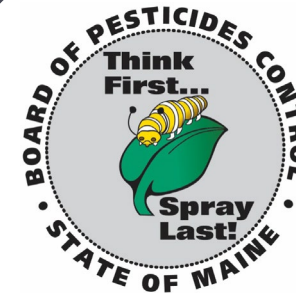


# Contamination of Pesticide Products By “Forever Chemicals”; What We Know About PFAS & Pesticides

Pamela J. Bryer, Ph.D., Pesticides  
Toxicologist  
Board of Pesticides Control  
Maine Department of Agriculture,  
Conservation, & Forestry






# Why is the BPC talking about PFAS?

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- Several PFAS chemicals have recently been associated with certain pesticide products
- Containers can react with the contents and create some PFAS



A person wearing a red life vest is rowing a wooden boat on dark, rippling water. The person is seen from behind, using a wooden oar. The scene is dimly lit, suggesting dusk or dawn.

PFAS & pesticides is a very nuanced topic,  
we are still learning about the connection.

---

We've been using PFAS compounds in our daily lives for 60+ years

# PFAS are common in our lives

## Sources of PFAS?

- GoreTex / waterproof breathable clothing
- Teflon / non-stick cookware
- Dental floss / slick non-stick anything
- Fast food containers / oil proof & waterproof papers and cardboard
- Firefighting foams
- Medicines
- Refrigerants/ Aerosols
- Many industrial applications

DESSERT AND  
BREAD WRAPPERS



BURGER AND  
SANDWICH WRAPPERS



PAPERBOARD

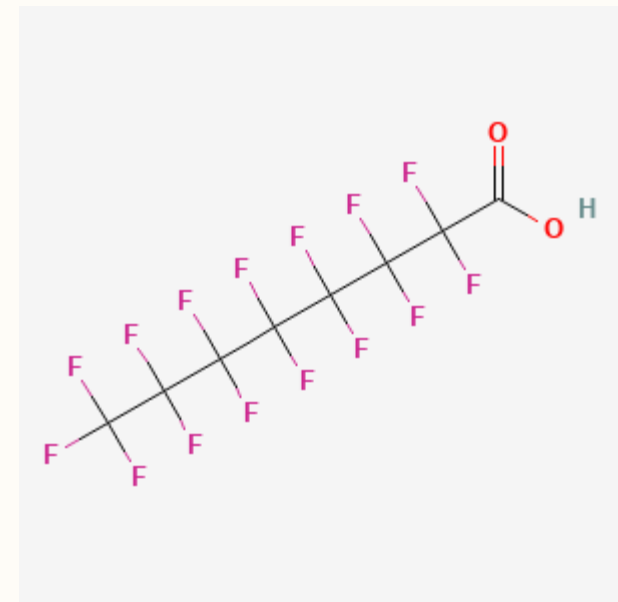




# Per- and Polyfluoroalkyl Substances (PFAS)

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- Pronounced as “P -fas”
- Often confused with “P -foss” which is a specific type of PFAS

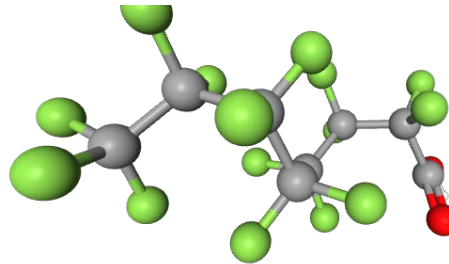


Perfluorooctanoic acid  
C8



We will come back to this topic in a bit...

## Not all molecules with fluorine are PFAS



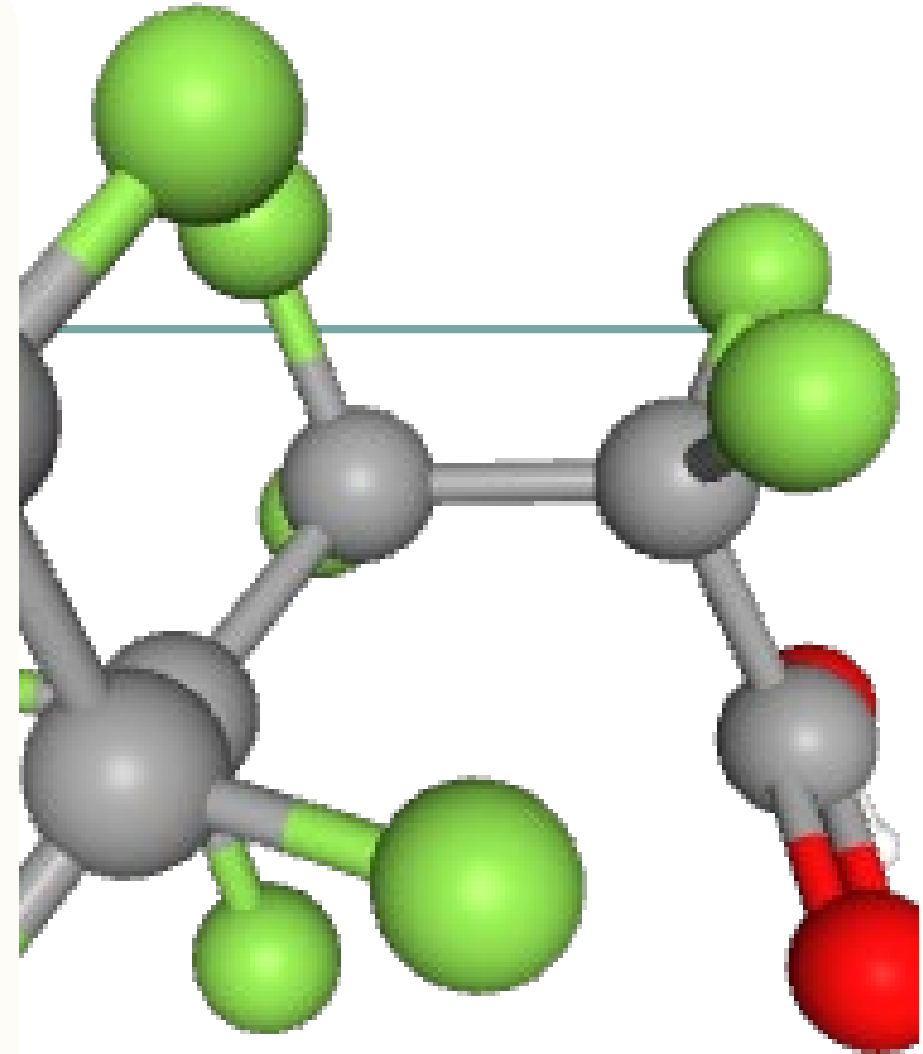
- Fluorine is a naturally occurring element, rare in organisms
- Many compounds are “organofluorines”
- Fluorocarbons
- Fluorine gas



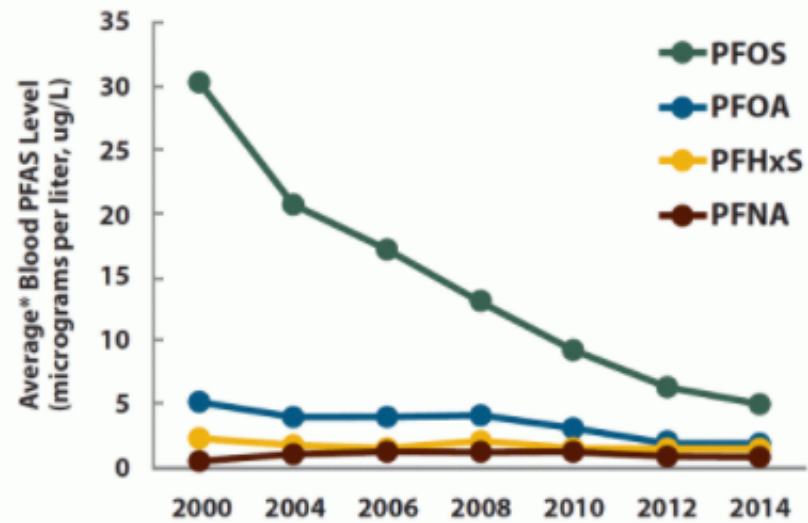
# “Forever chemicals”!?

---

- It is hard to generalize about a group of 10,000+ of anything, but...
- PFOA isn't degraded by bacteria / microorganisms, or water, or sunlight; one study estimates:
  - *256 years at ocean surface*
  - *>25,000 years coastal ocean*



## Blood Levels of the Most Common PFAS in People in the United States from 2000-2014



\* Average = geometric mean

**Data Source:** Centers for Disease Control and Prevention. Fourth Report on Human Exposure to Environmental Chemicals, Updated Tables, (January 2017). Atlanta, GA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention.

PFOA (blue) in the U.S. general population is 2.08 micrograms per liter (mcg/L) of blood

*-about ½ lost every 3 years from your body*





# Human health effects

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- Immune system
- Increased cholesterol
- Liver enzyme changes
- Increased blood pressure & pre-eclampsia
- Higher rates of testicular & kidney cancer
- Slight decrease in birth weight

# The Anvil 10+10 story

## Timeline

- Citizen concerned about water quality following mosquito spraying organized collection of samples of the sprayed pesticide
- Samples came back positive for several different PFAS



The screenshot shows the PEER website header with navigation links: HOME, CONTACT PEER, ABOUT, AREAS OF WORK, NEWSROOM, LEGAL RESOURCE CENTER, and a DONATE button. The main content area features a green banner with the title "Aerially Sprayed Pesticide Contains PFAS" and the date "Dec 1, 2020". Below the banner, the text reads: "For Immediate Release: Tuesday, December 1, 2020. Contact: Kyla Bennett (508) 230-9933; Kirsten Stade kstade@peer.org". The main headline is "Aerially Sprayed Pesticide Contains PFAS" followed by a sub-headline "“Forever Chemicals” Potentially Spread Over Millions of Acres". The body text states: "Washington, DC — State efforts to control mosquito-borne illnesses may be creating a new health problem. The insecticide Massachusetts and numerous other states use for mosquito control, both applied aerially and sprayed from trucks along roads, contains per-and polyfluoroalkyl substances (PFAS), according to lab test results posted today by Public Employees for Environmental Responsibility (PEER)." On the right side, there is a sidebar with the PEER logo, phone number (202-265-7337), a "Send an email" link, and "SUBSCRIBE" and "DONATE" buttons. At the bottom right of the sidebar, it says "RECENT PRESS RELEASES".

September 1, 2020



# The Anvil 10+10 story

## Timeline (side note)

- Prior to this press release the state regulatory pesticide community had been hearing about this issue.
- In 2019, via email, EPA stated that there were no current PFAS compounds as active ingredients or as inerts



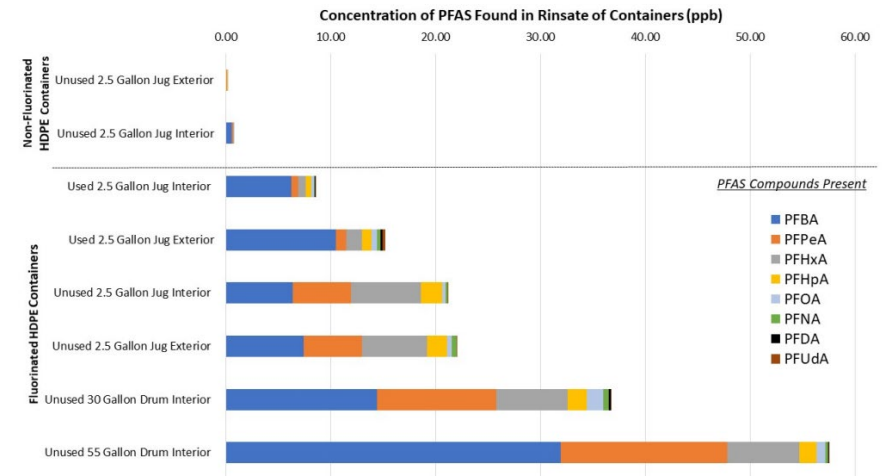
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September 1, 2020

# The Anvil 10+10 story

## Timeline

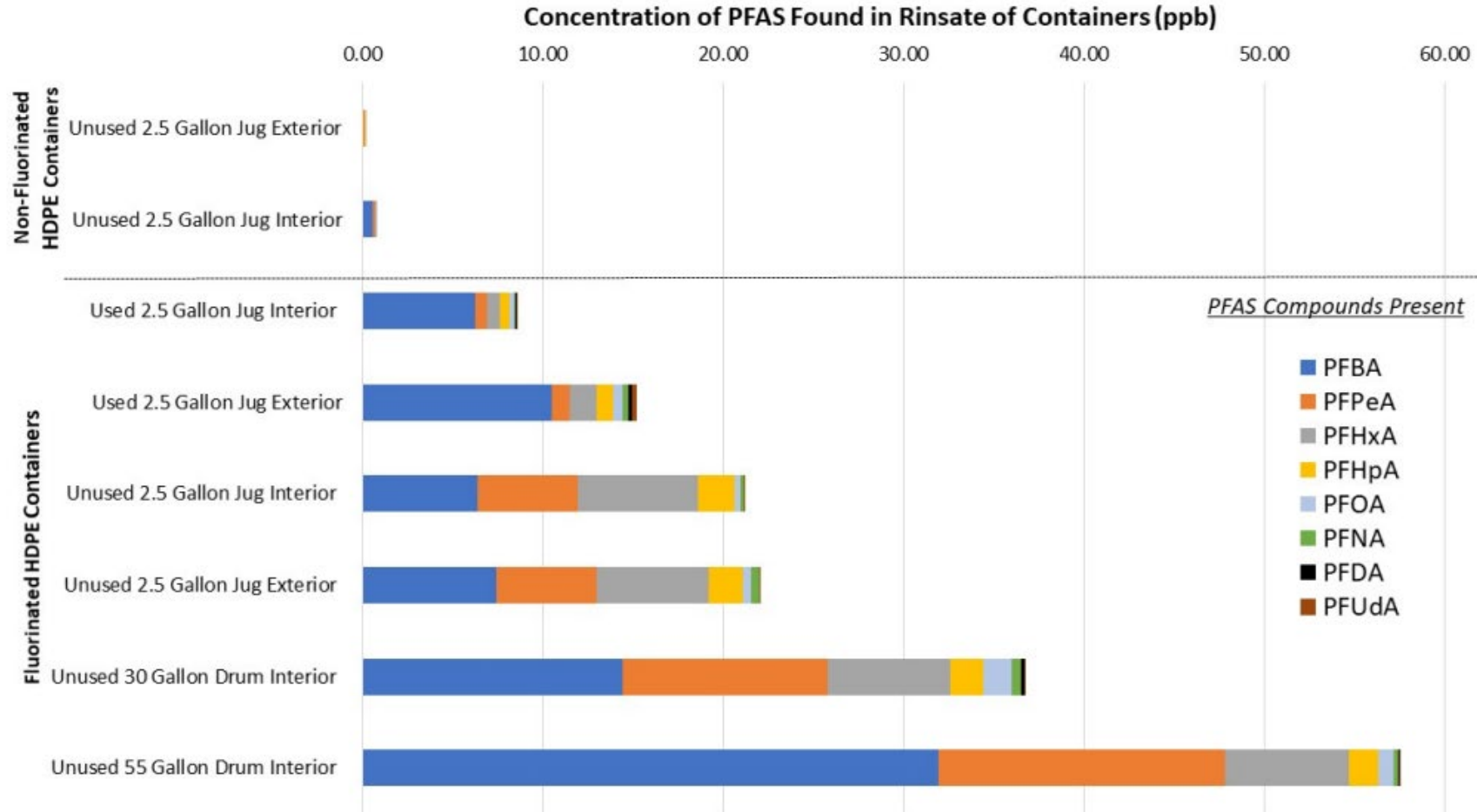
- Mass followed up with testing, confirming PFAS
- EPA collected samples from:
  - Product as sold but unopened
  - Product prior to being packaged
  - Packaging prior to being filled



March 5, 2021



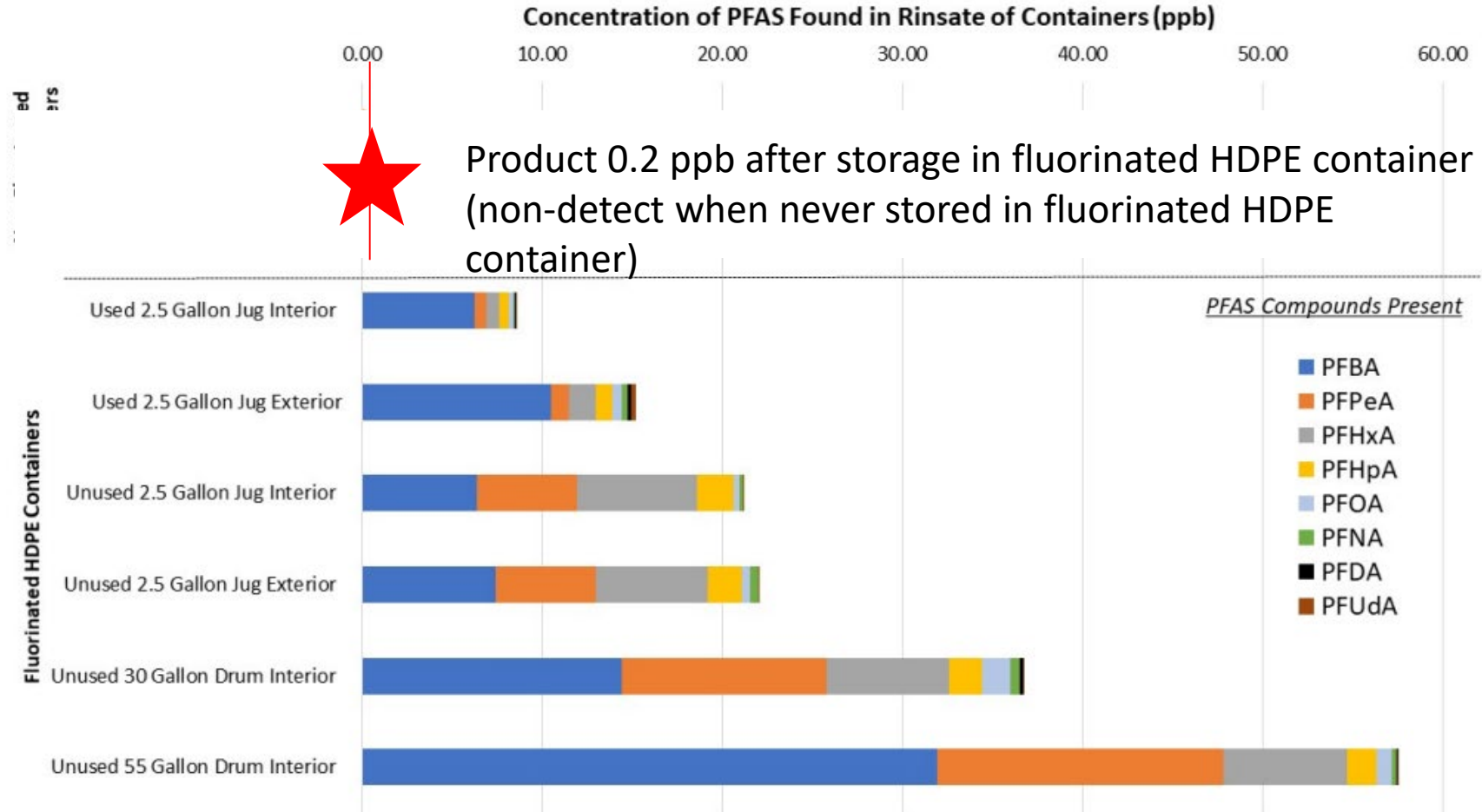
# The Anvil 10+10 story



March 5, 2021

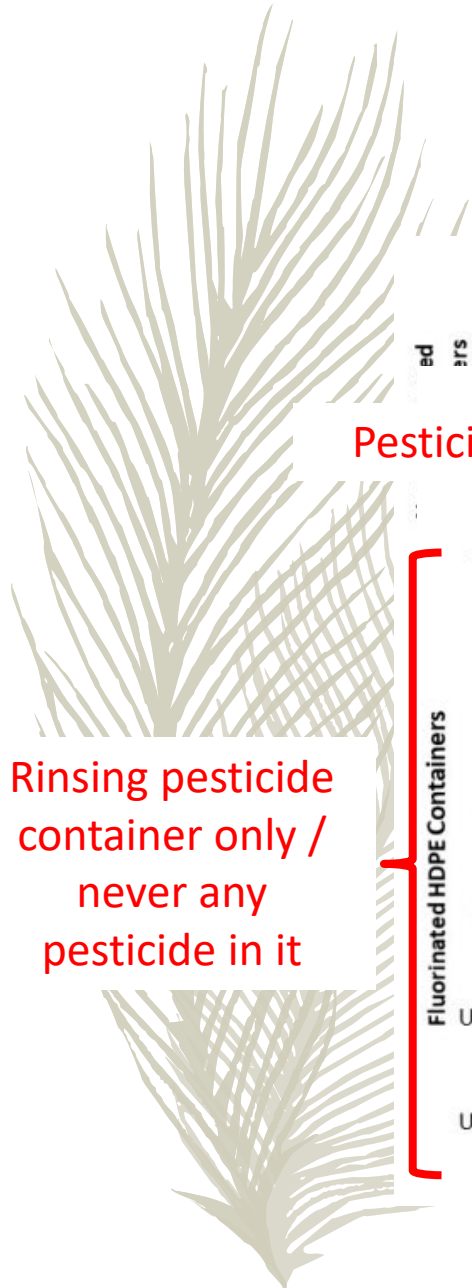


# The Anvil 10+10 story



March 5, 2021

# The Anvil 10+10 story



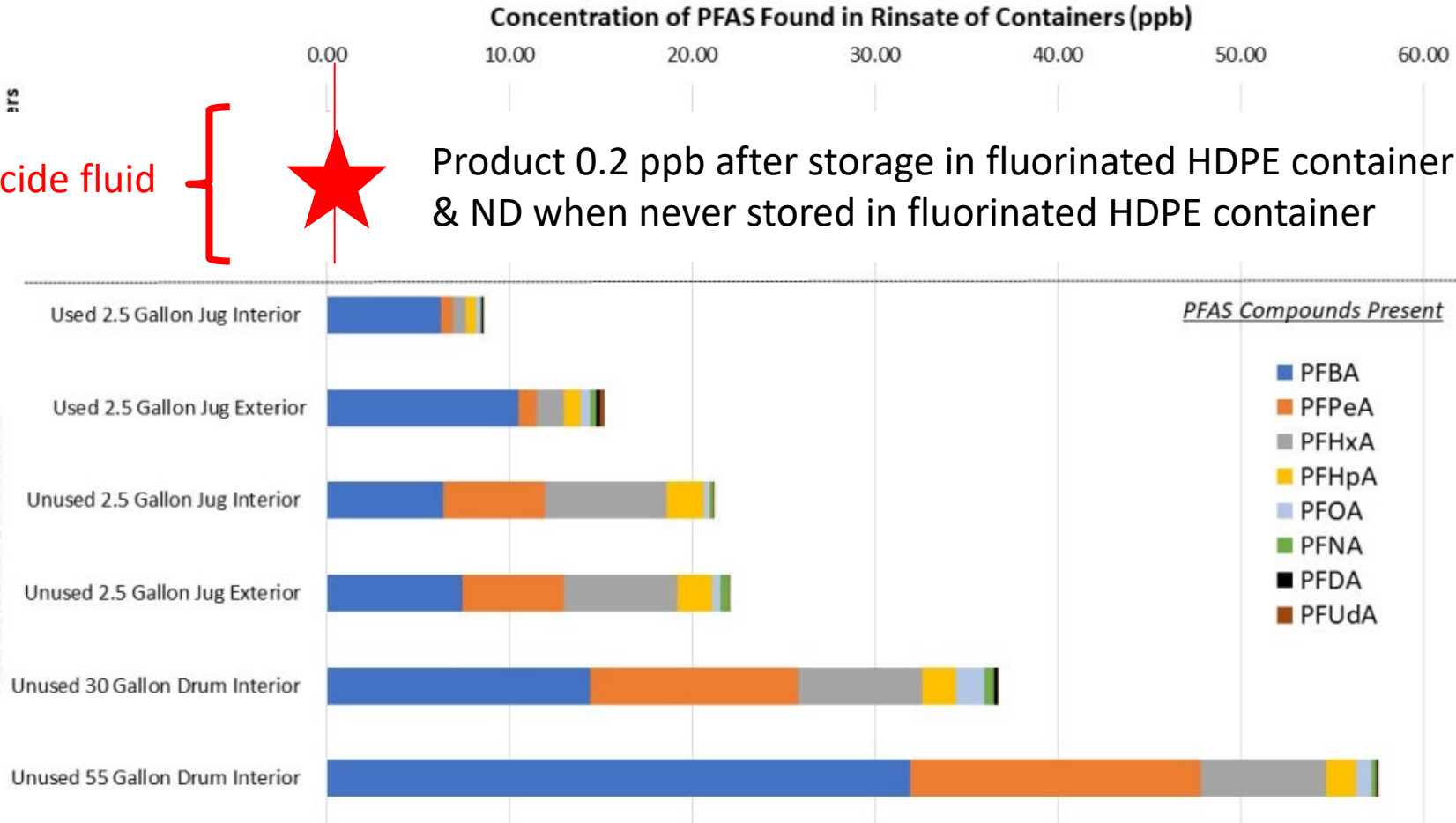
Pesticide fluid



Product 0.2 ppb after storage in fluorinated HDPE container & ND when never stored in fluorinated HDPE container

Rinsing pesticide container only / never any pesticide in it

Fluorinated HDPE Containers



March 5, 2021



# The Anvil 10+10 story

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EPA confirmed there are PFAS coming from these products, but the big question then was, WHY?















- Was it added during the manufacture of the containers?
- Contamination of the containers during manufacturing?
- Fluorination of the containers



# The Anvil 10+10 story

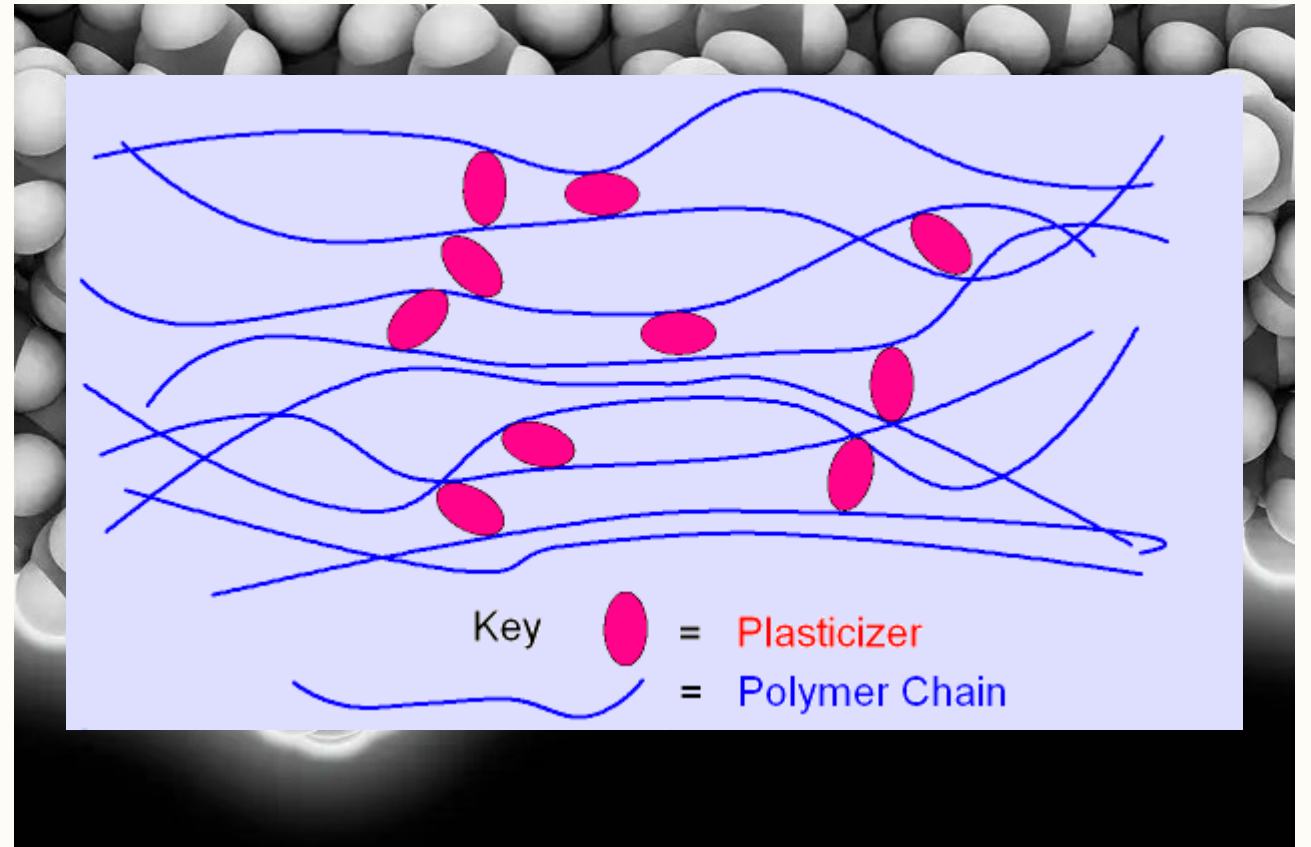
Anvil 10+10 was packaged in  
Number 2 - HDPE plastic

– Fluorination

 PETE	 HDPE	 PVC	 LDPE	 PP	 PS	 OTHER
<b>Polyethylene Terephthalate</b>	<b>High-Density Polyethylene</b>	<b>Polyvinyl Chloride</b>	<b>Low-Density Polyethylene</b>	<b>Polypropylene</b>	<b>Polystyrene</b>	<b>Other</b>
Common products: soda & water bottles; cups, jars, trays, clamshells	Common products: milk jugs, detergent & shampoo bottles, flower pots, grocery bags	Common products: cleaning supply jugs, pool liners, twine, sheeting, automotive product bottles, sheeting	Common products: bread bags, paper towels & tissue overwrap, squeeze bottles, trash bags, six-pack rings	Common products: yogurt tubs, cups, juice bottles, straws, hangers, sand & shipping bags	Common products: to-go containers & flatware, hot cups, razors, CD cases, shipping cushion, cartons, trays	Common types & products: polycarbonate, nylon, ABS, acrylic, PLA; bottles, safety glasses, CDs, headlight lenses
Recycled products: clothing, carpet, clamshells, soda & water bottles	Recycled products: detergent bottles, flower pots, crates, pipe, decking	Recycled products: pipe, wall siding, binders, carpet backing, flooring	Recycled products: trash bags, plastic lumber, furniture, shipping envelopes, compost bins	Recycled products: paint cans, speed bumps, auto parts, food containers, hangers, plant pots, razor handles	Recycled products: picture frames, crown molding, rulers, flower pots, hangers, toys, tape dispensers	Recycled products: electronic housings, auto parts,
						

# The Anvil 10+10 story

- Fluorination of plastics and what plastics are

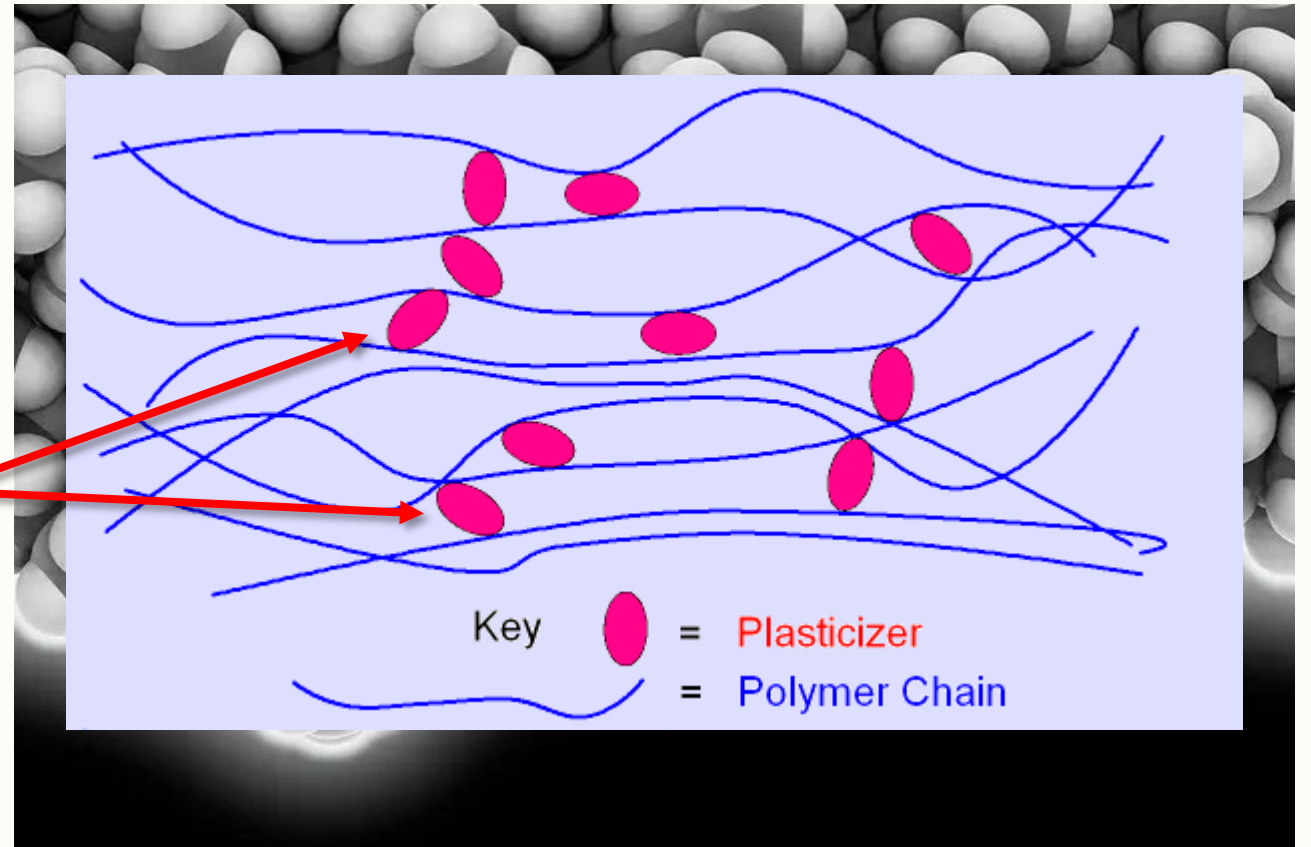




# The Anvil 10+10 story

- Fluorination of plastics and what plastics are

See these plasticizers? They help the plastic sheet together. They are not well connected to the long strands.

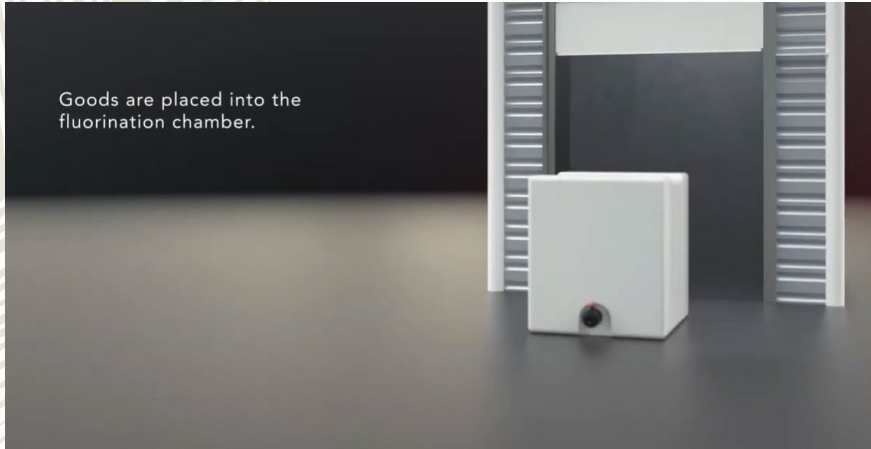




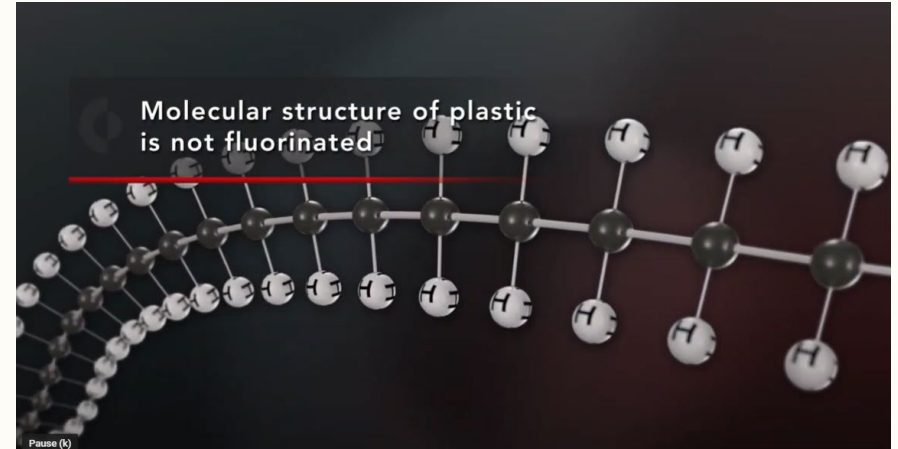
# Fluorination of containers

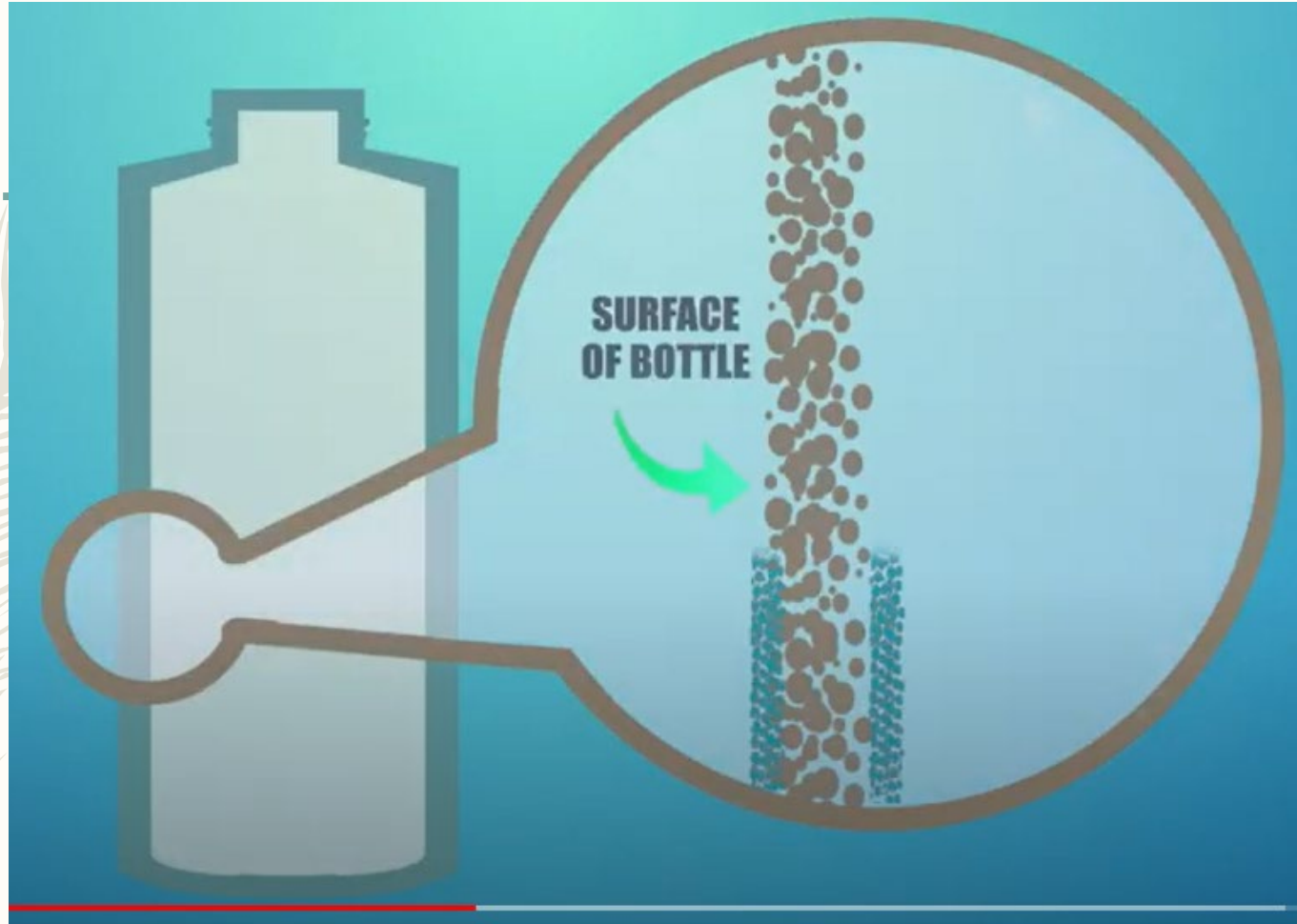
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Goods are placed into the fluorination chamber.



Molecular structure of plastic is not fluorinated



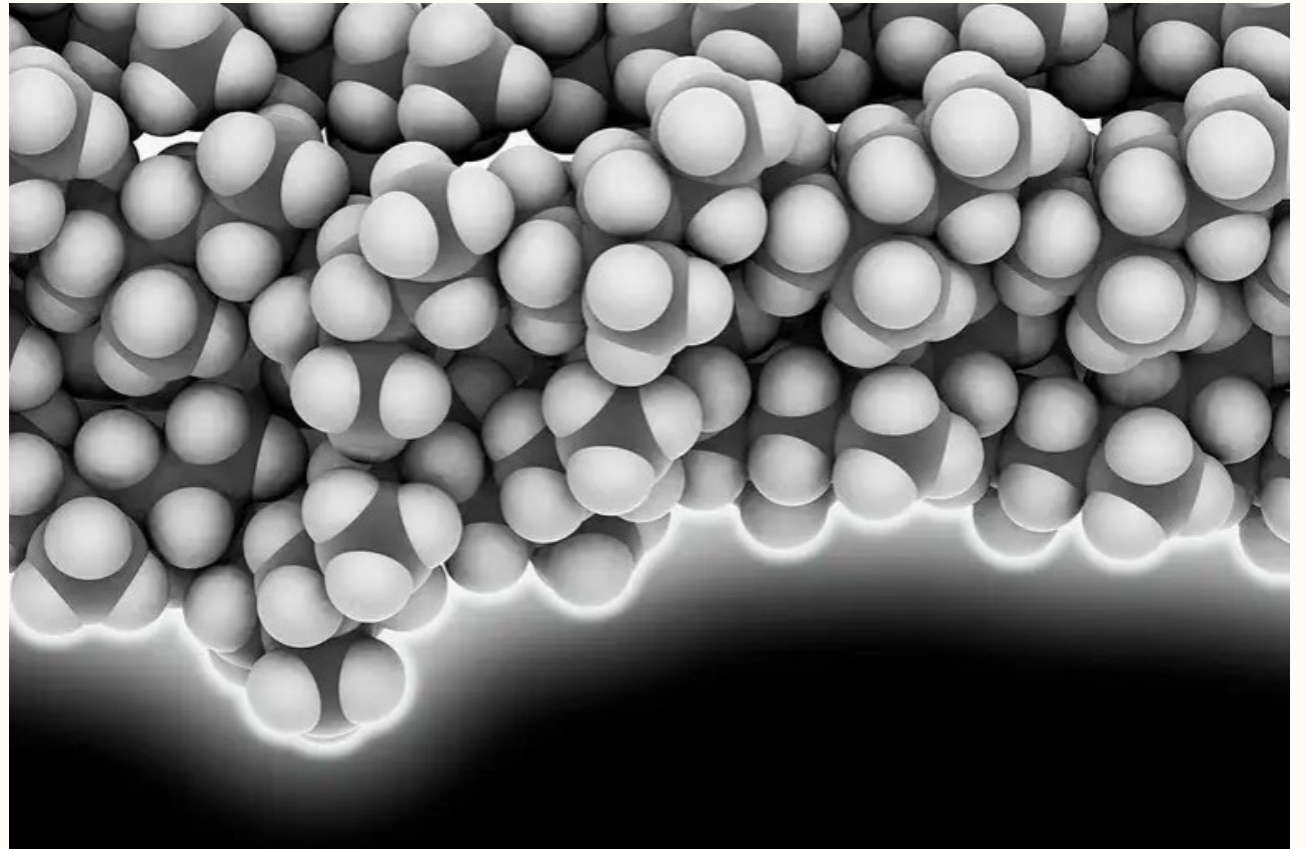




# The Anvil 10+10 story

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- Fluorination of plastics and what plastics are

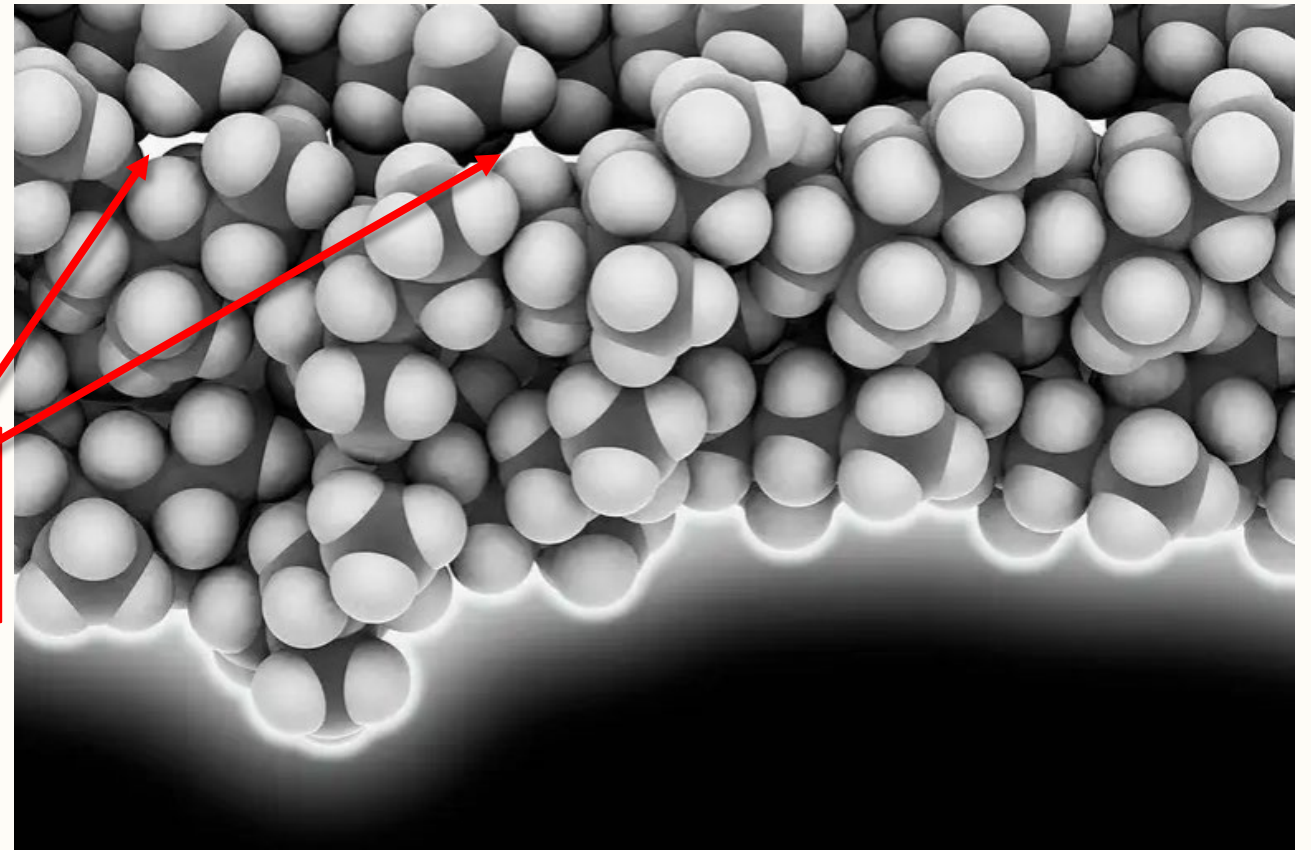




# The Anvil 10+10 story

- Fluorination of plastics and what plastics are

See these gaps? These gaps let oxygen in and flavors out. This is what fluorination fixes.





# levels of fluorination

level 1

level 2

level 3

level 4

level 5

super level 5

level 9

highest level SPAL

1:26 / 1:51

CC

Settings

Fullscreen

SPAL

The diagram illustrates the levels of fluorination, showing a progression from level 1 to level 9. The levels are represented by horizontal bars of varying shades of blue and green, with the highest level (SPAL) highlighted in orange. The video player interface at the bottom shows the current time (1:26) and total duration (1:51), along with standard playback controls.



We have been  
fluorinating containers  
since the 1970s

---

FDA, as promulgated in 1983,  
allows fluorination of plastic food-  
contact materials that produces up  
to 5,000 parts per billion (ppb) of  
total fluorine in the food.



That's fluorine not PFAS

epa.gov/pesticides/pfas-packaging

United States Environmental Protection Agency

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- Pest Control and Pesticide Safety for Consumers
- Pesticide Registration

## Per- and Polyfluoroalkyl Substances (PFAS) in Pesticide Packaging

As part of the U.S. Environmental Protection Agency's (EPA) extensive efforts to address PFAS, the Agency is making new information available about EPA testing showing PFAS contamination from fluorinated containers. [Read EPA's press statement.](#)

While the Agency continues to investigate and assess potential impacts on health or the environment, the affected pesticide manufacturer has voluntarily stopped shipment of any products in fluorinated high-density polyethylene (HDPE) containers.

On March 5, 2021, EPA released testing data showing PFAS contamination from the fluorinated HDPE containers used to store and transport a mosquito control pesticide product. The Agency also outlined its next steps as it continues working with a variety of stakeholders to collect additional information on this issue. [Read EPA's press statement.](#)

On September 29, 2021, EPA released an internally validated method for detecting 28 PFAS compounds in oily matrices. The method is intended to help pesticide manufacturers, state regulators, and other interested stakeholders test pesticide products formulated in oil, petroleum distillates, or mineral oils for PFAS. [View Method for the Analysis of PFAS in Oily Matrix \(pdf\)](#). [Read the update here.](#) EPA used this oily matrix method to analyze three stored samples of mosquito control pesticide products (Permanone 30-30 and PermaSease 30-30) and determined that none of the tested samples contained PFAS at or above the Agency's method limit of detection. [View the Results \(pdf\)](#).

# EPA's Response

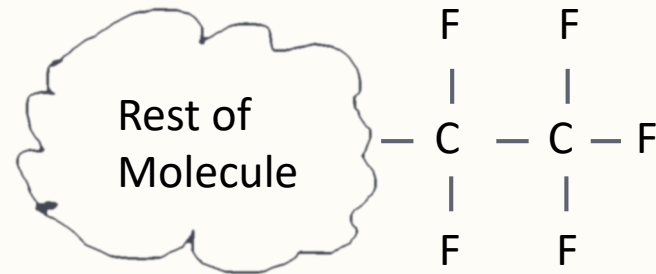
- Timeline
- Test methods
- Test results
- Links to other information



# EPA Q & A

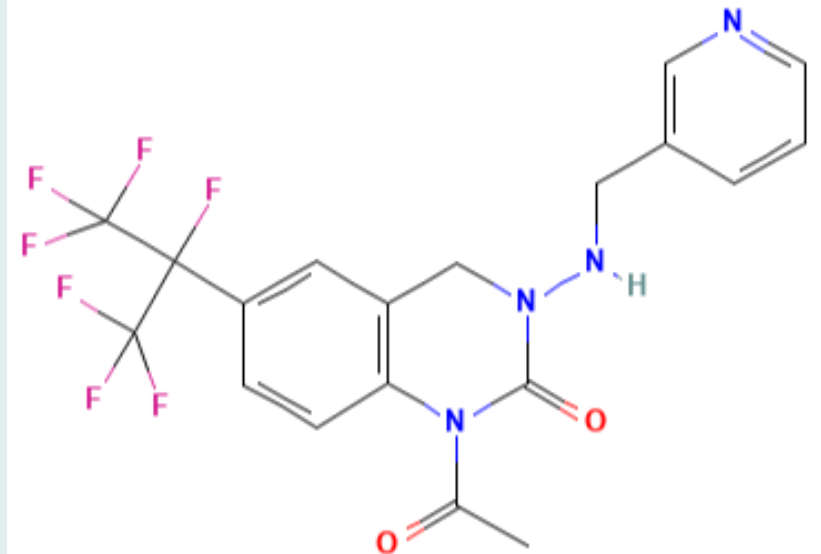
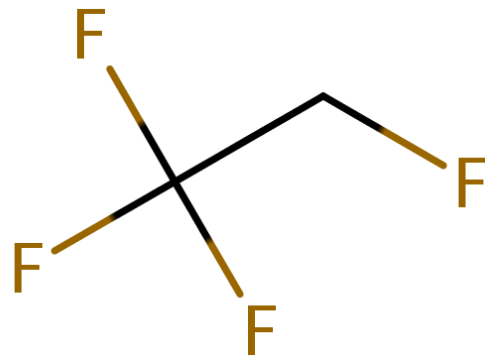
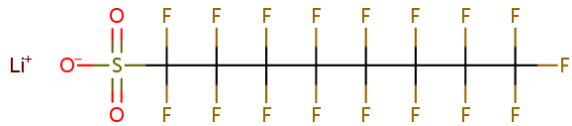
## 1. What is the definition of a PFAS compound in the context of pesticides?

- R-CF<sub>2</sub>-CF(R<sub>1</sub>)(R<sub>2</sub>) where R, R<sub>1</sub>, and R<sub>2</sub> do not equal H and the carbon to carbon bond is saturated



# EPA Q & A

1. What is the definition of a PFAS compound in the context of pesticides?





# EPA Q & A

---

**2. When did EPA first learn of this contamination? What steps have been taken since initial PFAS discovery in the pesticide product?**

- September 1, 2020, Public Employees for Environmental Responsibility (PEER) contacted the Massachusetts Reclamation Board, the Massachusetts Department of Agricultural Resources' (MDAR) Division of Pest Services, and other state agencies claiming that there were unspecified PFAS in a pesticide used for mosquito control. EPA Region 1 was notified that same day.



# EPA Q & A

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**2. When did EPA first learn of this contamination? What steps have been taken since initial PFAS discovery in the pesticide product?**

- January 13, 2021, to minimize risks to human health and the environment, EPA asked states with existing stock of the mosquito product distributed in fluorinated HDPE containers to discontinue use and hold until its final disposition is determined.





# EPA Q & A

---

**2. When did EPA first learn of this contamination? What steps have been taken since initial PFAS discovery in the pesticide product?**

- January 13, 2021, ...cont...The pesticide manufacturer has notified all its customers regarding management of the product, voluntarily stopped shipments of all products in fluorinated HDPE containers and is now using non-fluorinated containers.



# EPA Q & A

---

**2. When did EPA first learn of this contamination? What steps have been taken since initial PFAS discovery in the pesticide product?**

- January 14, 2021, EPA issued a TSCA subpoena to the company that fluorinates the containers supplied to the manufacturer of the pesticide in which PFAS was discovered to learn more about the fluorination process used on the HDPE containers.



# EPA Q & A

---

## **2. When did EPA first learn of this contamination? What steps have been taken since initial PFAS discovery in the pesticide product?**

- EPA is actively working with the Food and Drug Administration, the U.S. Department of Agriculture, and industry and trade organizations to raise awareness of this emerging issue and discuss expectations of product stewardship. For example, EPA is coordinating with the Ag Container Recycling Council, the American Chemistry Council, Crop Life America, the Household & Commercial Products Association, and the National Pest Management Association.



# EPA Q & A

---

**2. When did EPA first learn of this contamination? What steps have been taken since initial PFAS discovery in the pesticide product?**

- The Agency is also testing different brands of fluorinated containers to determine whether they contain and/or leach PFAS, and if so, learn the conditions affecting leaching.





# EPA Q & A

---

**2. When did EPA first learn of this contamination? What steps have been taken since initial PFAS discovery in the pesticide product?**

- Testing method published appropriate for oily pesticide mixtures



# EPA Q & A

---

## **4. What should pesticide registrants do if they find PFAS in their production lines?**

- Under [FIFRA Section 6\(a\)\(2\)](#), pesticide registrants should report to EPA additional factual information on unreasonable adverse effects, including metabolites, degradates, and impurities (such as PFAS).



# EPA Q & A

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**6. Does EPA allow pesticide manufacturers to include PFAS in their formulations as inert ingredients which do not have to be reported?**

- No, EPA requires all inert ingredients in pesticide formulations to be reported as part of the Confidential Statement of Formula.



# EPA Q & A

---

## 2. What PFAS compounds were detected on or in the containers?

Abbreviated	Full Name
PFBA	Perfluoro-butanoic acid
PFPeA	Perfluoro-pentanoic acid
PFHxA	Perfluoro-hexanoic acid
PFHpA	Perfluoro-heptanoic acid
PFOA	Perfluoro-octanoic acid
PFNA	Perfluoro-nananoic acid
PFDA	Perfluoro-decanoic acid
PFUdA	Perfluoro-undecanoic acid

Levels ranging from 20 to 50 parts per billion





# EPA Q & A

---

## **4. Do we know to what degree long term storage or hot/cold storage conditions might affect the concentration of PFAS leaching?**

- EPA is planning to conduct a study to determine under what conditions, generally, PFAS compounds will leach from container walls into the pesticide products.



## EPA Q & A

---

**5. What consideration, if any, is being given to pesticide container recycling programs in regard to the fluorinated HDPE containers?**

- EPA has been in contact with the Ag Container Recycling Council.



# EPA Q & A

---

## **6. Should people be concerned about the possibility of being exposed to PFAS from pesticide container contamination? What about other containers?**

- The PFAS detections in rinsate from the tested containers do not represent PFAS concentrations in the environment or human exposure to PFAS.
- While EPA is early in its investigation, the Agency will use all available regulatory and non-regulatory tools to determine the scope of this emerging issue and its potential impact on human health and the environment.



# EPA Q & A

---

## **8. Do the data requirements for containers require information about fluorination to be submitted if containers are fluorinated?**

- Yes, EPA's storage and stability/corrosion characteristics data requirements require registrants to provide details on the type of container used to distribute the product commercially, which can include fluorinated High Density Polyethylene (HDPE) containers.





# EPA Q & A

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## **9. Do existing FIFRA container regulations address the use of fluorinated HDPE containers?**

- FIFRA pesticide container regulations do not specifically address the fluorination of plastic containers, i.e., the regulations do not require fluorination, nor do they prohibit fluorination of plastic pesticide containers.
- However, some of the Department of Transportation requirements that are referred to and adopted in the pesticide container regulations may impact a pesticide manufacturer's decision to fluorinate containers.



# EPA Q & A

---

## **2. What are the alternatives to Anvil 10+10 for mosquito spray, and are the alternative pesticide products stored the same way?**

- Fluorinated polyethylene and HDPE are used for numerous applications such as food packaging and containers for chemical storage, including pesticides.
- This is the first time that EPA has been aware of fluorinated HDPE container use as a potential source of PFAS contamination in a pesticide.
- EPA is using its authorities under FIFRA and TSCA to obtain more information about the potential scope of this contamination and to evaluate whether other regulated products may be affected.



# EPA Q & A

---

**3. What should states and others do with existing stock of Anvil 10+10?**

**4. Will affected products be placed under Stop Sale/Stop Use by EPA or State Lead Agencies?**

- EPA asked states with existing stock of the mosquito product distributed in HDPE containers to discontinue use and contact the manufacturer about their product exchange program.
- EPA will respond to any additional PFAS supply-chain contamination issues on a case-by-case basis. For example, EPA worked with the mosquito product manufacturer to remove contaminated product from the supply chain.



# EPA Q & A -Summary

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- New issue, working on it.
- None of the product that is known to have PFAS has been used -all of it was withdrawn and replaced by manufacturer.
- All of the big federal agencies are working to determine the scope of this issue.

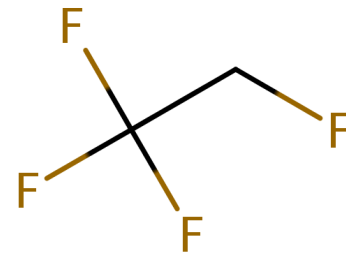


# State of Maine actions

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LD 1503 defines PFAS as:

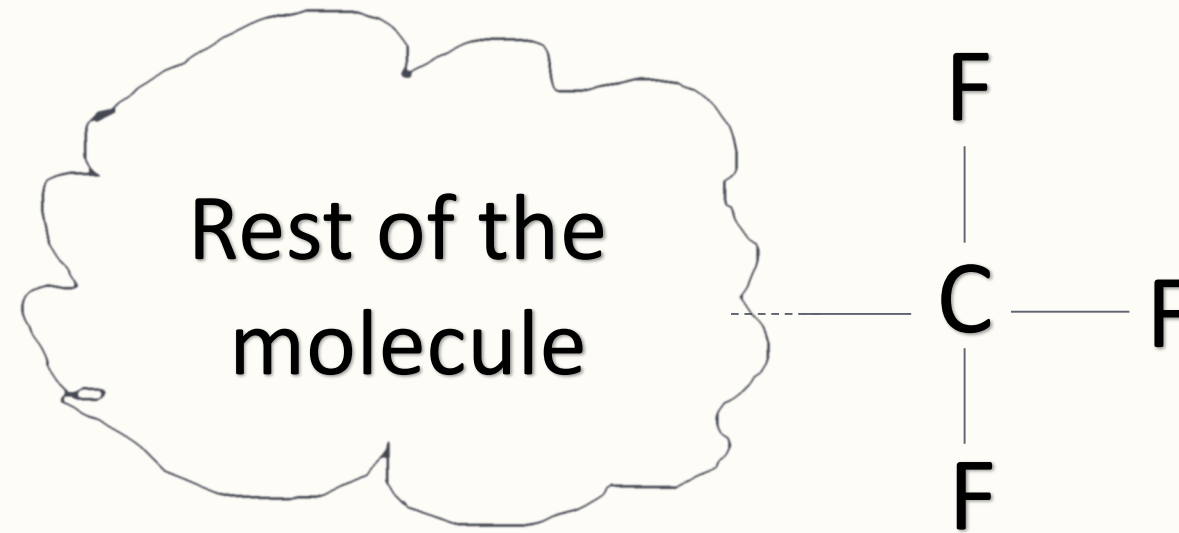
F. "Perfluoroalkyl and polyfluoroalkyl substances" or "PFAS" means substances that include any member of the class of fluorinated organic chemicals containing at least one fully fluorinated carbon atom.



# State of Maine actions

---

This definition is close to other definitions but different.



-CF<sub>3</sub>

# State of Maine actions

---

This definition is close to other definitions but different.



Rest of the  
molecule

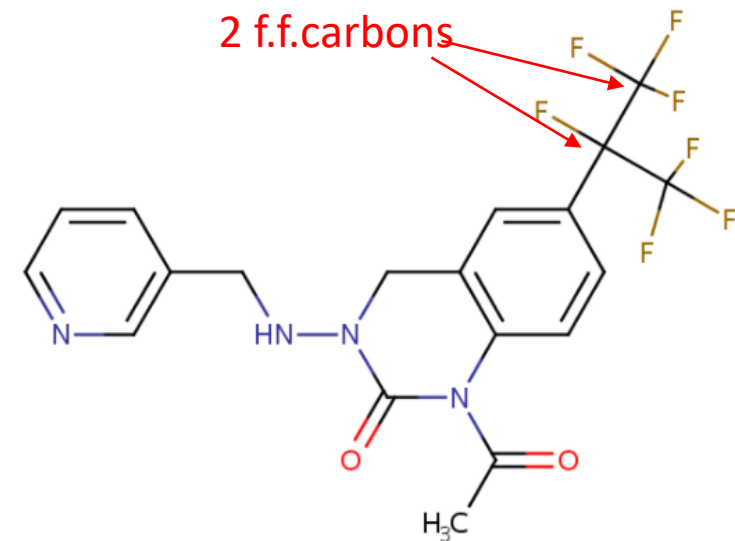
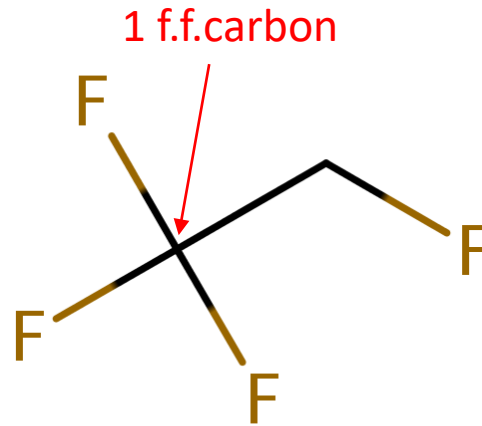
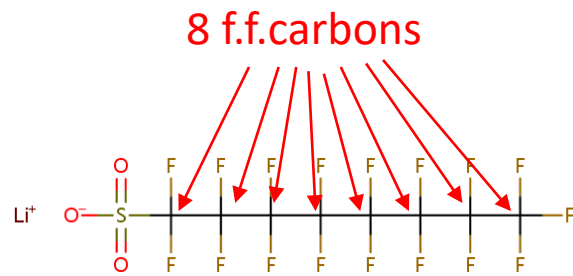
The diagram shows two irregular, cloud-like shapes representing molecular fragments. The left shape is labeled 'Rest of the molecule'. A dashed line connects its right edge to a central carbon atom (C). The carbon atom is bonded to two fluorine atoms (F) above and below it. Another dashed line connects the carbon atom to the left edge of the right cloud-like shape, which is also labeled 'Rest of the molecule'. Below the central carbon atom is the text '-CF2-'.

Rest of the  
molecule

-CF2-

# PFAS classification

- Depending on the definition between a few hundred to 12,000+ chemicals classified as PFAS

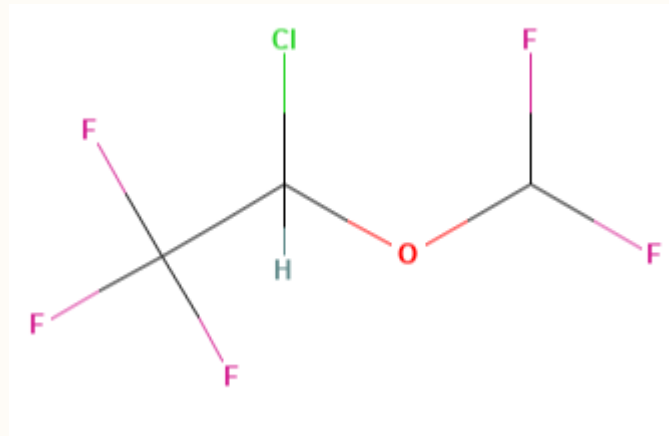




# How does the State of Maine definition of PFAS change things?

---

- Chemicals not previously classified as PFAS will become “PFAS”
- Unknown number of pesticides and inert/other ingredients

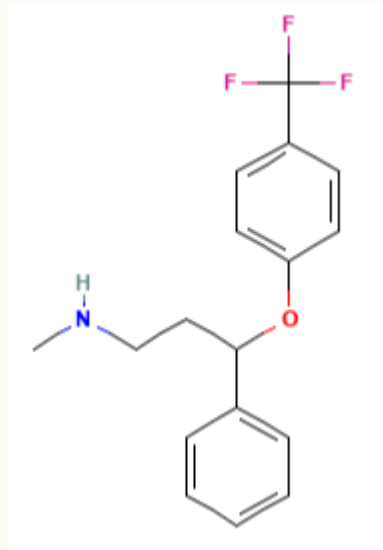


Isoflurane: general anesthetic and muscle relaxant activities

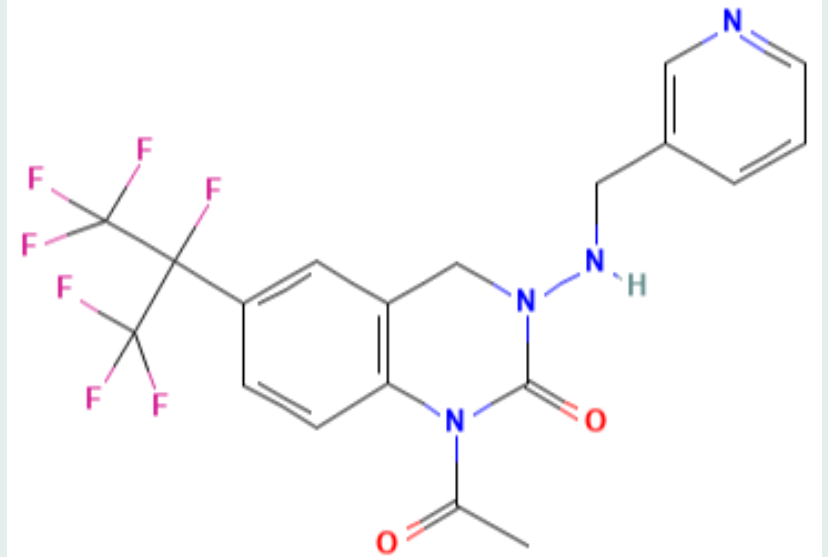
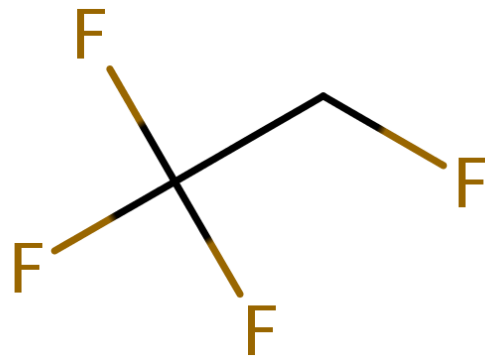
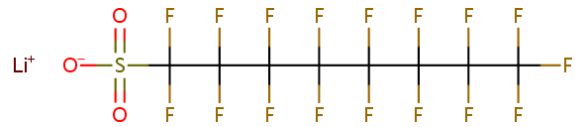
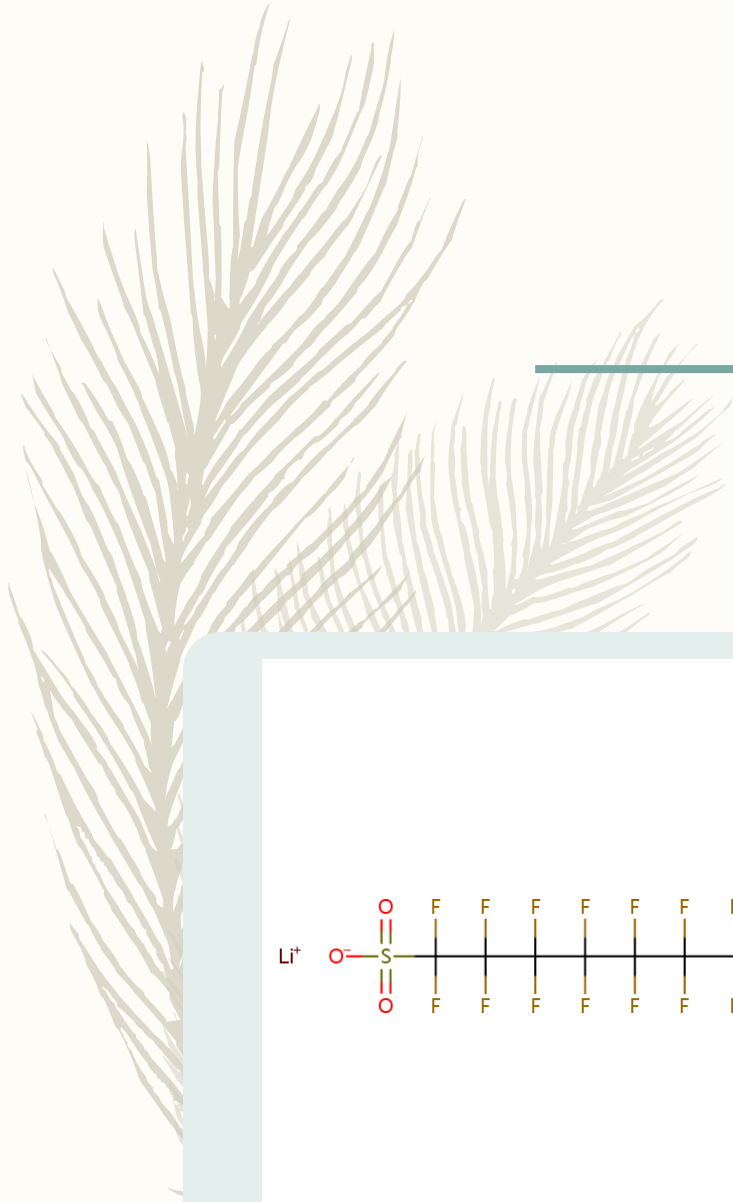
# How does the State of Maine definition of PFAS change things?

---

- Chemicals not previously classified as PFAS will become “PFAS”
- Unknown number of pesticides and inert/other ingredients



fluoxetine: selective serotonin reuptake inhibitor (SSRI) widely used as an antidepressant



# OECD PFAS Discussion on How to Define PFAS...

---

## OECD definition:

- PFASs are defined as fluorinated substances that contain at least one fully fluorinated methyl or methylene carbon atom (without any H/Cl/Br/I atom attached to it), i.e. with a few noted exceptions, any chemical with at least a perfluorinated methyl group ( $-\text{CF}_3$ ) or a perfluorinated methylene group ( $-\text{CF}_2-$ ) is a PFAS.

## The points they make about this definition:

- ...The decision to broaden the definition compared to Buck et al. is not connected to decisions on how PFASs should be grouped in regulatory and voluntary actions....

# OECD PFAS Discussion on How to Define PFAS...

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## OECD definition:

- PFASs are defined as fluorinated substances that contain at least one fully fluorinated methyl or methylene carbon atom (without any H/Cl/Br/I atom attached to it), i.e. with a few noted exceptions, any chemical with at least a perfluorinated methyl group ( $-\text{CF}_3$ ) or a perfluorinated methylene group ( $-\text{CF}_2-$ ) is a PFAS.

## The points they make about this definition:

- ...The term “PFASs” is a broad, general, non-specific term, which does not inform whether a compound is harmful or not, but only communicates that the compounds under this term share the same trait for having a fully fluorinated methyl or methylene carbon moiety...





# As we discuss this important to distinguish between

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## – **Adulterants**

- Typified by “classic PFAS”
- May or may not be well classified by risk assessment (PFOA)

**Vs.**

## – **Intentionally added**

- Definition changes the scope
- In pesticides, accompanied by a risk assessment



# Pesticide risk assessments address many of the issues of “classic” PFAS

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- Soil half-life
- Aquatic half-life
- Bioaccumulation potential
- Major degradation products
- Leaching potential
- Suite health effects studies

The attributes that make PFAS so difficult environmentally/health effects are all included as parts of the required data collection during registration.

# How big of a deal is container adulteration?

---

- How much do pesticide containers add PFAS to the environment? and
- Is that ok?



# How big of a deal is container adulteration?

---

- How much do pesticide containers add PFAS to the environment?
- Anvil 10 + 10 maximum is 0.6 oz per acre





# How big of a deal is container adulteration?

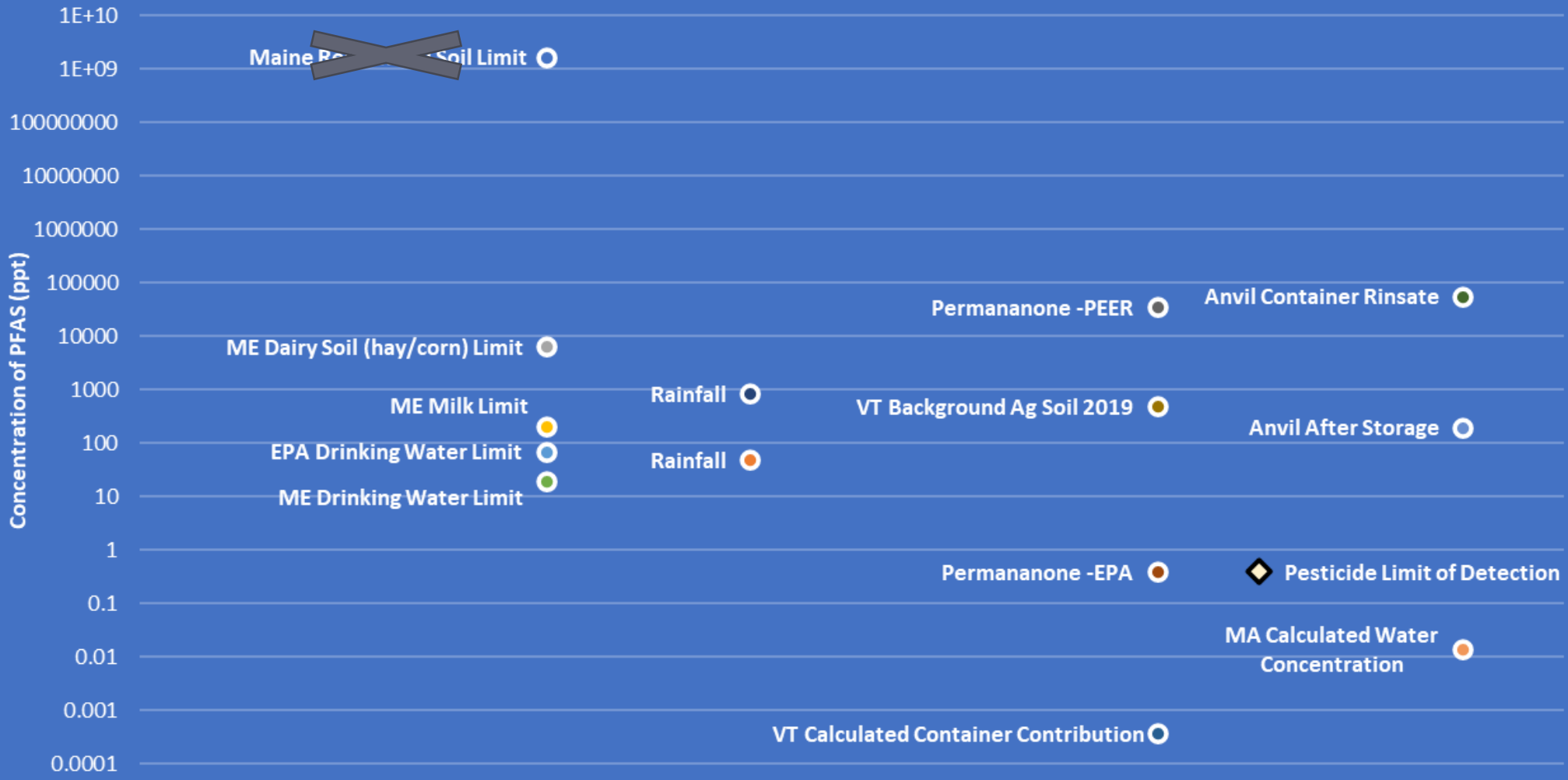
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- How much do pesticide containers add PFAS to the environment?
- Anvil 10 + 10 maximum is 0.6 oz per acre

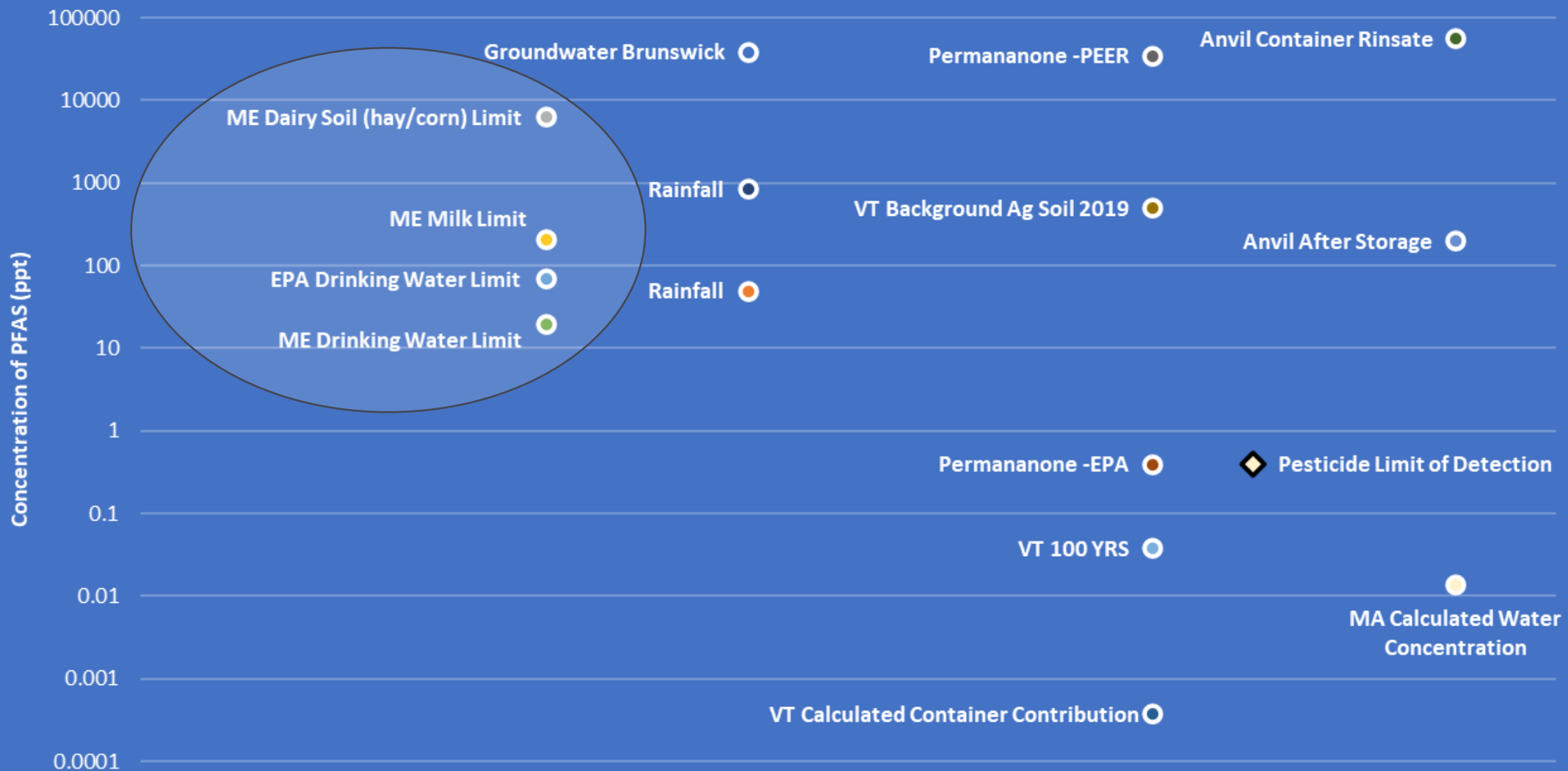




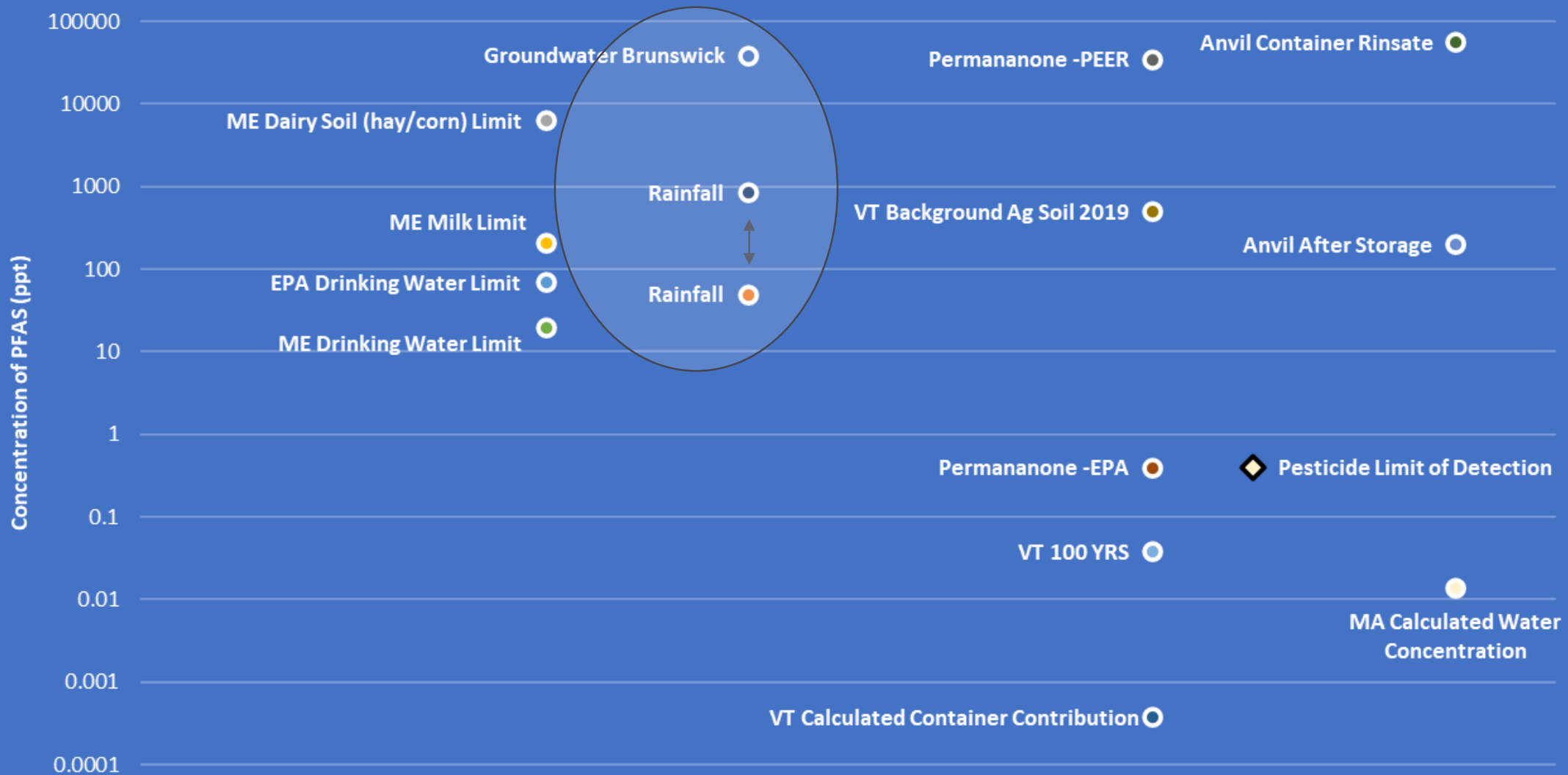
# RELATIVE PFAS CONCENTRATIONS (IN PARTS PER TRILLION, PPT)



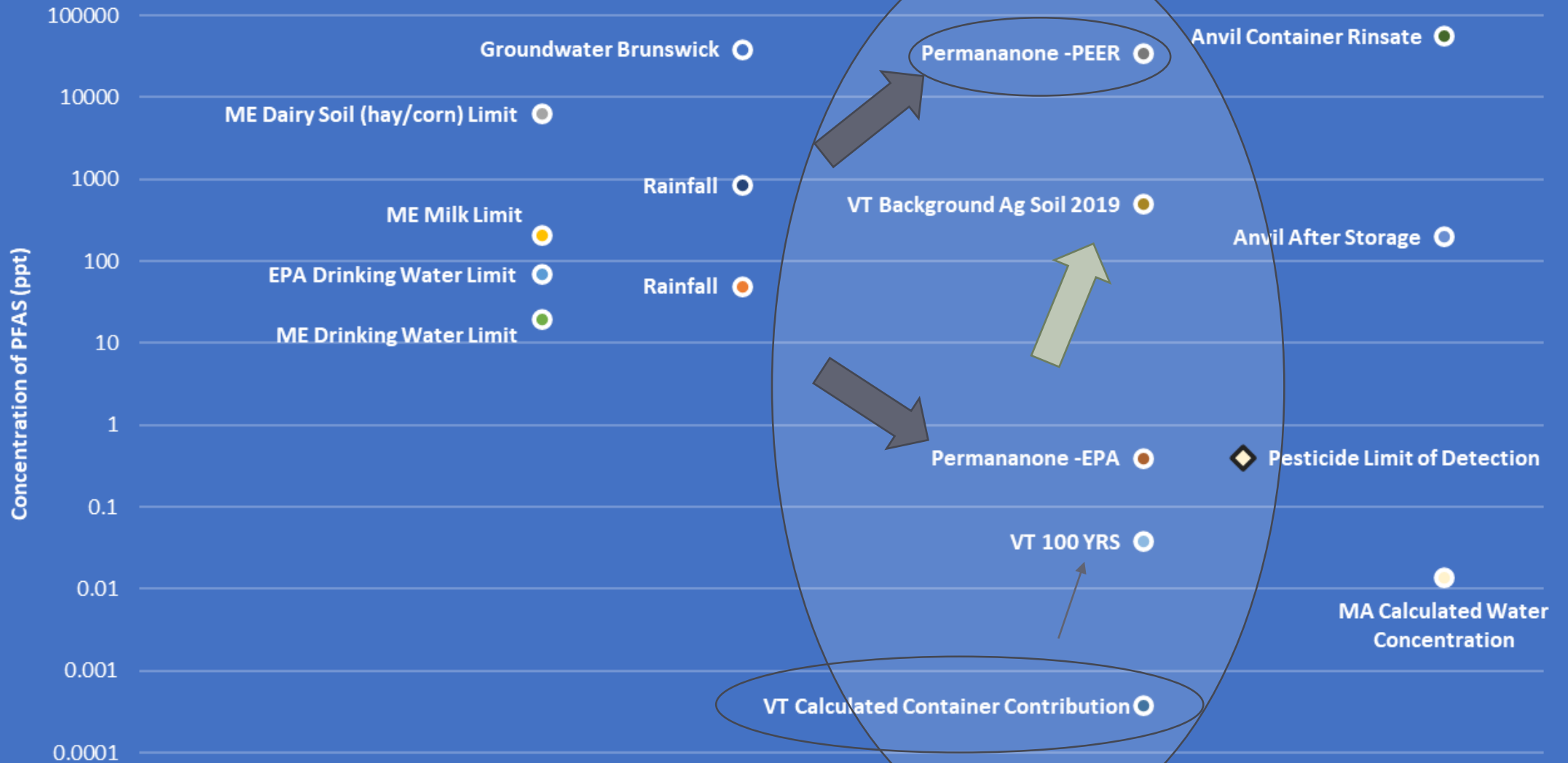
# RELATIVE PFAS CONCENTRATIONS (IN PARTS PER TRILLION, PPT)



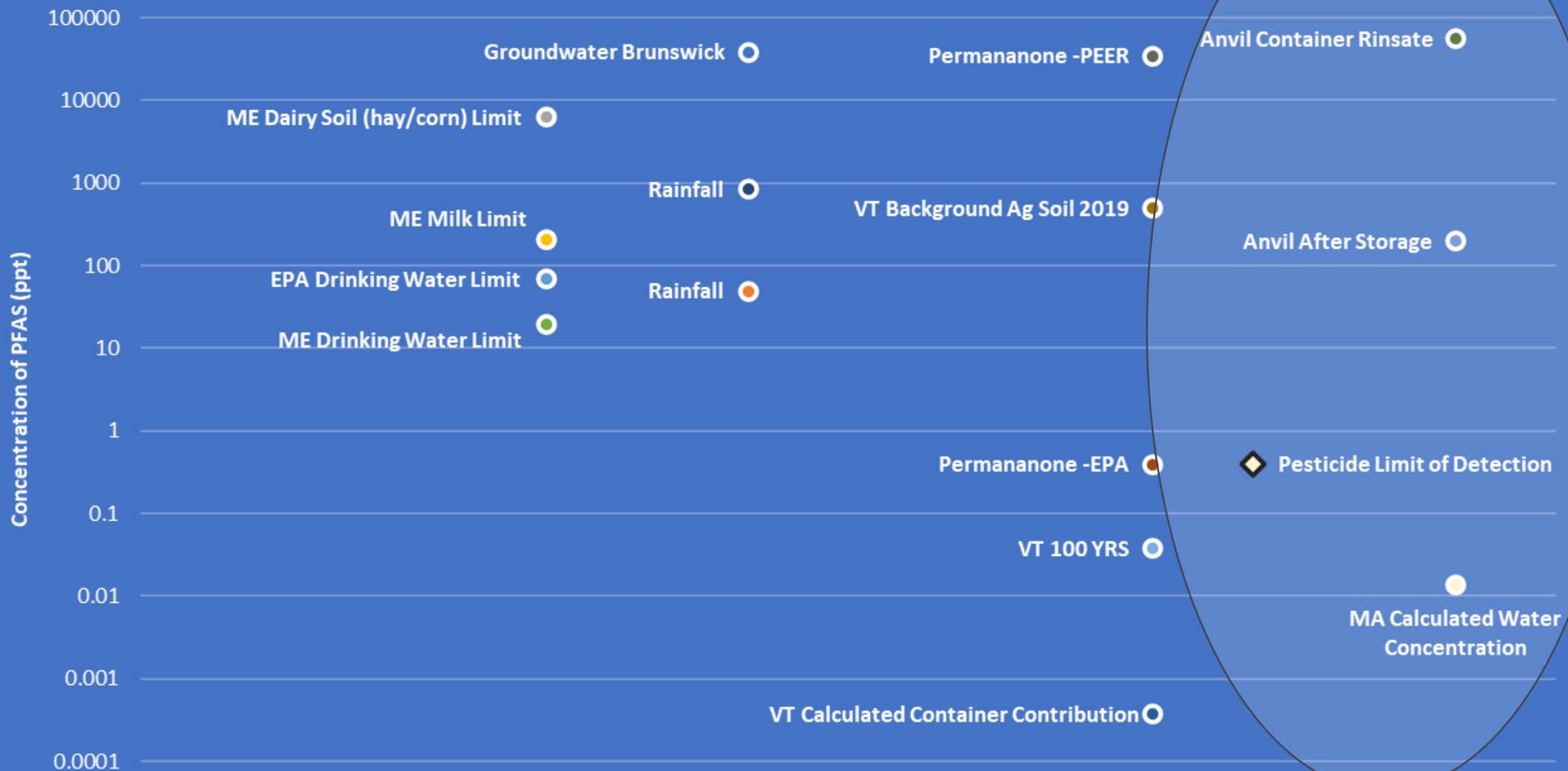
# RELATIVE PFAS CONCENTRATIONS (IN PARTS PER TRILLION, PPT)



# RELATIVE PFAS CONCENTRATIONS (IN PARTS PER TRILLION, PPT)



# RELATIVE PFAS CONCENTRATIONS (IN PARTS PER TRILLION, PPT)









# My contact information

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Pam Bryer

Pesticides Toxicologist

Maine Board of Pesticides Control

[pamela.j.bryer@maine.gov](mailto:pamela.j.bryer@maine.gov)

Main line:

207-287-2931

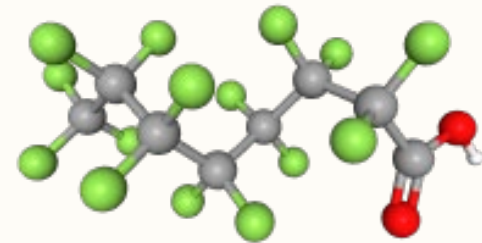
[pesticides@maine.gov](mailto:pesticides@maine.gov)

-or- just reach out to our office

# Per- and Polyfluoroalkyl Substances (PFAS)

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- Pronounced as “P -fas”
- Often confused with “P -foss” which is a specific type of PFAS
- Also hear: “P -foe-ah” which is another specific type of PFAS



Perfluorooctanoic acid (PFOA)  
C8

# Per- and Polyfluoroalkyl Substances (PFAS)

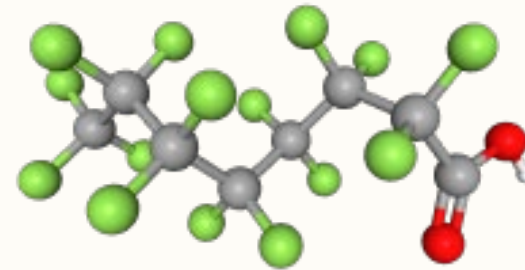
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Fluorine = Green

Carbon = Gray

Oxygen = Red

Hydrogen = White



Perfluorooctanoic acid  
C8

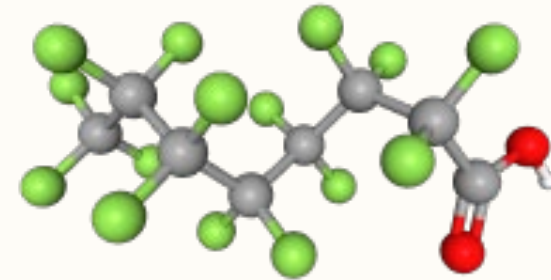
# Per- and Polyfluoroalkyl Substances (PFAS)

Fluorine = Green  
(sometimes purple)

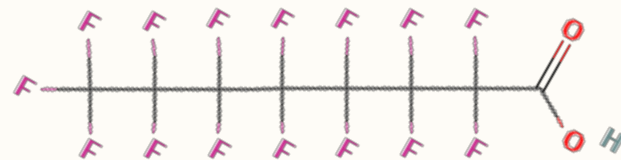
Carbon = Gray

Oxygen = Red

Hydrogen = White



Perfluorooctanoic acid  
C8

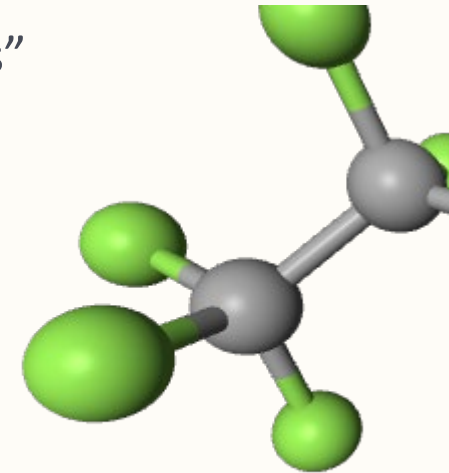




# Per- and Polyfluoroalkyl Substances (PFAS)

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- Fluorine to Carbon bond is one of the strongest chemical bonds
- This is why they are called “forever chemicals”
- Takes a lot of energy to break the fluorine off of the carbon



Fluorine molecules hold other molecules tight & close

## PERIODIC TABLE OF ELEMENTS

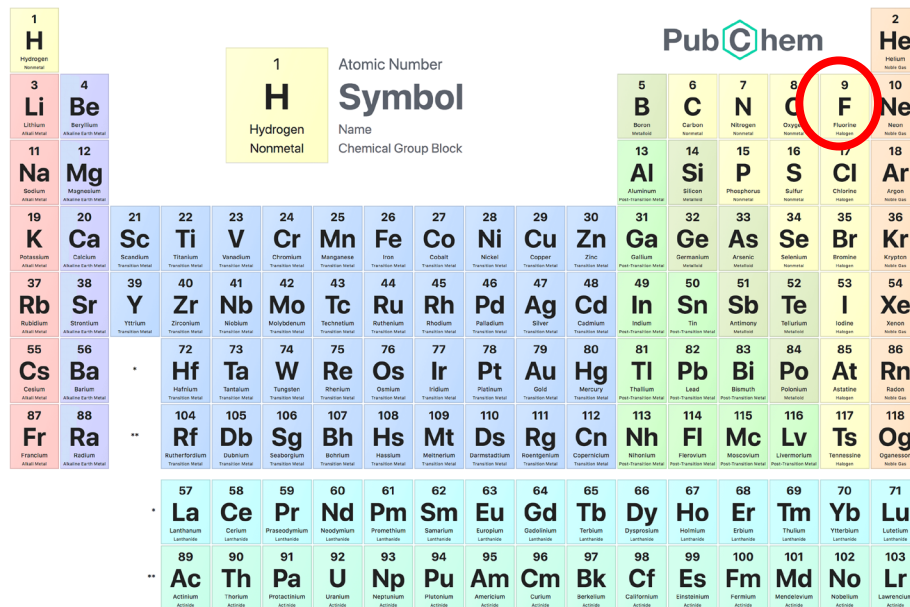
PubChem

1 <b>H</b> Hydrogen Alkali Metal																	2 <b>He</b> Helium Noble Gas	
3 <b>Li</b> Lithium Alkali Metal	4 <b>Be</b> Beryllium Alkali Earth Metal																	10 <b>Ne</b> Neon Noble Gas
11 <b>Na</b> Sodium Alkali Metal	12 <b>Mg</b> Magnesium Alkali Earth Metal																	18 <b>Ar</b> Argon Noble Gas
19 <b>K</b> Potassium Alkali Metal	20 <b>Ca</b> Calcium Alkali Earth Metal	21 <b>Sc</b> Scandium Transition Metal	22 <b>Ti</b> Titanium Transition Metal	23 <b>V</b> Vanadium Transition Metal	24 <b>Cr</b> Chromium Transition Metal	25 <b>Mn</b> Manganese Transition Metal	26 <b>Fe</b> Iron Transition Metal	27 <b>Co</b> Cobalt Transition Metal	28 <b>Ni</b> Nickel Transition Metal	29 <b>Cu</b> Copper Transition Metal	30 <b>Zn</b> Zinc Transition Metal	31 <b>Ga</b> Gallium Post-transition Metal	32 <b>Ge</b> Germanium Metalloid	33 <b>As</b> Arsenic Metalloid	34 <b>Se</b> Selenium Nonmetal	35 <b>Br</b> Bromine Halogens	36 <b>Kr</b> Krypton Noble Gas	
37 <b>Rb</b> Rubidium Alkali Metal	38 <b>Sr</b> Strontium Alkali Earth Metal	39 <b>Y</b> Yttrium Transition Metal	40 <b>Zr</b> Zirconium Transition Metal	41 <b>Nb</b> Niobium Transition Metal	42 <b>Mo</b> Molybdenum Transition Metal	43 <b>Tc</b> Technetium Transition Metal	44 <b>Ru</b> Ruthenium Transition Metal	45 <b>Rh</b> Rhodium Transition Metal	46 <b>Pd</b> Palladium Transition Metal	47 <b>Ag</b> Silver Transition Metal	48 <b>Cd</b> Cadmium Transition Metal	49 <b>In</b> Indium Post-transition Metal	50 <b>Sn</b> Tin Post-transition Metal	51 <b>Sb</b> Antimony Metalloid	52 <b>Te</b> Tellurium Metalloid	53 <b>I</b> Iodine Halogens	54 <b>Xe</b> Xenon Noble Gas	
55 <b>Cs</b> Cesium Alkali Metal	56 <b>Ba</b> Barium Alkali Earth Metal	72 <b>Hf</b> Hafnium Transition Metal	73 <b>Ta</b> Tantalum Transition Metal	74 <b>W</b> Tungsten Transition Metal	75 <b>Re</b> Rhenium Transition Metal	76 <b>Os</b> Osmium Transition Metal	77 <b>Ir</b> Iridium Transition Metal	78 <b>Pt</b> Platinum Transition Metal	79 <b>Au</b> Gold Transition Metal	80 <b>Hg</b> Mercury Transition Metal	81 <b>Tl</b> Thallium Post-transition Metal	82 <b>Pb</b> Lead Post-transition Metal	83 <b>Bi</b> Bismuth Post-transition Metal	84 <b>Po</b> Polonium Metalloid	85 <b>At</b> Astatine Halogens	86 <b>Rn</b> Radon Noble Gas		
87 <b>Fr</b> Francium Alkali Metal	88 <b>Ra</b> Radium Alkali Earth Metal	104 <b>Rf</b> Rutherfordium Transition Metal	105 <b>Db</b> Dubnium Transition Metal	106 <b>Sg</b> Seaborgium Transition Metal	107 <b>Bh</b> Bohrium Transition Metal	108 <b>Hs</b> Hassium Transition Metal	109 <b>Mt</b> Meitnerium Transition Metal	110 <b>Ds</b> Darmstadtium Transition Metal	111 <b>Rg</b> Roentgenium Transition Metal	112 <b>Cn</b> Copernicium Transition Metal	113 <b>Nh</b> Nihonium Post-transition Metal	114 <b>Fl</b> Flerovium Post-transition Metal	115 <b>Mc</b> Moscovium Post-transition Metal	116 <b>Lv</b> Livermorium Post-transition Metal	117 <b>Ts</b> Tennessine Halogens	118 <b>Og</b> Oganesson Noble Gas		
		57 <b>La</b> Lanthanum Lanthanide	58 <b>Ce</b> Cerium Lanthanide	59 <b>Pr</b> Praseodymium Lanthanide	60 <b>Nd</b> Neodymium Lanthanide	61 <b>Pm</b> Promethium Lanthanide	62 <b>Sm</b> Samarium Lanthanide	63 <b>Eu</b> Europium Lanthanide	64 <b>Gd</b> Gadolinium Lanthanide	65 <b>Tb</b> Terbium Lanthanide	66 <b>Dy</b> Dysprosium Lanthanide	67 <b>Ho</b> Holmium Lanthanide	68 <b>Er</b> Erbium Lanthanide	69 <b>Tm</b> Thulium Lanthanide	70 <b>Yb</b> Ytterbium Lanthanide	71 <b>Lu</b> Lutetium Lanthanide		
		89 <b>Ac</b> Actinium Actinide	90 <b>Th</b> Thorium Actinide	91 <b>Pa</b> Protactinium Actinide	92 <b>U</b> Uranium Actinide	93 <b>Np</b> Neptunium Actinide	94 <b>Pu</b> Plutonium Actinide	95 <b>Am</b> Americium Actinide	96 <b>Cm</b> Curium Actinide	97 <b>Bk</b> Berkelium Actinide	98 <b>Cf</b> Californium Actinide	99 <b>Es</b> Einsteinium Actinide	100 <b>Fm</b> Fermium Actinide	101 <b>Md</b> Mendelevium Actinide	102 <b>No</b> Nobelium Actinide	103 <b>Lr</b> Lawrencium Actinide		

- Fluorine is a small molecule (top of the table)
- Fluorine has strength (same as others in the column)

Fluorine molecules hold other molecules tight & close

# PERIODIC TABLE OF ELEMENTS

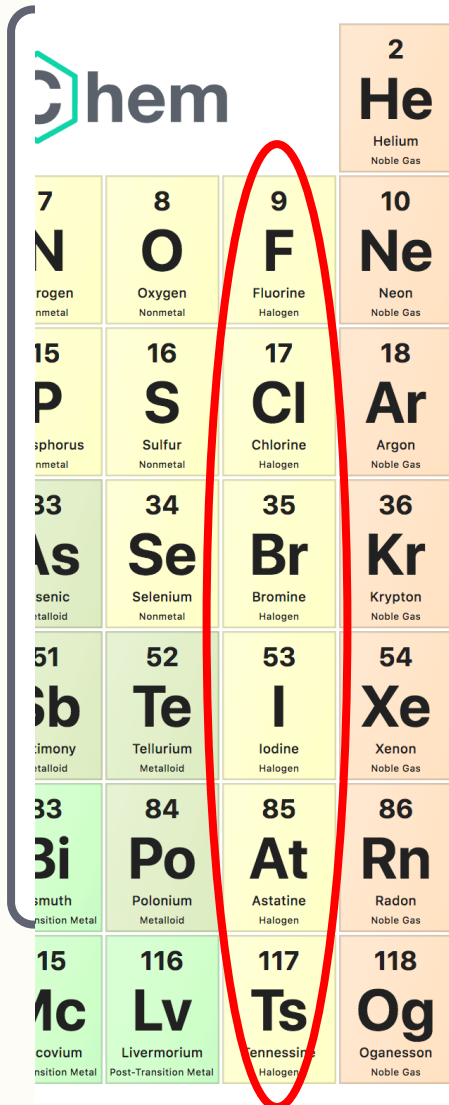


The image shows a standard periodic table of elements. The element Fluorine (F) is highlighted with a red circle. A large red arrow points downwards from the Fluorine element towards the text on the right. A legend in the top left corner explains the table's structure: Atomic Number (1), Symbol (H), Name (Hydrogen), and Chemical Group Block (Nonmetal).

1 H Hydrogen																	2 He Helium						
3 Li Lithium	4 Be Beryllium																	5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon
11 Na Sodium	12 Mg Magnesium																	13 Al Aluminum	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon
19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton						
37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon						
55 Cs Cesium	56 Ba Barium		72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon						
87 Fr Francium	88 Ra Radium		104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds Darmstadtium	111 Rg Roentgenium	112 Cn Copernicium	113 Nh Nihonium	114 Fl Flerovium	115 Mc Moscovium	116 Lv Livermorium	117 Ts Tennessine	118 Og Oganesson						
		57 La Lanthanum	58 Ce Cerium	59 Pr Praseodymium	60 Nd Neodymium	61 Pm Promethium	62 Sm Samarium	63 Eu Europium	64 Gd Gadolinium	65 Tb Terbium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium	71 Lu Lutetium							
		89 Ac Actinium	90 Th Thorium	91 Pa Protactinium	92 U Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium							

- Fluorine is a small molecule (top of the table)
- Fluorine has strength (same as others in the column)

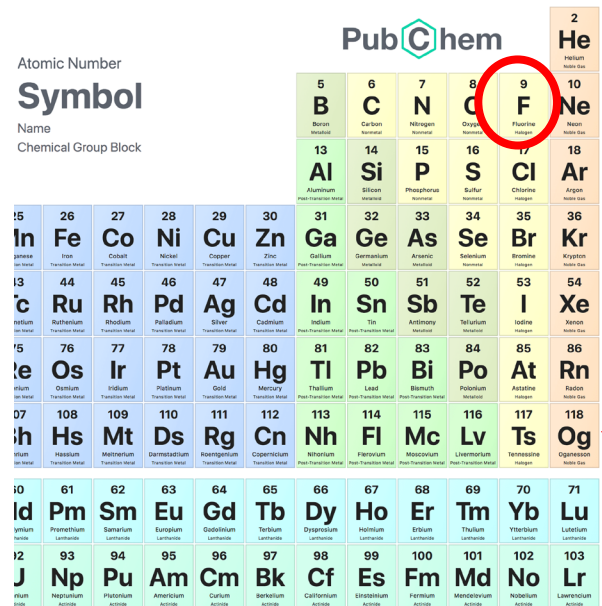
# ELEMENTS



chem

2	He		
Helium			Noble Gas
7	8	9	10
N	O	F	Ne
Nitrogen	Oxygen	Fluorine	Neon
Nonmetal	Nonmetal	Halogen	Noble Gas
15	16	17	18
P	S	Cl	Ar
Phosphorus	Sulfur	Chlorine	Argon
Nonmetal	Nonmetal	Halogen	Noble Gas
33	34	35	36
As	Se	Br	Kr
Arsenic	Selenium	Bromine	Krypton
Metalloid	Nonmetal	Halogen	Noble Gas
51	52	53	54
Sb	Te	I	Xe
Antimony	Tellurium	Iodine	Xenon
Metalloid	Metalloid	Halogen	Noble Gas
83	84	85	86
Bi	Po	At	Rn
Bismuth	Polonium	Astatine	Radon
Post-Transition Metal	Metalloid	Halogen	Noble Gas
115	116	117	118
Mc	Lv	Ts	Og
Moscovium	Livermorium	Tennesseium	Oganesson
Post-Transition Metal	Post-Transition Metal	Halogen	Noble Gas

## TABLE OF ELEMENTS



PubChem

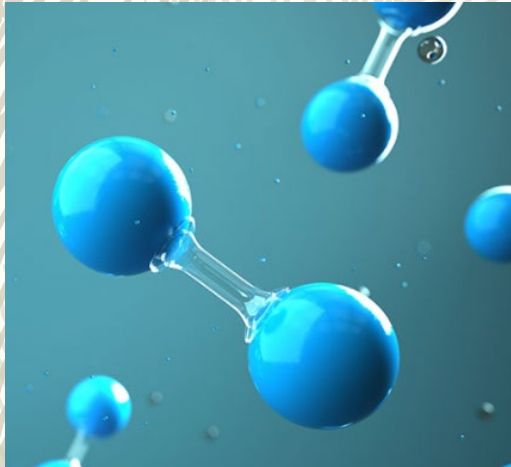
Atomic Number  
Symbol  
Name  
Chemical Group Block

5	6	7	8	9	10		
B	C	N	O	F	Ne		
Boron	Carbon	Nitrogen	Oxygen	Fluorine	Neon		
Nonmetal	Nonmetal	Nonmetal	Nonmetal	Halogen	Noble Gas		
13	14	15	16	17	18		
Al	Si	P	S	Cl	Ar		
Aluminum	Silicon	Phosphorus	Sulfur	Chlorine	Argon		
Post-Transition Metal	Metalloid	Nonmetal	Nonmetal	Halogen	Noble Gas		
29	30	31	32	33	34	35	36
Cu	Zn	Ga	Ge	As	Se	Br	Kr
Copper	Zinc	Gallium	Germanium	Arsenic	Selenium	Bromine	Krypton
Transition Metal	Transition Metal	Post-Transition Metal	Metalloid	Nonmetal	Nonmetal	Halogen	Noble Gas
47	48	49	50	51	52	53	54
Ag	Cd	In	Sn	Sb	Te	I	Xe
Silver	Cadmium	Indium	Tin	Antimony	Tellurium	Iodine	Xenon
Transition Metal	Transition Metal	Post-Transition Metal	Post-Transition Metal	Post-Transition Metal	Metalloid	Halogen	Noble Gas
79	80	81	82	83	84	85	86
Au	Hg	Tl	Pb	Bi	Po	At	Rn
Gold	Mercury	Thallium	Lead	Bismuth	Polonium	Astatine	Radon
Transition Metal	Transition Metal	Post-Transition Metal	Post-Transition Metal	Post-Transition Metal	Post-Transition Metal	Halogen	Noble Gas
111	112	113	114	115	116	117	118
Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og
Roentgenium	Copernicium	Nihonium	Flerovium	Moscovium	Livermorium	Tennesseium	Oganesson
Transition Metal	Transition Metal	Post-Transition Metal	Post-Transition Metal	Post-Transition Metal	Post-Transition Metal	Post-Transition Metal	Noble Gas
71	72	73	74	75	76	77	78
Lu	Hf	Ta	W	Re	Os	Ir	Pt
Lutetium	Hafnium	Tantalum	Tungsten	Rhenium	Osmium	Iridium	Platinum
Lanthanide	Transition Metal	Transition Metal	Transition Metal	Transition Metal	Transition Metal	Transition Metal	Transition Metal
103	104	105	106	107	108	109	110
Lr	Rf	Db	Sg	Bh	Hs	Mt	Ds
Lanthanum	Rutherfordium	Dubnium	Seaborgium	Berkelium	Hassium	Mendelevium	Darmstadtium
Lanthanide	Transition Metal	Transition Metal	Transition Metal	Transition Metal	Transition Metal	Transition Metal	Transition Metal
101	102	103	104	105	106	107	108
Md	No	Lr	Rf	Db	Sg	Bh	Hs
Mendelevium	Nobelium	Lanthanum	Rutherfordium	Dubnium	Seaborgium	Berkelium	Hassium
Actinide	Actinide	Lanthanide	Transition Metal	Transition Metal	Transition Metal	Transition Metal	Transition Metal

Fluorine molecules hold other molecules tight & close

- Fluorine is a small molecule (top of the table)
- Fluorine has strength (same as others in the column)

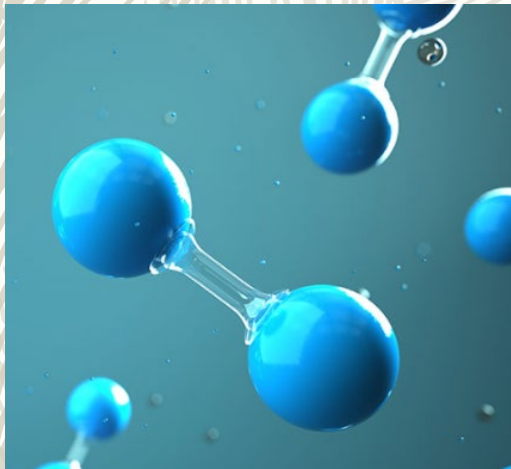
# Fluorine molecules hold other molecules tight & close







<b>Bond</b>	<b>H—F</b>	<b>H—Cl</b>	<b>H—Br</b>	<b>H—I</b>
<b>Length</b>	0.917 Å	1.275 Å	1.415 Å	1.609 Å
<b>Strength</b>	136 kcal/mol	103 kcal/mol	87 kcal/mol	71 kcal/mol
	571 kJ/mol	432 kJ/mol	366 kJ/mol	298 kJ/mol



# Fluorine molecules hold other molecules tight & close



				
<b>Bond</b>	<b>H—F</b>	<b>H—Cl</b>	<b>H—Br</b>	<b>H—I</b>
<b>Length</b>	0.917 Å	1.275 Å	1.415 Å	1.609 Å
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