine; image by Carol Boldt via Wikimedia Commons.

Policy Measures to Regulate HFOs and TFA

Maine to Ban Sale of PFAS Refrigerants and PFAS-Containing HVAC&R Equipment in 2040

Unlike the U.S. EPA, Maine defines PFAS to include some fluorinated refrigerants, including TFA-producing HFO-1234yf.

The U.S. Environmental Protection Agency (EPA) does not consider f-gases or their degradation product TFA to be part of PFAS.

However, the state of Maine takes a different view. It plans to ban the sale of certain refrigerants, foams and aerosol propellants as well as cooling, heating, ventilation, air-conditioning and refrigeration equipment that contain "intentionally added PFAS" beginning in 2040.

The bans fall under Maine's updated PFAS law, which went into effect in August 2024. The law is one of the most aggressive state PFAS laws in the U.S., with prohibitions of PFAS in a wide range of consumer products starting in 2026, including cleaning products, cookware and cosmetics. It is the only U.S. state law known to schedule a ban for PFAS in HVAC&R products.

Notably, Maine, like at least 23 other states, defines PFAS as "substances that include any member of the class of fluorinated organic chemicals containing at least one fully fluorinated carbon atom." This definition, endorsed by more than 150 scientists, covers certain f-gases, including HFCs and HFOs, as well as TFA. The "at least one fully fluorinated carbon atom" definition is nearly identical to one developed for the OECD (Organisation for Economic Co-operation and Development) in 2021 and used around the world.

However, Maine's PFAS definition is not being used by the EPA's Office of Pollution Prevention and Toxics (OPPT), which has taken a number of approaches in recent years. Most recently, in its PFAS reporting rule, the EPA acknowledged that its definition "does not include substances that only have a single fluorinated carbon."

Intentionally added PFAS

Maine further defines "intentionally added PFAS" as "PFAS added to a product or one of its product components to provide a specific characteristic, appearance or quality or to perform a specific function." In addition to refrigerants, small amounts of PFAS are found in HVAC&R equipment in components like O-rings, the seal of the expansion valve and electronics.

Products containing intentionally added PFAS also include products that consist solely of PFAS under the law, meaning certain HFC and HFO refrigerants by themselves would be covered by the law, including HFC-125, HFC-134a, HFC-143a, HFO-1234yf, HFO-1234ze(E), HFO-1336mzz(Z) and HFO-1336mzz(E). It would not cover HFC-32, which is not a PFAS.

Maine's 2024 PFAS law also applies to HVAC&R equipment sold "in a fluorinated container or in a container that otherwise contains intentionally added PFAS." However, the prohibition does not apply to products sold "in used condition" or to "parts and other servicing needs for cooling, heating, ventilation, air-conditioning or refrigeration equipment, including refrigerants used in the servicing of such equipment" as long as the refrigerant is approved under the EPA's Significant New Alternatives Policy (SNAP) program.

Maine's updated PFAS law also establishes a "PFAS source reduction program" based on available funding. This will aim at reducing "the presence of PFAS in discharges to air, water and land by encouraging the use of safer alternatives to, and the proper management of materials containing, PFAS." The program may include information targeted to industrial or commercial users of PFAS and the education of the general public. It would support the adoption of natural refrigerants as an alternative to f-gases.

Maine has established a PFAS in Products program that can address questions about the new law at PFASproducts@Maine.gov.

TFA not covered as byproduct

Maine's law notes that Intentionally added PFAS includes "any degradation byproducts serving a functional purpose or technical effect within the product or its components." That would not apply to TFA, which forms in the atmosphere from the oxidation of certain f-gases, particularly HFO-1234yf, and comes down to earth in rainfall. However, HFO-1234yf itself would be covered, thereby preventing the formation of TFA in the atmosphere.

TFA, which is used in industrial and pharmaceutical applications, may be prohibited as a PFAS by the Maine law in 2032, when bans of PFAS not already prohibited (except for refrigerants and HVAC&R equipment) go into effect. "The law does not provide exemptions for any specific categories of PFAS," said Blazka Zgec, Environmental Specialist in the Office of the Commissioner for the Maine Department of Environmental Protection (DEP). But proliferation of TFA in the environment – in surface water, drinking water, soil, human blood serum, plants and plant-based foods – stems mostly from the breakdown of refrigerants and other products like certain pesticides, pharmaceuticals and other PFAS. Last August, the *Bangor Daily News*, a major Maine publication, reported on the growth of TFA in the environment, noting that neither Maine nor the federal government is regulating or testing for TFA.

Currently unavoidable use

The Maine DEP provides exemptions for any products "for which it has determined the use of PFAS in the product is a currently unavoidable use (CUU)" meaning it is "essential for health, safety or the functioning of society and for which alternatives are not reasonably available." In its updated "Chapter 90 – Products Containing Perfluoroalkyl and Polyfluoroalkyl Substances," adopted in April 2025, Maine outlines instructions for obtaining a CUU exemption.

Amara Strande, after whom Minnesota's PFAS law is named, at a press conference in 2023. Image from Clean Water Action

Minnesota Works on Process to Assess Whether PFAS Refrigerants Would be Banned in 2032

'Amara's Law,' one of the most aggressive PFAS regulations in the U.S., requires PFAS products to be 'essential' to avoid prohibition.

The state of Minnesota, which passed one of the most aggressive PFAS laws in the U.S. in 2023, is engaged in rulemaking to establish a process to determine whether PFAS refrigerants and other products are "essential" to avoid prohibition in 2032.

Known as "Amara's Law," the 2023 PFAS legislation was named in memory of Amara Strande, a young woman who advocated for the bill and spoke at the Minnesota Legislature in March 2023, a month before losing her fight against cancer linked to PFAS exposure. The law bans non-essential uses of PFAS. It passed with bipartisan support and the backing of businesses and advocacy groups.

Parts of the law have already started to take effect. Beginning in 2025, 11 categories of new consumer products – including carpeting, cleaning products, children's products, dental floss and cookware – sold or distributed in Minnesota must be made without PFAS. Reporting requirements on remaining PFAS use will begin in 2026. In 2032 bans on non-essential uses of PFAS in other new products, such as certain refrigerants and pesticides, will take place unless the use of the PFAS in the product is determined to be an essential and thus a "currently unavoidable use."

Notably, Minnesota, Maine and at least 22 other states define PFAS as "substances that include any member of the class of fluorinated organic chemicals containing at least one fully fluorinated carbon atom." This definition, endorsed by more than 150 scientists, covers certain f-gases, including HFCs and HFOs, as well as TFA, an atmospheric degradation product of certain commonly uses f-gases.

In another Midwestern state, Michigan, a study of rainwater led by the Ecology Center last year found TFA to be the largest PFAS contributor in two out of three sample locations. While the toxicity of TFA is still being debated, "its persistence and mobility

and the greatly increasing concentrations found in the environment are all red flags that are enough to put the brakes on," said Gillian Zaharias Miller, Senior Scientist at the Ecology Center.

Ongoing and evolving analysis

Following the adoption of Amara's Law, the Minnesota Pollution Control Agency (MPCA) has been engaged in rulemaking is to establish criteria it will use to determine which, if any, uses of intentionally added PFAS will qualify as currently unavoidable uses because they are deemed essential for the health, safety or functioning of society. This will be an ongoing and evolving analysis so that products currently deemed unavoidable can be banned if new technology or alternatives become available. A comment period took place in 2024.

"By 2032 [any PFAS] that is non-essential for the health, safety and functioning society will be banned in Minnesota," said Avonna Starck, Minnesota State Director of Clean Water Action, a Washington, D.C.-based NGO that was instrumental in passing Amara's Law. "So if there is a manufacturer that is producing something – and that would include refrigerants – and they want to make the argument that it's essential, they will have to go through an exemption process with the Minnesota Pollution Control Agency."

In the case of f-gas refrigerants, Starck agreed that many are not essential because there are safer natural refrigerant alternatives. However, industry representatives have engaged in "fear mongering" about whether banning f-gases would mean "we're not going to have refrigerators," she said. "So we really had to educate people on what were the safer alternatives, what was happening within the realm of refrigeration."

> *"By 2032 [any PFAS] that is non-essential for the health, safety and functioning society will be banned in Minnesota."*
>
> ***Avonna Starck, Minnesota State Director of Clean Water Action***

Industry representatives also argued that chemicals like HFOs are safer than higher-GWP f-gases. "But they're not telling the whole truth on what happens with HFOs when they break down [into TFA]," Starck said. "And so we did a lot of educating of legislators around what HFOs are, how they're used, what happens when they break down and how they get into our water."

In comments to the Minnesota Pollution Control Agency, the American Chemistry Council, a trade group, said it opposed "the concept of unavoidable uses" and argued that it "would establish requirements for hundreds of companies to file for exemptions to sell basic products across Minnesota," including refrigeration and HVAC. "No state, federal, or international regulatory authority has yet to implement such a massive restriction on fluoro technology as the one considered in Minnesota," the group added.

In 2024, a small group of Republican lawmakers took to social media, pledging to dismantle Amara's Law, Clean Water Action reported on its website. "We're seeing a flurry of exemption requests, attempts to change the definition of PFAS, and various tactics to delay implementation," Starck wrote in a blog.

In the end, the question will be whether certain f-gases and other PFAS "are needed and there are no other safer alternatives," she said.

Starck noted that Amara Strande passed away three days before the first Minnesota House vote on the PFAS bill named after her and two days before her 21st birthday. Her sister, Nora, has been carrying on lobbying for stronger PFAS laws at the federal level in Washington, D.C. "So the family is still involved in this work and still really active in carrying on a Amara's legacy," said Starck, adding, "Amara really made this happen."

Amara Strande's story and the law it inspired have attracted international attention. It has been referenced in a documentary on fighting PFAS in Japan, and Starck was recently interviewed for a second Japanese documentary. She was also recently visited by Cate Faehrmann, a state legislator from New South Wales, Australia.

Minnesota state flag. Image by Clker-Free-Vector-Images from Pixabay.

Minnesota Starts Toxicity Review of TFA, an HFO Byproduct

The state's Department of Health invited interested parties to share information on TFA toxicity studies.

The state of Minnesota's Department of Health (MDH) has initiated a toxicity review of trifluoroacetate (TFA). It is one of the first such governmental reviews to take place in the U.S.

The MDH conducts a review of information on a chemical's toxicity "to determine if a health-based guidance value for groundwater, air or other environmental media can be developed or updated," says the agency on its website.

Trifluoroacetate is a negatively charged ion (or anion) created when trifluoroacetic acid (also abbreviated TFA) is absorbed in rain in the atmosphere, following the breakdown of fugitive f-gases. Trifluoroacetate salts, like sodium trifluoroacetate, can be formed on the ground. In any case, the toxicity of trifluoroacetate and trifluoroacetic acid would be virtually the same in small concentrations. (In this article TFA henceforth refers to trifluoroacetic acid.)

TFA and its salts fall under Minnesota's definition of PFAS and are considered to be among the most widespread PFAS in the environment.

On April 9 MDH added trifluoroacetate to a list of several "chemicals under review," as part of the Drinking Water Contaminants of Emerging Concern (CEC) program. Chemicals remain on this list at least 30 days from the date they are added. During that time, MDH invited interested parties to share via its email health.risk@state.mn.us information on toxicity studies related to these chemicals. Upon completion of review or re-evaluation, chemicals may be added to the Human Health-Based Water Guidance Values Table.

Supported by Minnesota's Clean Water Fund, the MDH's CEC Initiative prioritizes chemicals that have been "found or are likely to be found in Minnesota drinking water and have little or no information available about human health risk," says the MDH website. It covers contaminants and potential contaminants in groundwater, surface water or soil.

Given the ubiquity of pollutants like trifluoroacetate, the CEC Initiative shares findings about CECs with individuals and groups inside and outside of state government, said the MDH.

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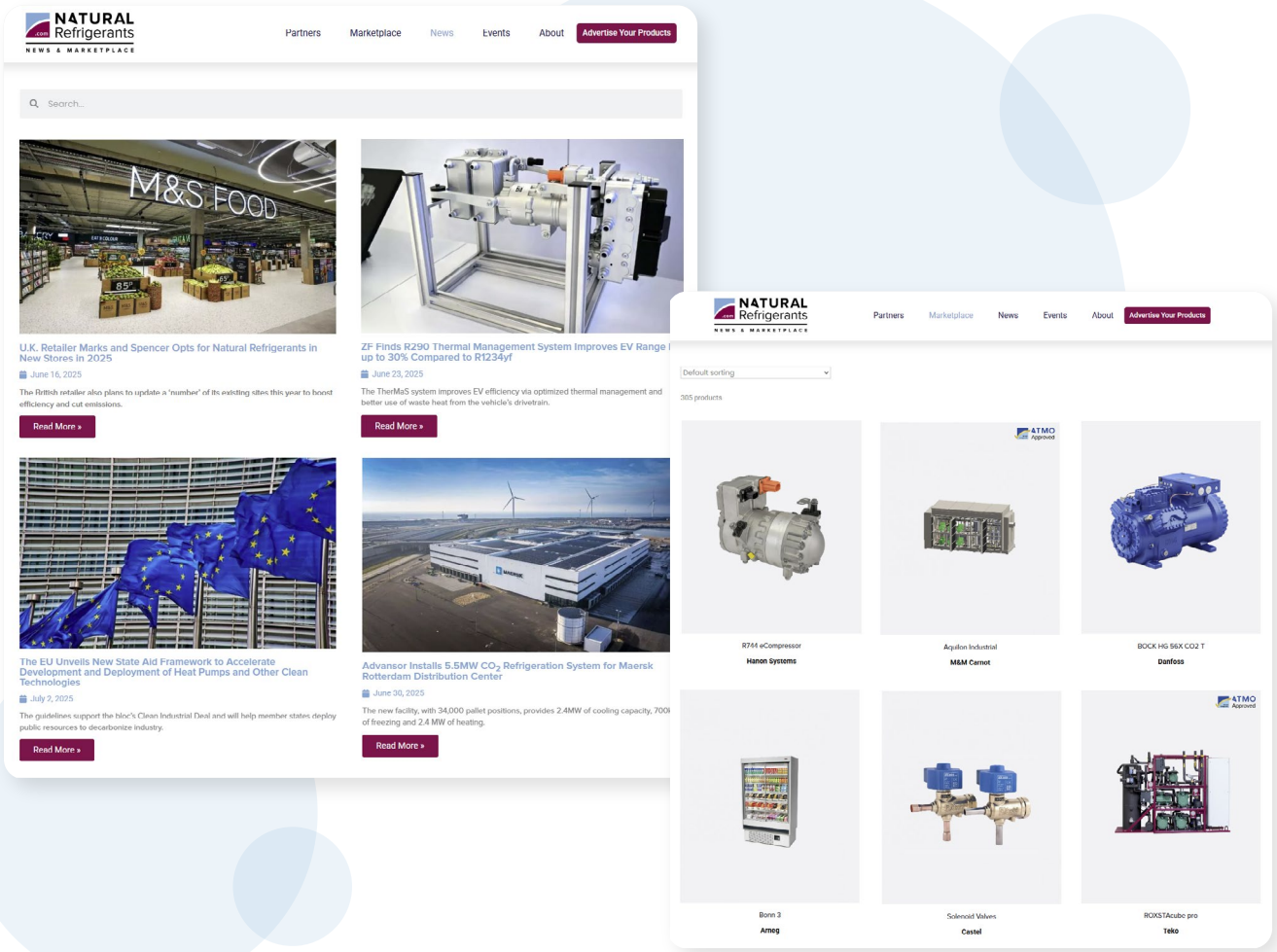

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Canadian flag; Image by ElasticComputeFarm from Pixabay.

Canada Seeks More Feedback on PFAS, Including F-Gases

The government looks for information on the availability of alternatives to PFAS in products and applications.

Environment and Climate Change Canada (ECCC), a federal agency, has invited interested parties to submit comments on the content of "Risk Management Approach for Per- and polyfluoroalkyl substances (PFAS), excluding fluoropolymers," released on March 5, 2025.

The report contains precautionary proposals for regulating PFAS, including HFOs and HCFOs, as a class.

"In coming months we will consult Canadians on proposed federal actions to improve transparency of information on the presence of substances of concern in products, including PFAS," said Steven Guilbeault, Canada's Minister of Environment and Climate Change. "These actions position us among the world's leaders in tackling harmful PFAS exposure."

The initial deadline for information was May 7.

Last year, Canada collected feedback on a preliminary report, the "Revised Risk Management Scope for PFAS."

The Canadian agencies are now seeking feedback in the following areas:

- Availability of alternatives to PFAS in products and applications in which they are currently used.
- Estimated timeframe to transition to PFAS alternatives, including challenges.
- Socio-economic impacts of replacing PFAS, including costs and feasibility of elimination or replacement.
- Quantities and concentrations of PFAS (including Chemical Abstracts Service Registry Numbers, units of measurement and applications) in products manufactured in, imported into and sold in Canada.

On March 5, 2025, the Canadian agencies also released the State of Per- and Polyfluoroalkyl Substances (PFAS) Report, which concludes that the class of PFAS, excluding fluoropolymers, "is harmful to human health and the environment." This report comprehensively addresses the proliferation of TFA in the environment.

"Given the potential for TFA to cause adverse effects and its ubiquitous presence in the environment and organisms alongside other PFAS, the potential for TFA to contribute to cumulative effects of PFAS in organisms is of concern," the State of PFAS report added. "As such, HFOs and HCFOs that are PFAS according to the definition of the class of PFAS are within the scope of this report."

Notably, both reports use a definition for PFAS established by the Organisation for Economic Co-operation and Development (OECD): PFAS are fluorinated substances that contain at least one fully fluorinated methyl or methylene carbon atom. This definition, widely endorsed by PFAS scientists, includes f-gases and TFA. The EU follows this definition, but the U.S. Environmental Protection Agency (EPA) does not, thereby excluding f-gases and TFA from American PFAS regulations. The EPA has also declined to address PFAS as a class despite calls to do so.

Three-phase PFAS bans

The Canadian government's authority to regulate chemicals derives from the Canadian Environmental Protection Act, 1999 (CEPA), which allows authorities to address substances that "may have immediate or long-term harmful effects on the environment or its biological diversity" and "constitute or may constitute a danger in Canada to human life or health." On March 8, 2025, the ECCC issued a proposed order to add PFAS as a class, excluding fluoropolymers, to Part 2 of CEPA Schedule 1. CEPA also allows regulation of substances that are considered highly persistent, such as TFA, or transform to persistent PFAS, such as HFO-1234yf.

In 2012, Canada banned specific long-chain PFAS such as PFOA and PFOS, which were found to be harmful to human health. In 2021, the government began addressing the rest of PFAS (excluding fluoropolymers) as a class; it is now proposing the new risk management actions through a three-phase PFAS prohibition schedule, with refrigerants such as HFOs and HCFOs falling under phase 3:

Phase 1: Uses not currently regulated in firefighting foams, due to high potential for environmental and human exposure.

Phase 2: Uses not needed for the protection of health, safety or the environment. This includes consumer products such as cosmetics, natural health products and non-prescription drugs, food packaging materials, textile uses and ski waxes.

Phase 3: Uses requiring further evaluation of the role of PFAS for which currently there may not be feasible alternatives and taking into consideration socio-economic factors. In addition to fluorinated gas applications such as refrigeration and spray-foam insulation, these include prescription drugs, medical devices and industrial food contact materials.

At each phase of risk management, exemptions will be considered when necessary, with attention to feasible alternatives and socio-economic factors.

Voluntary actions

In addition to the proposed prohibition of PFAS uses, complementary voluntary risk management actions are also being considered. These include:

- Exploring opportunities to increase disclosure of information (such as through labelling) regarding chemicals of concern.
- Engaging with interested sectors on highlighting industry-led voluntary phase out of PFAS.

Following a consultation period in the summer and fall of 2025, the government plans to publish a proposed regulation for phase 1 in the spring of 2027. Consultations for phases 2 and 3 will follow. Publication of final regulations would come no more than 18 months after publication of proposed regulations.

Proposed risk management actions are meant to be complementary to other regulations such as the Ozone-depleting Substances and Halocarbon Alternatives Regulations (ODSHAR), which control the use of CFCs, HCFCs and HFCs. Because HFOs and HCFOs are halocarbon alternatives, their addition to the ODSHAR may be considered.

In addition, other ongoing actions on PFAS will continue, such as development of drinking water guidelines and environmental quality guidelines, management of contaminated sites and the continued administration of existing risk management actions.

In a statement responding to the release of the PFAS reports on March 5, 2025, the Chemistry Industry Association of Canada (CIAC) said PFAS "are critical to a modern way of life," adding that "fluorinated substances are essential for many industrial sectors from electric vehicles to pharmaceuticals to cellular phones." CIAC said it will "share the proposed Risk Management timetable with its members and actively participate in discussions on how to best address the identified exposures of concern."

A February 2024 report called "Canada's PFAS Problem" by the Canadian NGO Environmental Defence argued that chemical industry lobbyists have come out "in record numbers" to resist federal government ambition to address PFAS as a class of chemicals. Environmental Defence urges the Canadian government "to take urgent action and tackle this issue in a more comprehensive way, as PFAS researchers have been promoting for years."

"These actions position us among the world's leaders in tackling harmful PFAS exposure."

Steven Guilbeault, Canada's Minister of Environment and Climate Change

Image from European Chemical Agency (ECHA).

European Chemical Agency Publishes Proposal to Restrict PFAS Chemicals, Including Some F-Gases and TFA

The proposal would restrict HFC-125, HFC-134a, HFC-143a, HFO-1234yf, HFO-1234ze(E), HFO–1336mzz(Z) and HFO-1336mzz(E).

The European Chemicals Agency (ECHA), an agency of the EU, on February 7, 2023, published a proposal from the national authorities of Denmark, Germany, the Netherlands, Norway and Sweden to restrict PFAS under REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals), the EU's chemicals regulation.

The long-awaited "Universal Restriction Proposal" – officially known as the Annex XV Restriction Report – would restrict the manufacture, use or sale of certain f-gas refrigerants as substances on their own or in blends according to certain thresholds.

This would include both HFCs and HFOs, such as HFC-125, HFC-134a, HFC-143a, HFO-1234yf, HFO-1234ze(E), HFO–1336mzz(Z) and HFO-1336mzz(E). The proposal would apply to TFA, an atmospheric degradation product of, notably, HFO-1234yf (100% conversion) and HFC-134a (up to 20% conversion).

The restrictions would apply 18 months from entry into force (EiF) of the final text. Restrictions on these f-gases would support the wider adoption of natural refrigerants across Europe.

"It is more about seeing the possibilities rather than the ghosts when selecting the optimal refrigerant for the project or a product," note the five countries submitting the proposal in Annex E.

The definition of PFAS used in the proposal is close to the one adopted by the Organisation for Economic Co-operation and Development (OECD) in 2021, which includes many f-gas refrigerants and TFA. This definition of PFAS has already been proposed in a complementary PFAS Restriction Intention on firefighting foams, creating a parallel workstream that reinforces the need to maintain this definition.
The proposal defines PFAS as "substances that contains at least one fully fluorinated methyl (CF3-)

or methylene (-CF2-) carbon atom (without any H/Cl/Br/I attached to it)."

F-gases considered PFAS were added to the SIN (Substitute It Now) List of hazardous chemicals compiled by ChemSec (The International Chemical Secretariat), a nonprofit organization funded by the Swedish government. TFA has been on the list since 2019.

Exemptions proposed

The proposal contains some time-based refrigerant exemptions:

- Refrigerants in low-temperature refrigeration below -50°C (-58°F) until 6.5 years after EiF
- Refrigerants in laboratory test and measurement equipment until 13.5 years after EiF
- Refrigerants in refrigerated centrifuges until 13.5 years after EiF
- Refrigerants used in maintenance and refilling of existing HVACR equipment for which no drop-in alternative exist until 13.5 years after EiF
- Refrigerants in mobile air-conditioning (MAC) systems in combustion engine vehicles with mechanical compressors until 6.5 years after EiF
- Refrigerants in transport refrigeration other than in marine applications until 6.5 years after EiF

And one general exemption:

- Refrigerants in HVACR-equipment in buildings where national safety standards and building codes prohibit the use of alternatives

The proposed exemptions could change based on the feedback to the final opinion published by the committee on socioeconomic analysis (SEAC)., or based on new information the European Commission will have when it drafts the final text.

ECHA's timeline

Between March and September 2023, public consultation on the Universal PFAS Restriction Proposal took place, resulting in the submission of more than 5,600 comments. Updates of the proposal were made after completion of discussions on each sector.

In 2025, between March and June, ECHA's committees on risk assessment (RAC) and socio-economic analysis (SEAC) have been discussing the restriction of f-gases as PFAS. That will be followed by provisional conclusions between June and September.

During quarter one of 2026, the SEAC opinion will be published; there will be a 60-day feedback period. In quarter two of 2026, the SEAC final opinion will be sent to the European Commission.

In quarter four of 2026, the European Commission will send the final text to the ECHA Member State Commission for approval. In quarter three of 2028, the Universal PFAS Restriction enters into force.

Coalition for PFAS Free Cooling & Heating Is Underway

The organization is dedicated to promoting natural refrigerants as alternatives to harmful PFAS refrigerants and supporting an ambitious European PFAS regulation.

The Coalition for PFAS Free Cooling & Heating was launched in October 2024, with ATMOsphere, publisher of this report, as a founding member.

The organization is dedicated to promoting natural refrigerants as alternatives to harmful PFAS in cooling and heating systems and supporting an ambitious European PFAS regulation.

In addition to ATMOsphere, members of the coalition include Fenagy, Secon, Teko, Konvekta, Refra, Güntner, Dorin, Vahterus and Zudek. The coalition is open to other companies focused on the use of PFAS-free natural refrigerants – CO_2 (R744), ammonia (R717), hydrocarbons, air and water, all found in nature – in HVAC&R applications.

Because PFAS refrigerants are increasingly considered a potential threat to human health and the environment, the Coalition for PFAS Free Cooling & Heating intends to promote restrictions on these refrigerants and their degradation products over the next two years through the impending EU PFAS Restriction Regulation. This will include engaging with policymakers and offering detailed research and technical data to prove that there are many commercially available alternatives today.

“It’s not easy for policymakers to address this PFAS file, especially with regard to refrigerants, which are the largest and fastest growing source of PFAS in Europe,” said Marc Chasserot, CEO of ATMOsphere. “We want to make sure that policymakers have accurate data so that they are fully informed about alternatives as they evaluate this critical issue.”

In the HVAC&R industry, PFAS can be found in the O-rings, seals and electronics of HVAC&R systems. In addition, many f-gas refrigerants, including HFC-134a, HFO-1234yf and HFO-1234ze(E), are considered PFAS in the EU because they have at least one fully fluorinated carbon atom. Importantly, HFO-1234yf, the most common HFO refrigerant, breaks down rapidly and completely in the atmosphere to produce another PFAS, TFA, which has been proliferating in the environment, including drinking water.

"We want to make sure that policymakers have accurate data so that they are fully informed about alternatives as they evaluate this critical issue."

Marc Chasserot, CEO of ATMOsphere

Natural refrigerants, which are already used as a substitute for ozone-layer-depleting CFCs and global-warming-increasing HFCs, can be used in place of PFAS refrigerants in virtually all applications, the Coalition believes. Natural refrigerant systems have been widely adopted in many European industries, including supermarkets, cold storage and food processing, demonstrating that these systems are energy efficient and cost competitive.

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Chapter 1
The Presence of HFOs and TFA in the Environment

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- Study Puts Annual Cost of Removing PFAS from the Environment in Europe, Including TFA, at €100 Billion (March 28, 2025): https://tinyurl.com/57eptsuu

Chapter 2
HFOs and TFA: Evidence of a Potential Threat to Human Health and the Environment

- Scientists Publish Statement Defending PFAS Definition that Includes F-Gases and TFA (June 20, 2025): https://tinyurl.com/mpdmya63
- How Harmful Is TFA? (February 13, 2025): https://tinyurl.com/3uufxu9n
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- Study Calls F-Gas Byproduct TFA a 'Planetary Boundary Threat' (November 4, 2024): https://tinyurl.com/dbt7cdks

- ATMO Europe: Natural Refrigerants Expert Kauffeld Predicts HFOs Have 8 Years Left (November 28, 2024): https://tinyurl.com/bddxv7az
- ATMO America: Famed PFAS Lawyer Bilott Sees 'History Repeating Itself' with F-Gas Refrigerants (June 15, 2024): https://tinyurl.com/m8vupf7c
- ATMO America: Scientists Address PFAS Implications of HFOs, TFA (June 19, 2024): https://tinyurl.com/muh8ykxk

Chapter 3
Policy Measures to Regulate HFOs and TFA

- Maine to Ban Sale of PFAS Refrigerants and PFAS-Containing HVAC&R Equipment in 2040 (December 20, 2024): https://tinyurl.com/3e57x74k
- Minnesota Works on Process to Assess Whether PFAS Refrigerants Would be Banned in 2032 (January 29, 2025): https://tinyurl.com/jhfnkfuk
- Minnesota Starts Toxicity Review of TFA, an HFO Byproduct (April 28, 2025): https://tinyurl.com/yzwfud9e
- Canada Seeks More Feedback on PFAS, Including F-Gases (April 1, 2025): https://tinyurl.com/5bm8wbhm
- European Chemical Agency Publishes Proposal to Restrict PFAS Chemicals, Including Some F-Gases and TFA (February 10, 2023): https://tinyurl.com/39j5zyfn
- Coalition for PFAS Free Cooling & Heating Is Underway (October 29, 2024): https://tinyurl.com/3s5vhzcv

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