The Perils of PFAS

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Virtual PFAS Conference - Delaware Academy of Medicine
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Potential conflicts of interest

I retired from NIEHS-10/3/19

I have spoken publicly about my understanding of PFAS toxicity.

I am serving as a PFAS plaintiff's expert

What are Per- and Polyfluoroalkyl Substances (PFAS)?

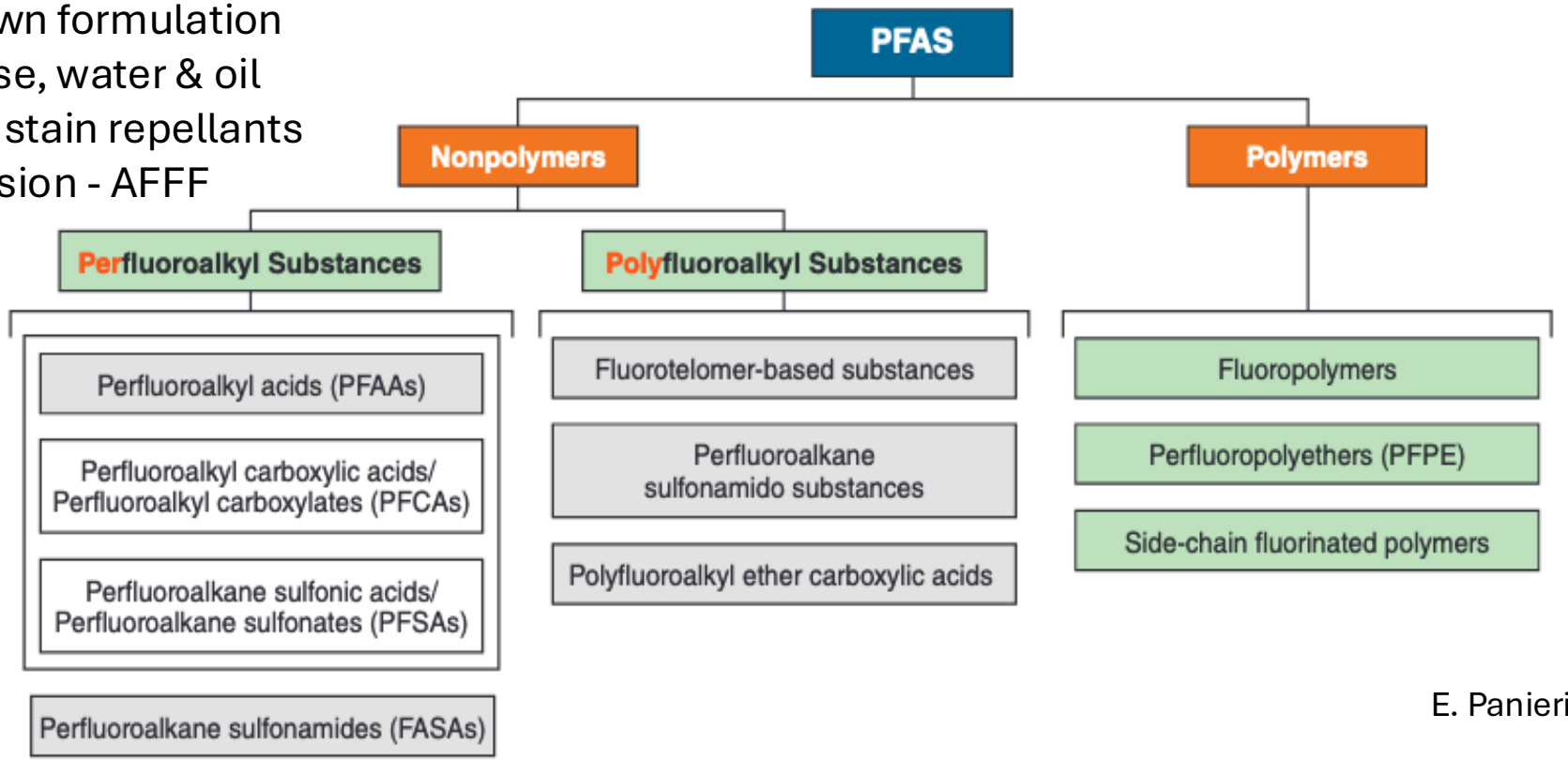
PFAS Definition: Molecule contains at least one fully fluorinated methyl [–CF_3] or methylene [–CF_2–] carbon atom (OECD, 2021)

Total number of PFAS
>15,000 chemicals
- Includes products, impurities and degradants
  - Teflon
  - Scotchguard
  - Aqueous Film Forming Foams (AFFFs)
- Many unknown formulation

Resistant to grease, water & oil
- Surfactants, stain repellants
- Fire suppression - AFFF

Persistent, mobile, and bioaccumulative

Emergence of short-chain alternatives - less well studied
- Few studied – same effects as long chains
- Ultra short chains (e,g, CF3, CF3COOH)



E. Panieri et al., Toxics (2022)

“NEW” PFAS found all the time!

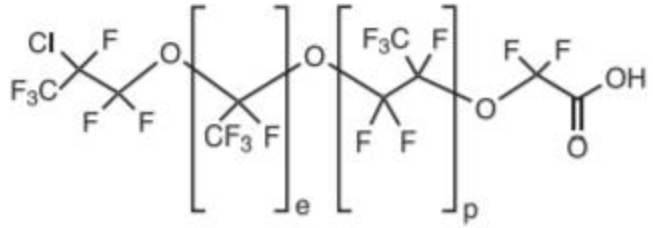


Fig. 1. A chloroperfluoropolyether carboxylate (ClPFPECA) identified by nontargeted MS analyses in soil samples from New Jersey. In the New Jersey samples, perfluoroethyl (e) plus perfluoropropyl (p) groups were observed to range in sum from one to four. The example congener depicted here would be designated (e,p) = 1,1. Isomers likely include an alternative terminal structure of $ClCF_2CF(CF_3)O$– (*13*, *14*) as well as relative positions for the perfluoroethyl and perfluoropropyl groups.

SOLVAY

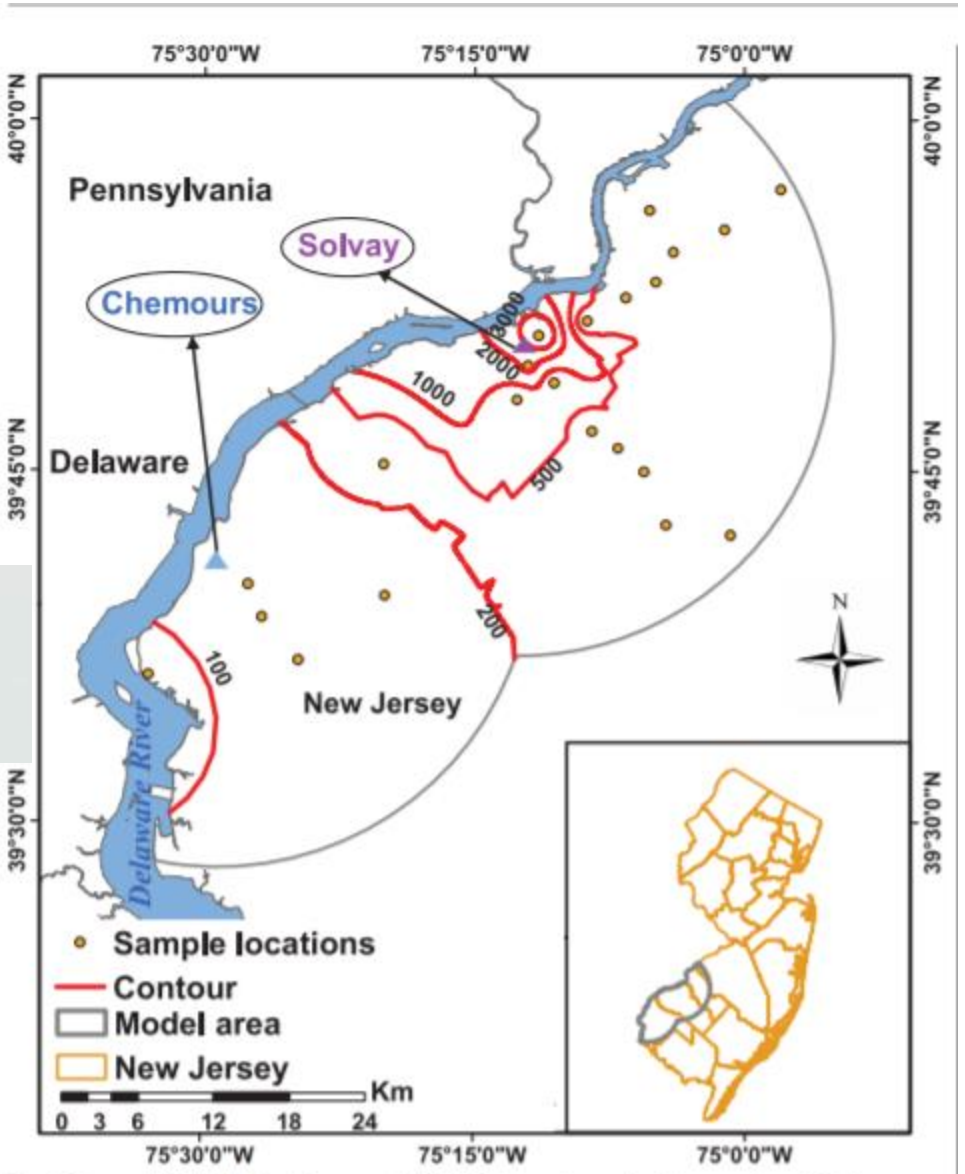
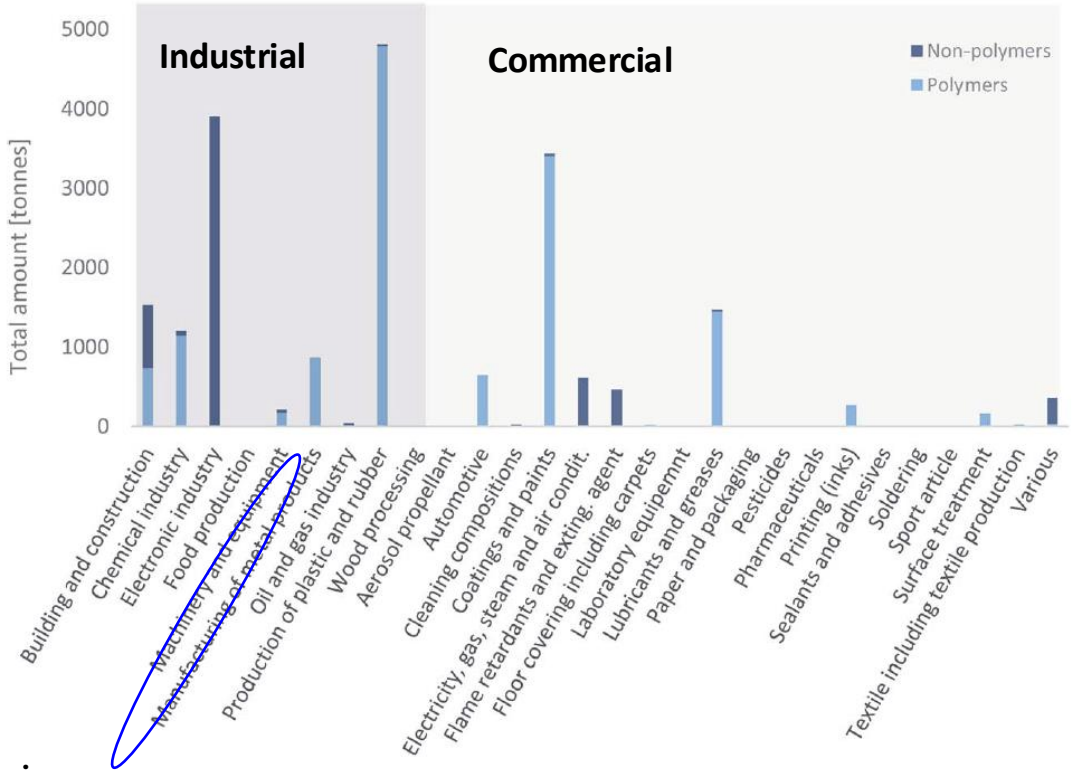


Fig. 4. Geographic distribution. Shown are ΣClPFPECAs in surface soils (picograms/gram). Contour lines were generated by using an algorithm in ArcMAP 10.6.1 that weighted the five nearest data points according to inverse-square distance. Despite some geographic sporadicity in the data and numerical artifacts where data are sparsely spaced, taken as a group the contours depict a clear pattern of increasing ΣClPFPECAs with proximity to Solvay.

Washington et al., Science 2020.

Occurrence of PFAS in various goods:

Gluge, J. et al, Environmental Science Processes & Impacts 2020, 1462-1468.



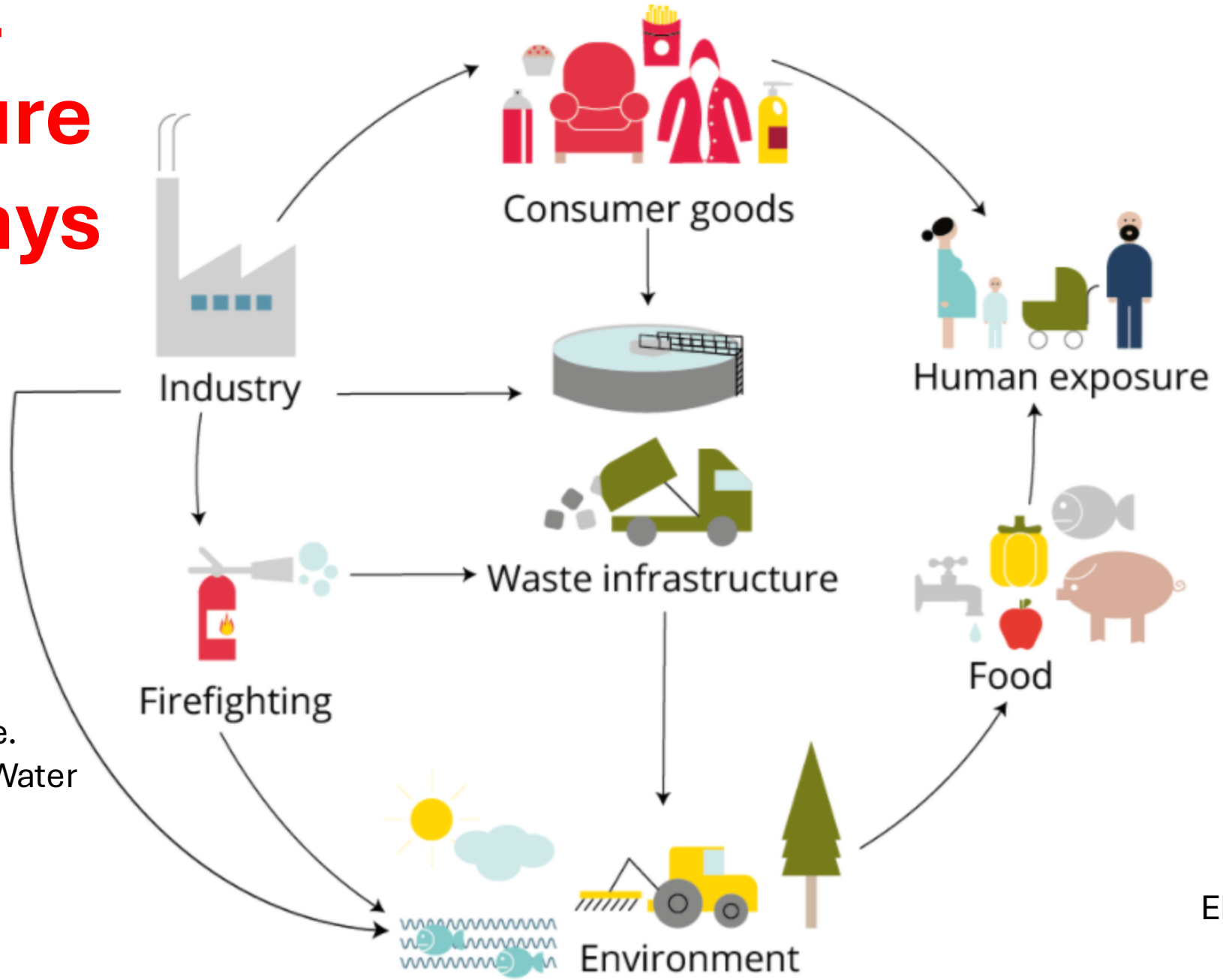
report

Carpet and Fabric
Food Packaging and Food
Pots and Pans
Clothing
Cardboard packaging
Firefighting foams (AFFF)
Cosmetics


NON
STICK
COOKWARE
PERSONAL
CARE PRODUCTS
WATER
RESISTANT
CLOTHING
PFAS
can be found in these products:
FAST FOOD
PACKAGING
STAIN
RESISTANT
FURNITURE
COSMETICS

Ingestion (Drinking Water, Food, Dust), Inhalation, Dermal

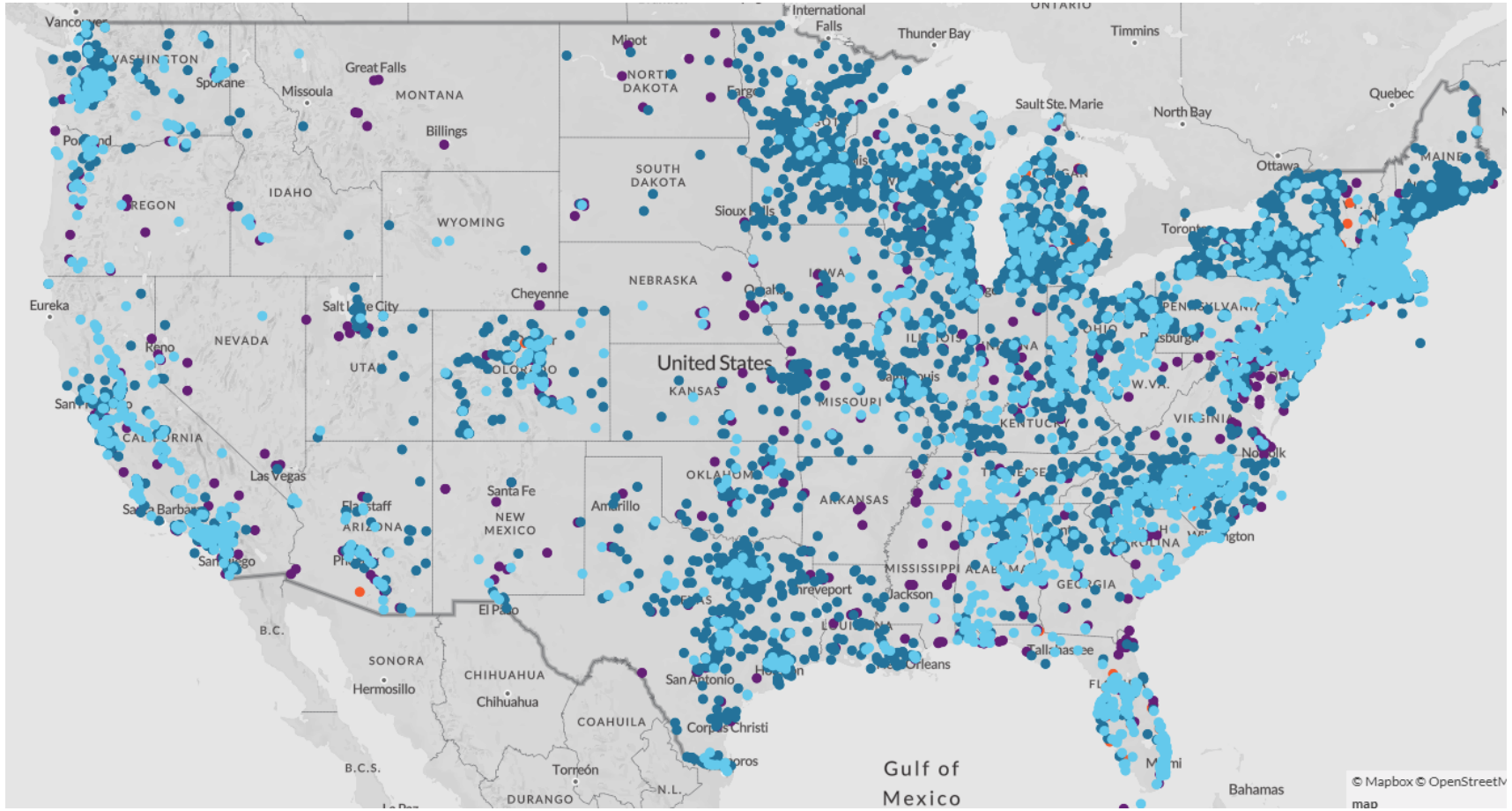
Typical Exposure Pathways



PFAS do not degrade.
PFAS pass through Water Treatment Plants

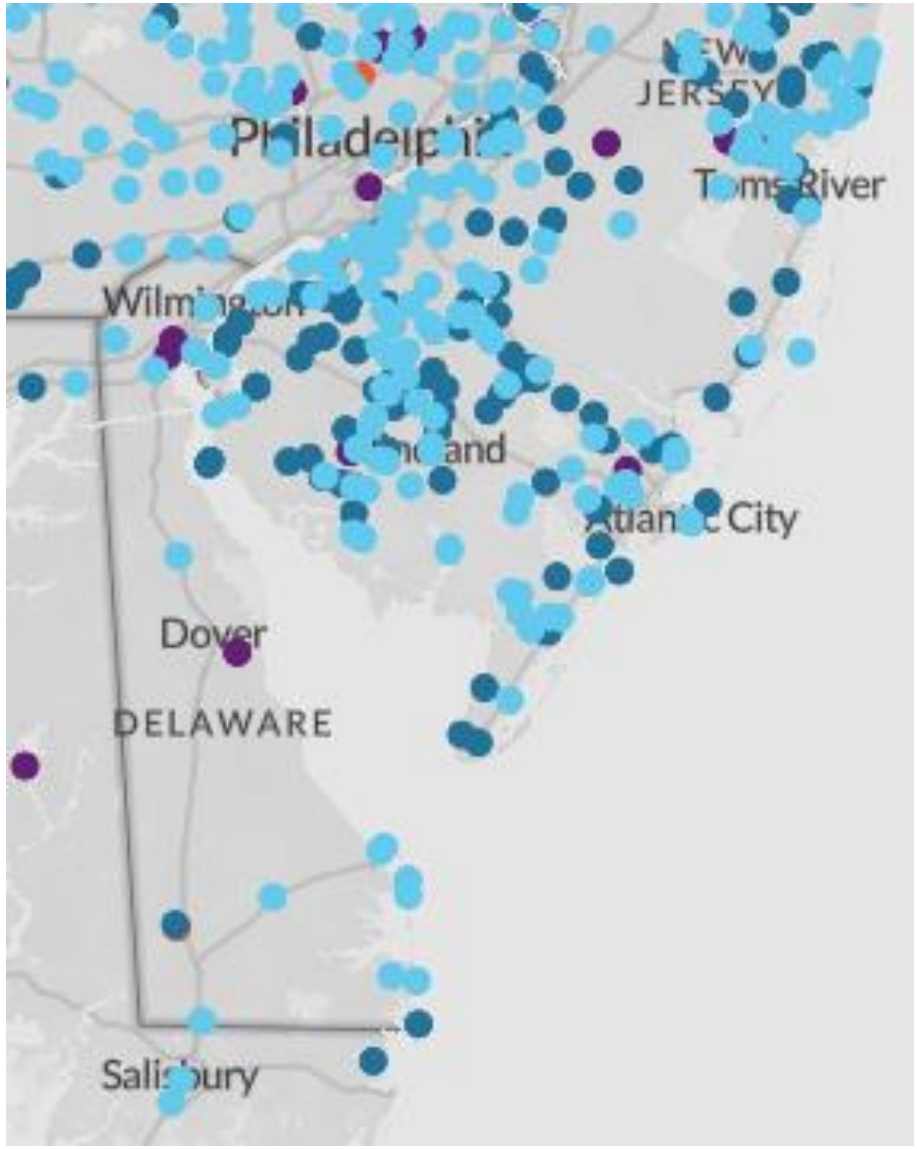
EEA, 2021

PFAS in US Drinking Water (August 15, 2025)



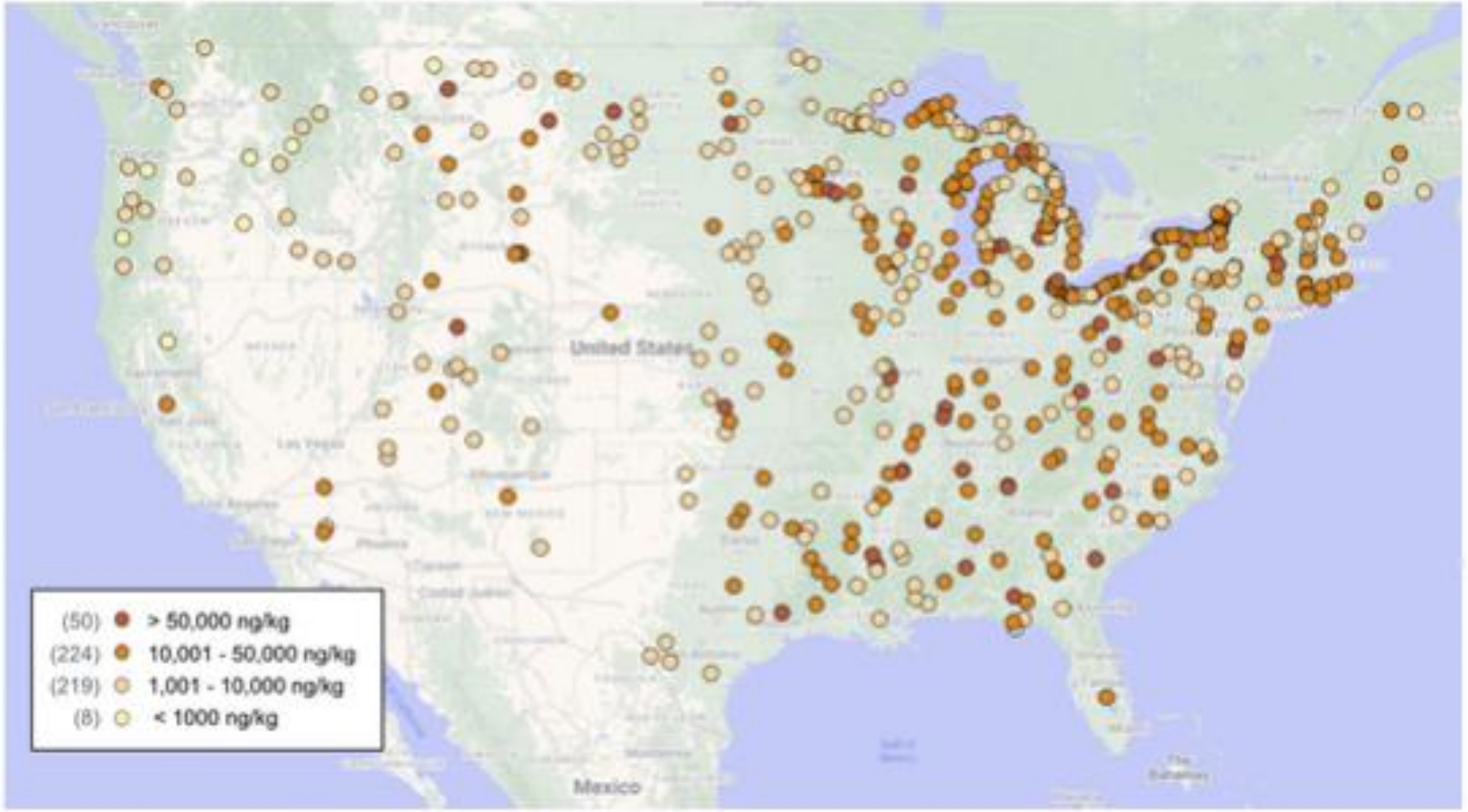
EWG

PFAS in Delaware Drinking Water (August 14, 2025)



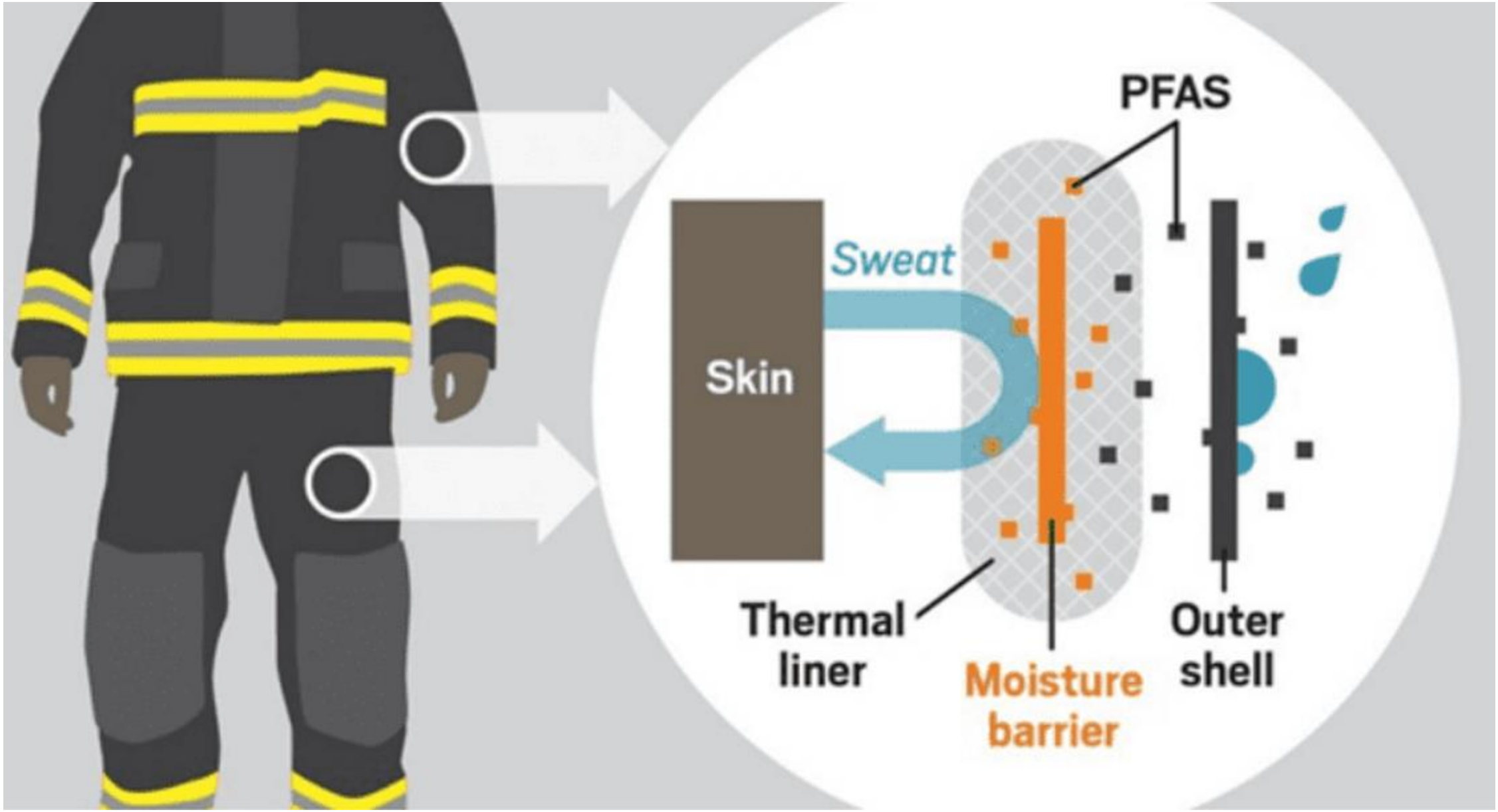
EWG based on EPA UCMR5 data

PFAS in US Freshwater Fish (2013-15)



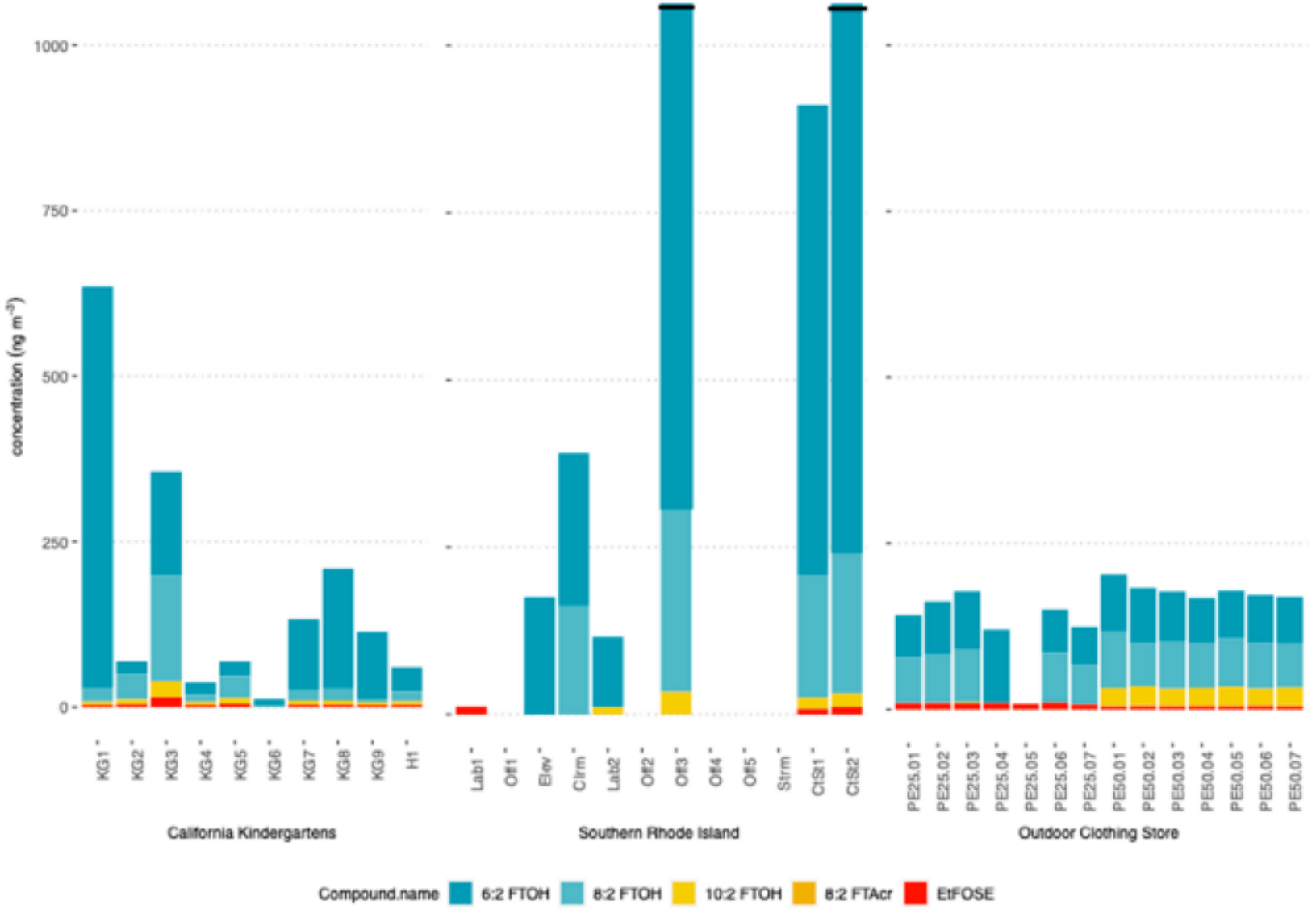
Barbo et al. 2023

Dermal Exposure



Environ. Sci. Technol. Lett. 2020, 7, 8, 594−599

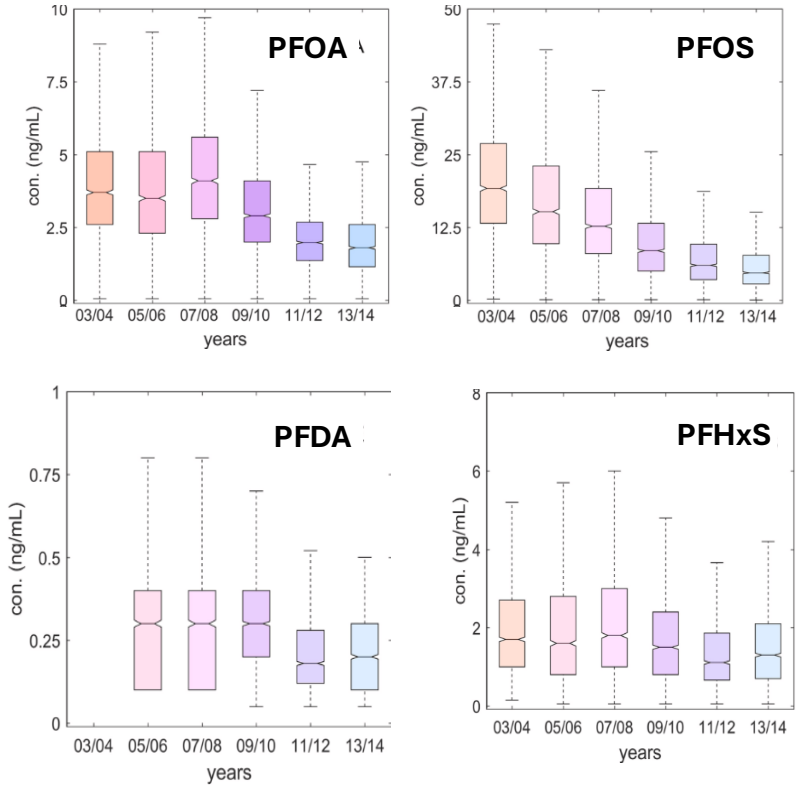
Inhalation Exposure: Volatile PFAS in Indoor Air



ME Morales-McDevitt et al., ES&T Lett. (2021) 8: 897-902

We *All* Have PFAS in Our Bodies

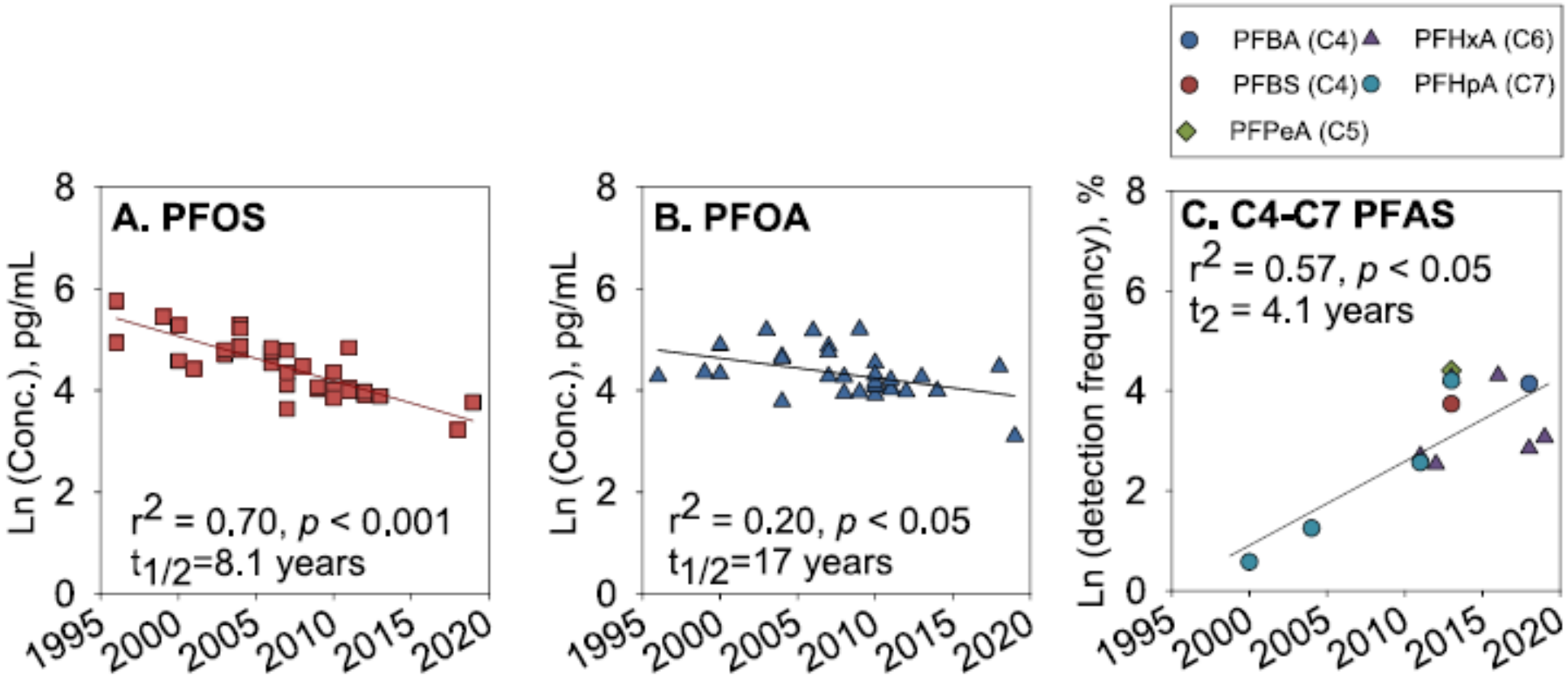
- Detected in humans globally
- >98% of people in the U.S. have measurable amounts of PFAS
- Levels of PFOA and PFOS have declined following phase-outs
- Changes in exposure to other PFAS are less pronounced



PFAS exposure trends in NHANES 2003 – 2014

Sunderland et al., J Expos Sci & Epidemiol, 2019
Dong et al., Ecotox and Environ Safety, 2019

PFAS in Human Breast Milk



Zheng et al., ES&T 2021

PFAS-exposure related health concerns began 1960s

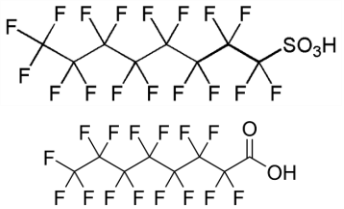
1930s

PTFE (Teflon) invented

1940s

1947: PFAS production begins at 3M plant in MN

PFOS & PFOA begin to be produced PTFE-based non-stick coatings produced



1950s

PFOS-based stain & water resistant products

PFOA-based protective coatings

1960s

PFOS-based fire fighting foam

1962: DuPont raises concerns re: health risks of PFAS in internal document

1970s

1978: Unpublished study shows adverse effects of PFOA in monkeys

1980: PFAS detected in serum of workers

1981: Concerns about birth defects in children born to women workers

PTFE-based waterproof fabrics PFNA & fluorotelomers begin to be produced

1980s

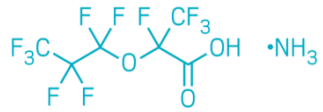
1987: PFOA causes cancer in rat study

1990s

1993: 3M begins to monitor PFOA in workers

2000s

2000-2002: DuPont begins producing PFOA at Chemours facility in Fayetteville, NC



2000: PFOA and PFOS detected in 100% of Americans in study; 3M announces phase-out of PFOA

2001: DuPont sued in class action lawsuit

1998: Samples from U.S. blood donors shown to contain PFAS

2004: DuPont settles class action suit (>80,000 plaintiffs) for $343 million; settlement funds C8 Health Study

2006: EPA invites 8 major companies to phase out PFOA by 2015 (95% reduction by 2010)

2009: Chemours commercially manufactures GenX as PFOA substitute

2010s

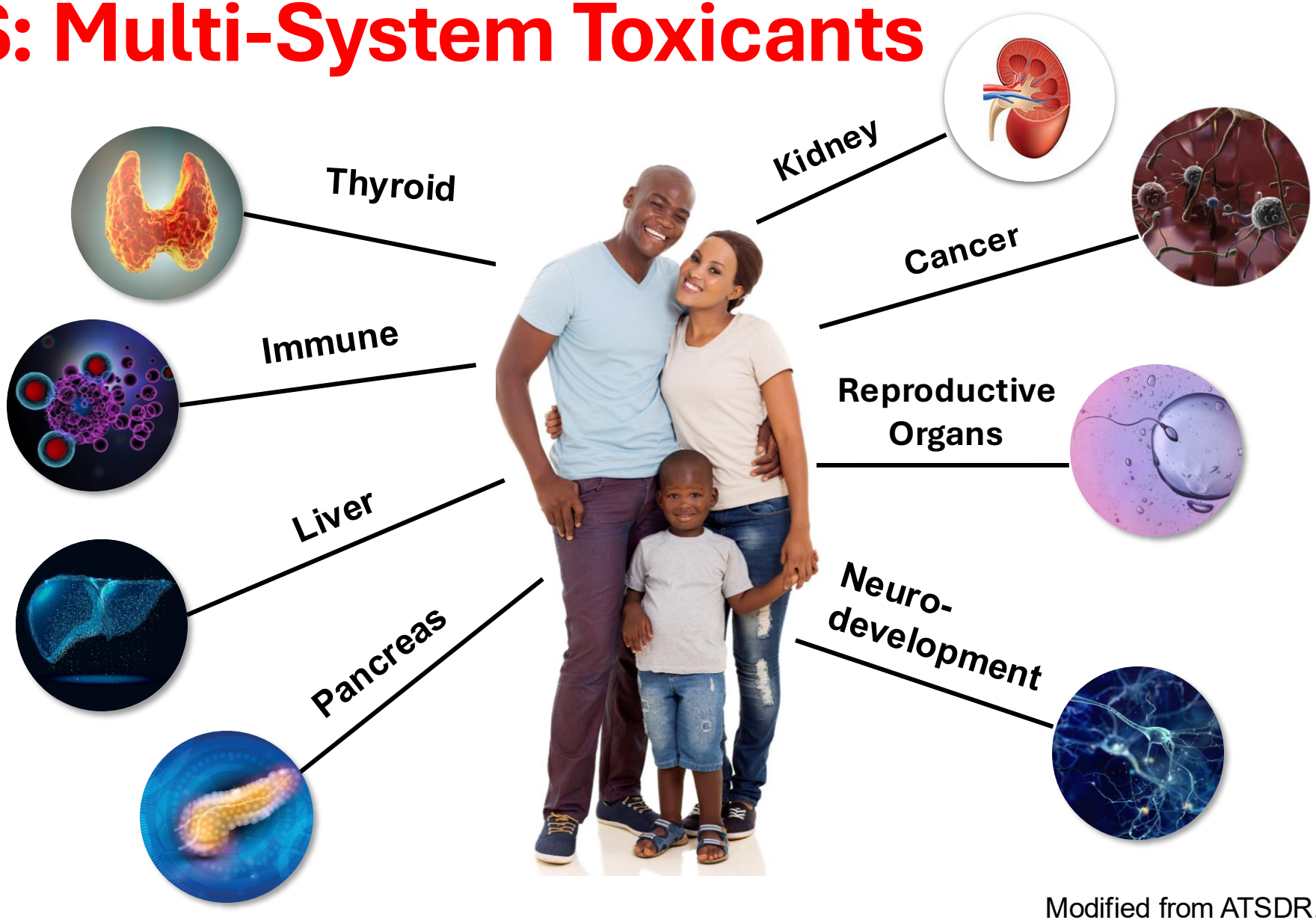
2012: Immune system effects related to PFAS reported in children

2015: Researchers publish report of novel PFAS (including GenX) in Cape Fear River

Present

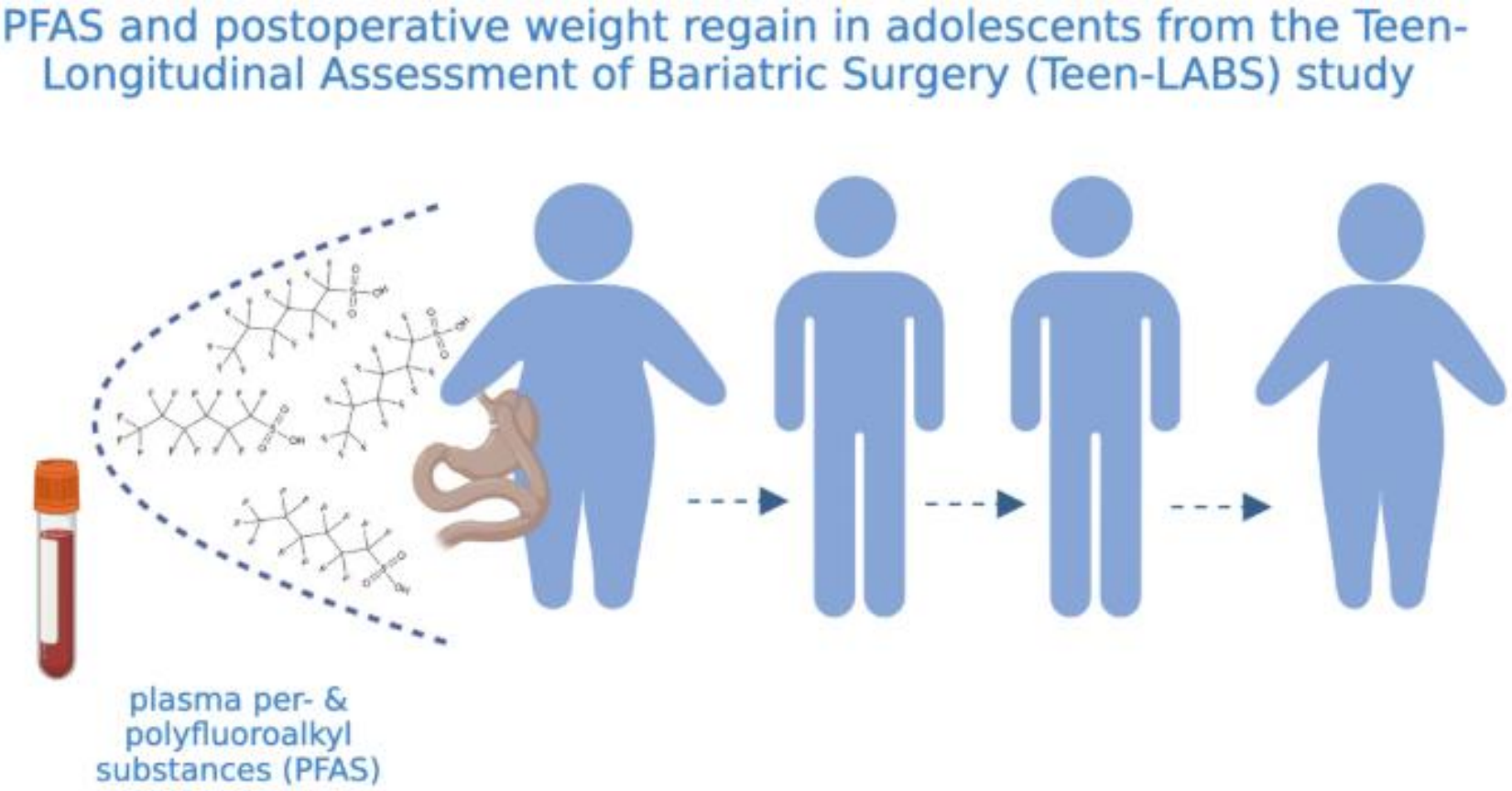
3M DUPONT Chemours SOLVAY

PFAS: Multi-System Toxicants



Modified from ATSDR, 2018

PFAS Associated with Weight Gain



Baumert et al., (2025)
https://doi.org/10.1002/oby.70009

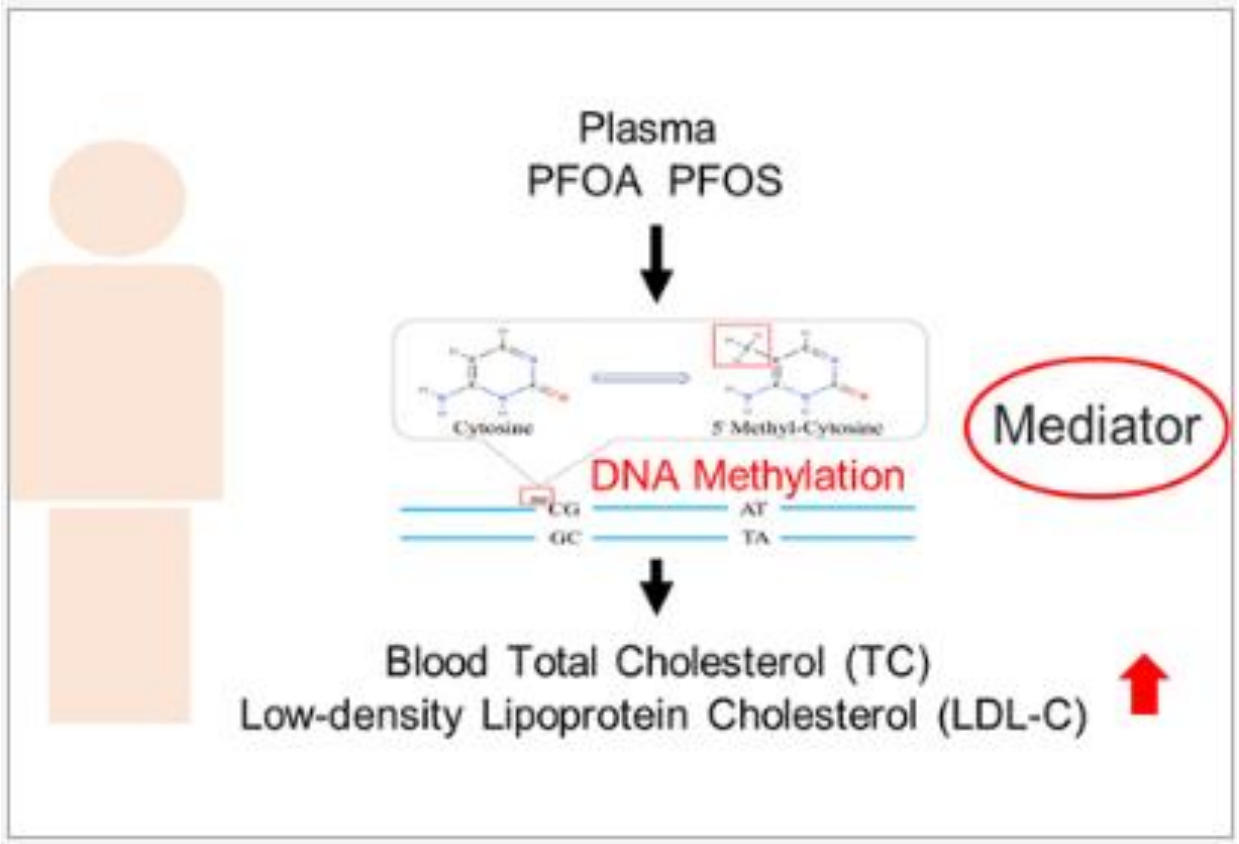
PFAS Disturbs Metabolism

- Sisters Study – 6-year follow-up
- Legacy PFAS mixtures associated with lipid and amino acid metabolism
- Novel PFAS mixtures affected additional pathways: carbohydrate, cofactor, vitamins, and hormones

Chang et al., Environ Int (2025)

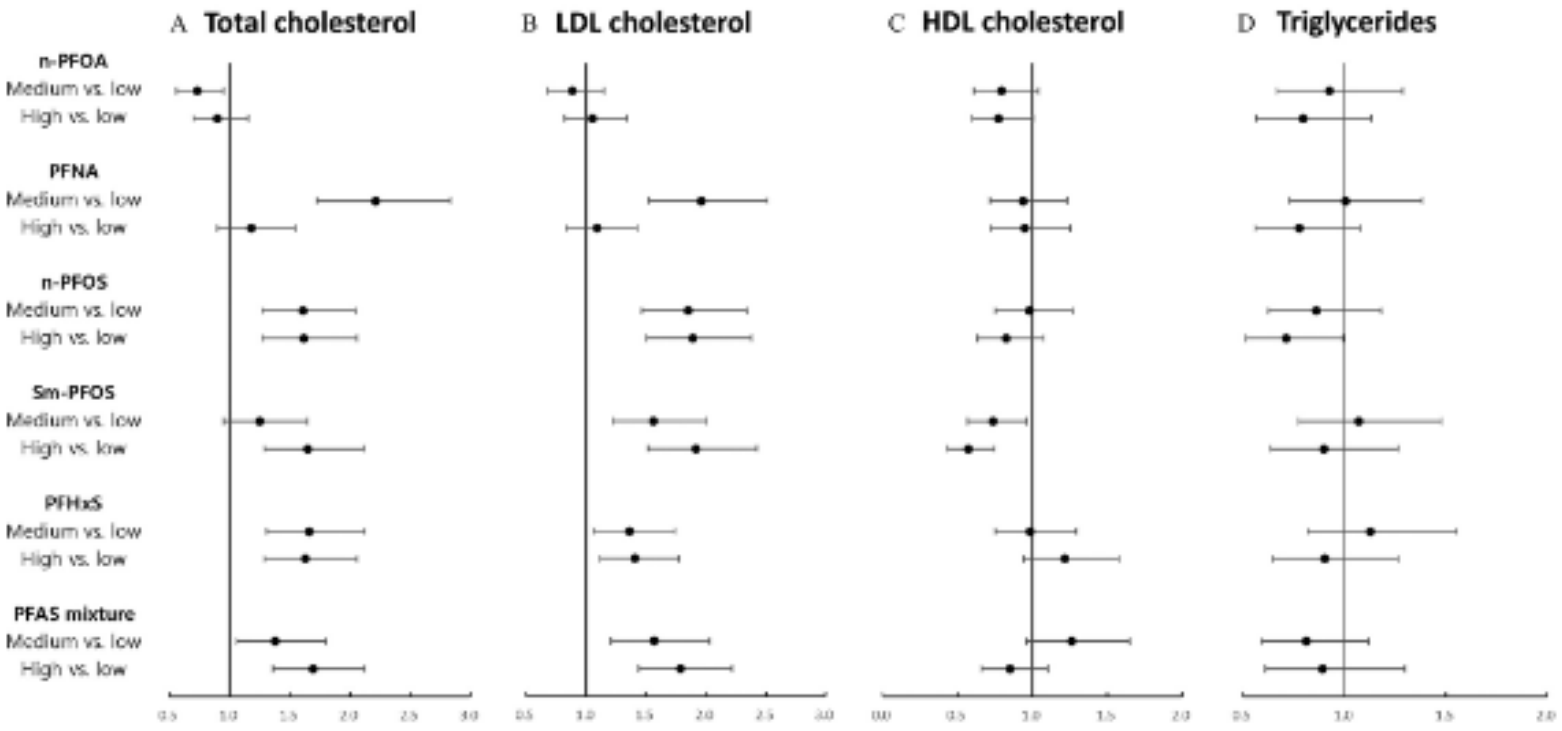
https://doi.org/10.1016/j.envint.2025.109590

Plasma PFAS and Blood Lipids



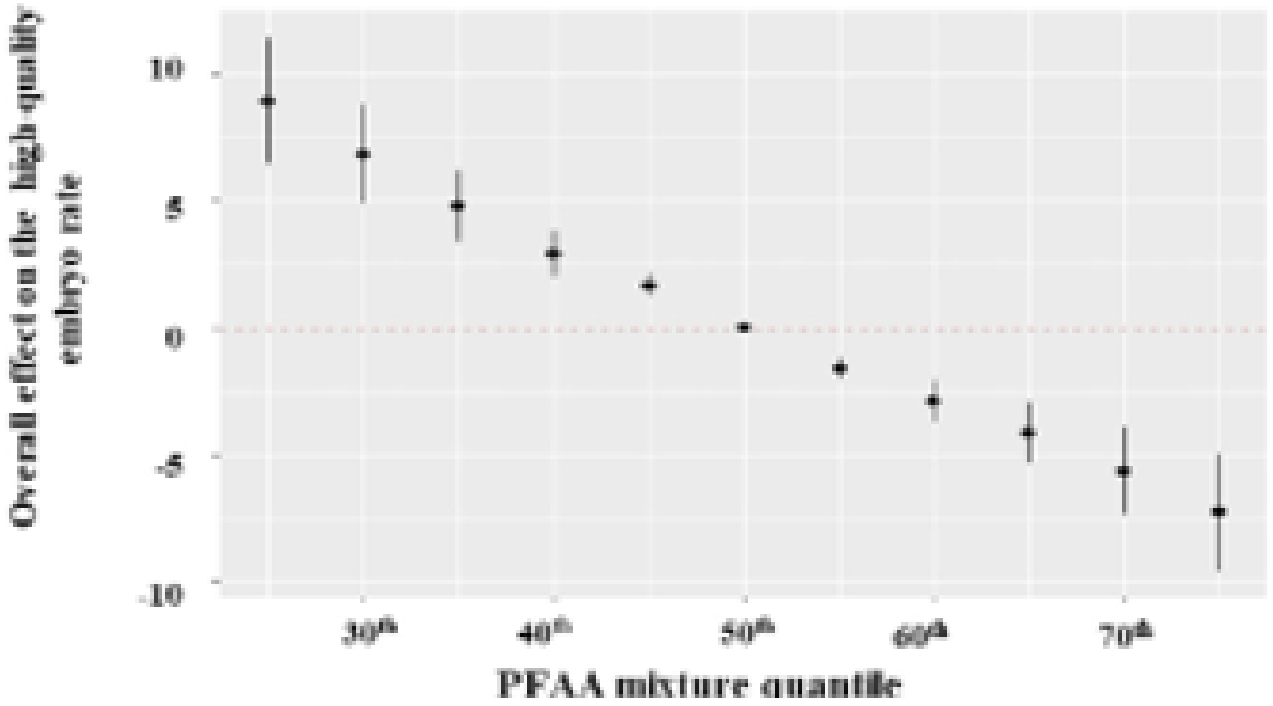
Cheng et al., ES&T (2022)
https://doi.org/10.1021/acs.est.2c04107

PFAS Associated with Lipid Trajectories in Middle-Aged Women



Kang et al., Env Health Perspect (2023)

PFAS in Follicular Fluid: Embryo Quality in IVF



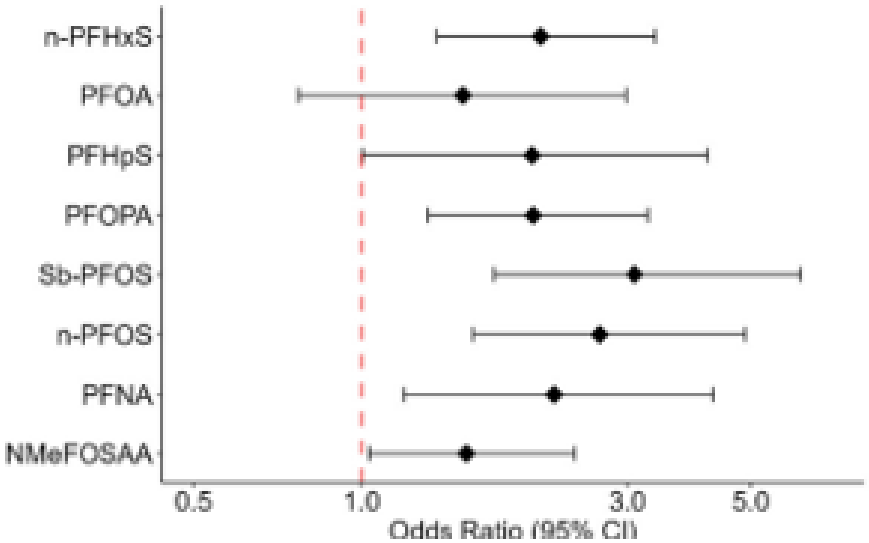
Zeng et al., Env Health Perspect (2023)

PFAS and Differential Sex Hormone Response in Male vs Female Teenagers

- Higher Blood PFAS Associated with
- Kisspeptin (Kiss 54) Increases in both Sexes
- SHBG Increases in Males, Decreases in Females
- In Males – FSH, TT, and E2 Decrease
- In Females – FSH, TT, and E2 Increase

Rodríguez-Carrillo et al., Env Pollution 335 (2023)

PFAS Exposure and Thyroid Cancer Risk

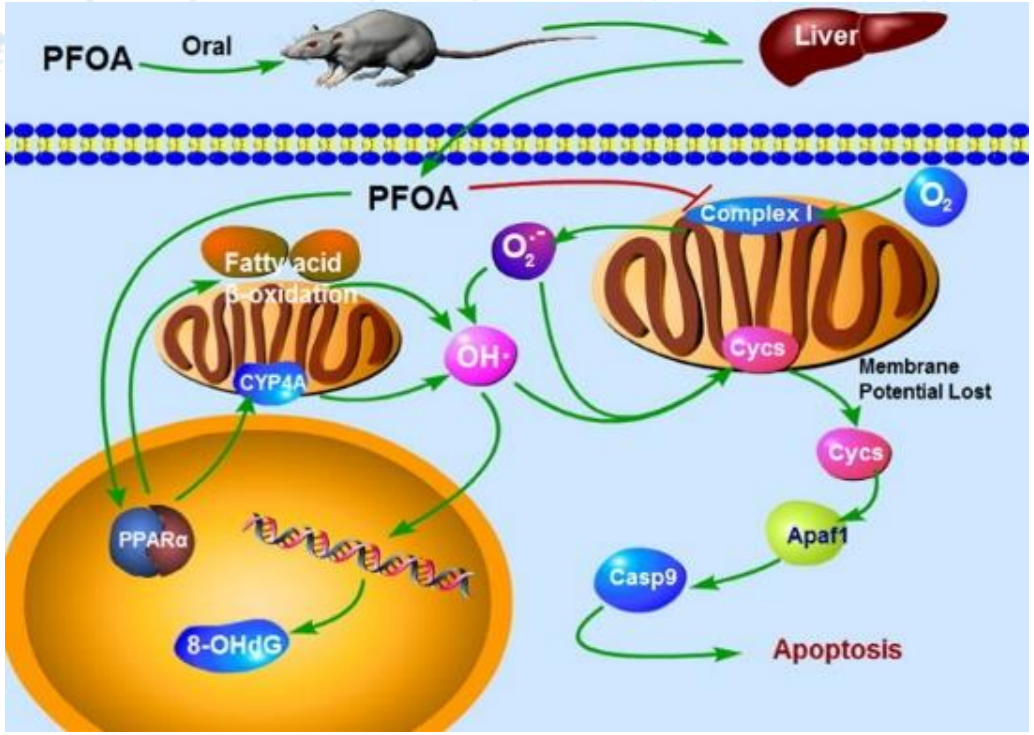


	OR	95% CI	pvalue	p.adjuste
n-PFHxS	2.10	1.36,3.37	0.001	0.003
PFOA	1.52	0.77,2.98	0.22	0.22
PFHpS	2.03	1.00,4.18	0.05	0.06
PFOPA	2.03	1.32,3.27	0.002	0.004
Sb-PFOS	3.09	1.73,6.13	<0.001	0.002
n-PFOS	2.67	1.59,4.88	<0.001	0.002
PFNA	2.22	1.19,4.28	0.01	0.02
NMeFOSAA	1.55	1.03,2.41	0.04	0.06

Van Gerwen et al., Lancet (2023)

Mechanisms of PFAS toxicity

- Activation of PPARs
- Alternate receptors: AR,ER, CAR, PXR, FXR,++
- Inhibiting fatty acid transport
- Interfering with mitochondrial function



Li et al., 2017

In silico Prediction of the Endocrine-Disrupting Ability of 49 PFAS

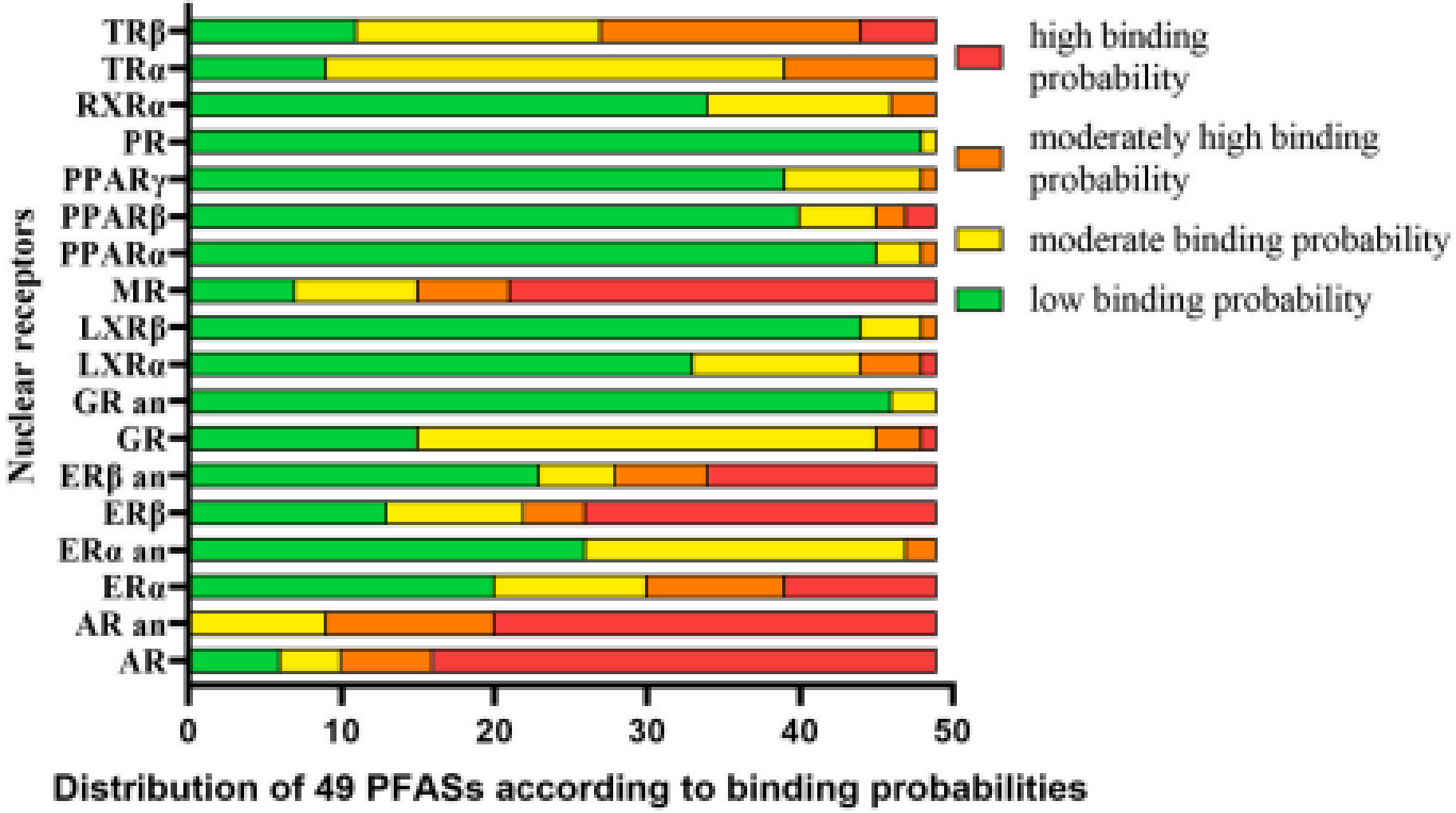
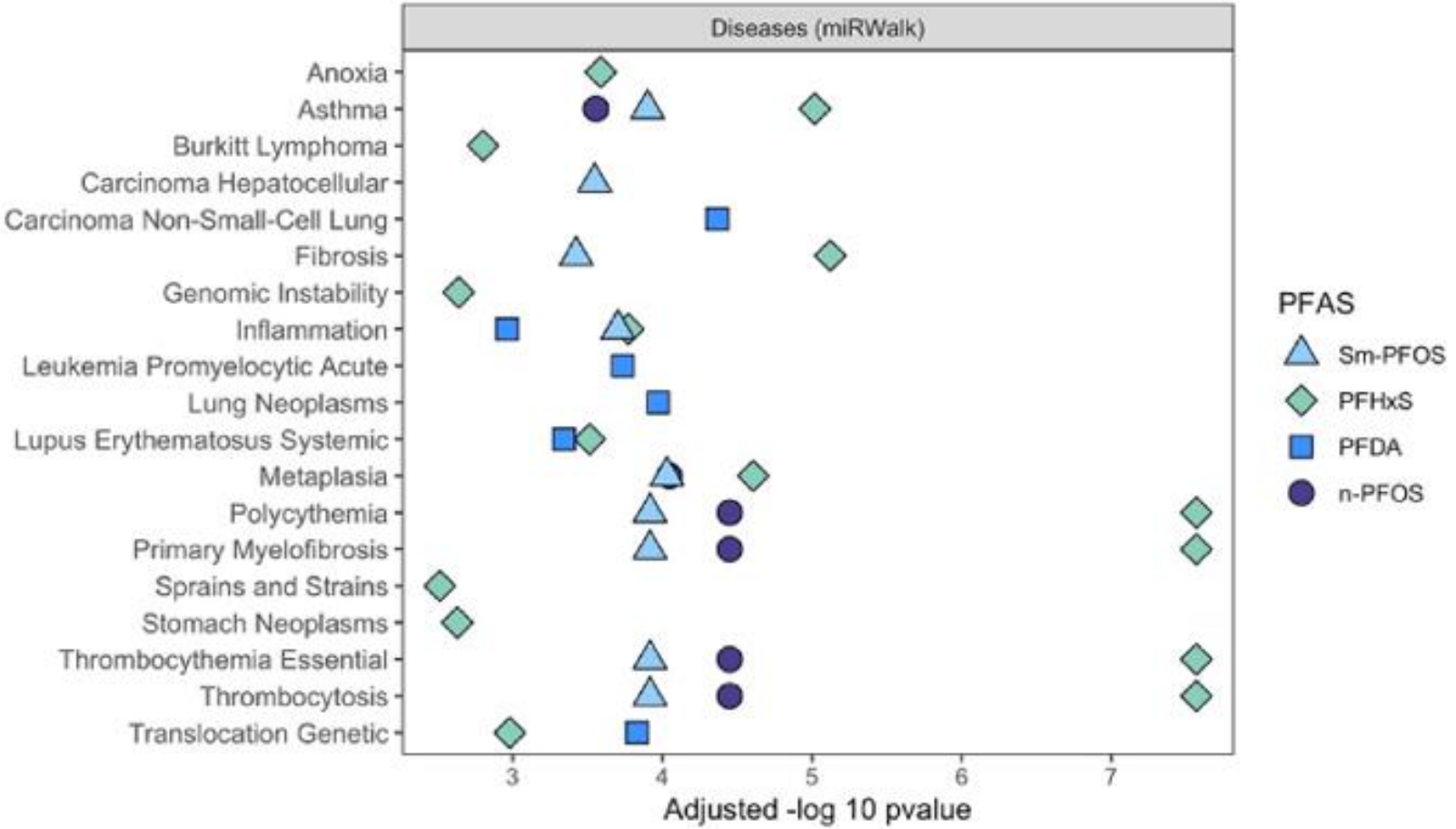


Fig. 2. Distribution of 49 PFASs based on their probabilities of binding with 18 NHRs.

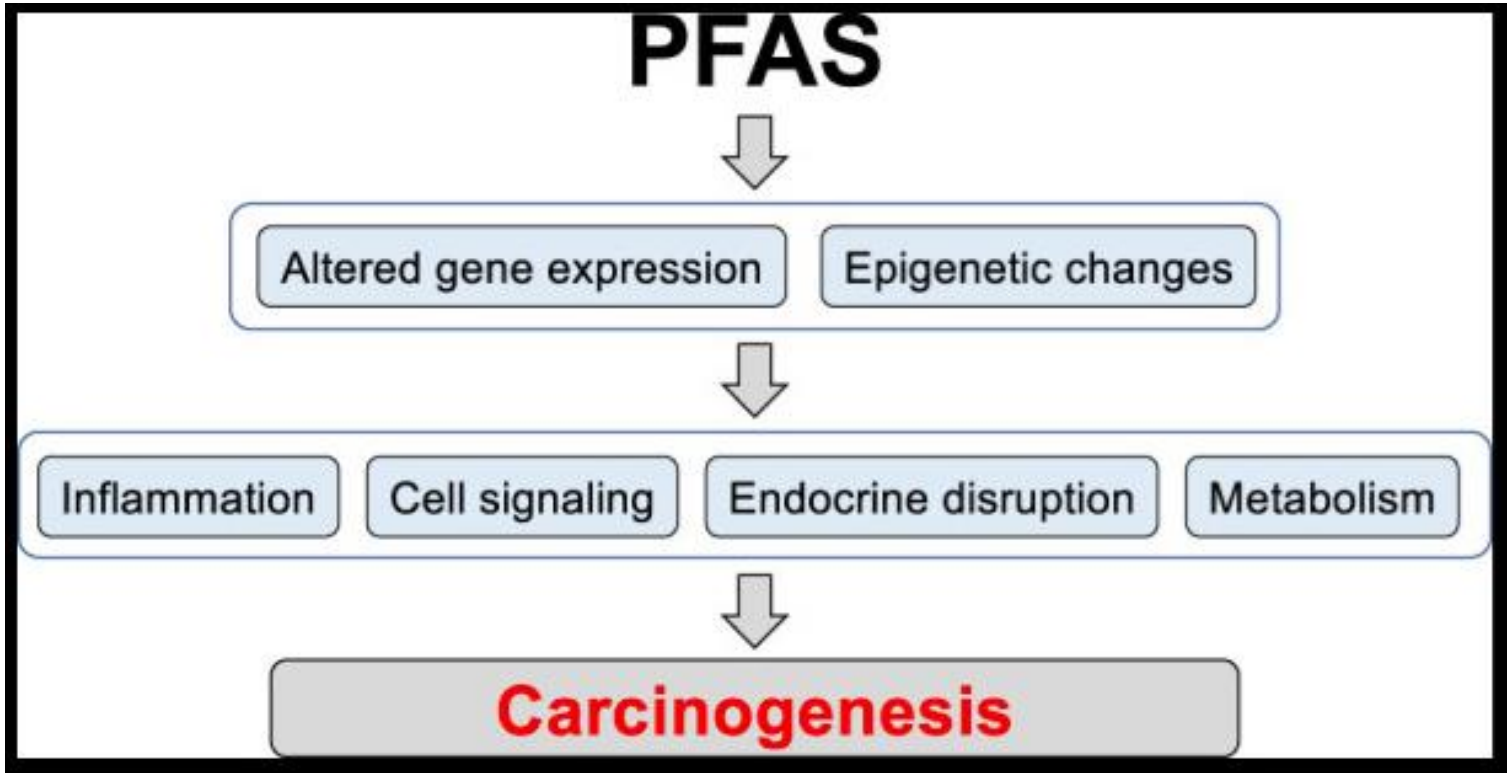
S. Yu et al., Chemosphere **290** (2022)

Disease Pathways Associated with PFAS



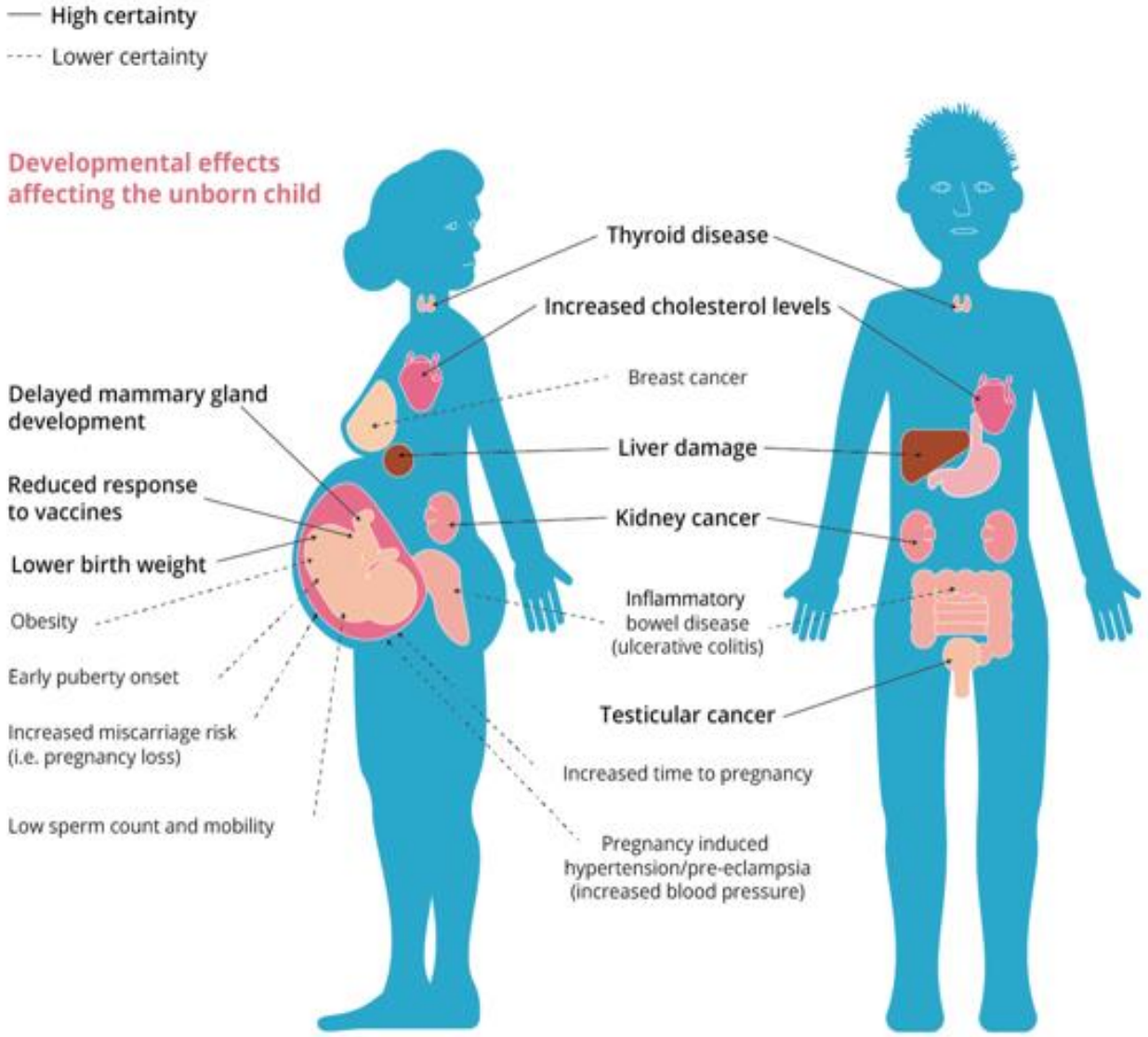
Furlong et al., Per- and polyfluoroalkyl substances (PFAS) and microRNA: An epigenome-wid
association study in firefighters. Environmental Research 279 (2025) 121766

Potential Mechanisms of PFAS and Cancer



Durham et al., Front Toxicol (2023)

Health Effects of PFAS Exposure



Sources: US National Toxicology Program (2016); C8 Health Project Reports (2012); WHO IARC (2017); Barry et al. (2013); Fenton et al. (2009); and White et al. (2011) apud Emerging chemical risks in Europe — 'PFAS'[1].

IARC classifications for PFOA and PFOS (November 2023)

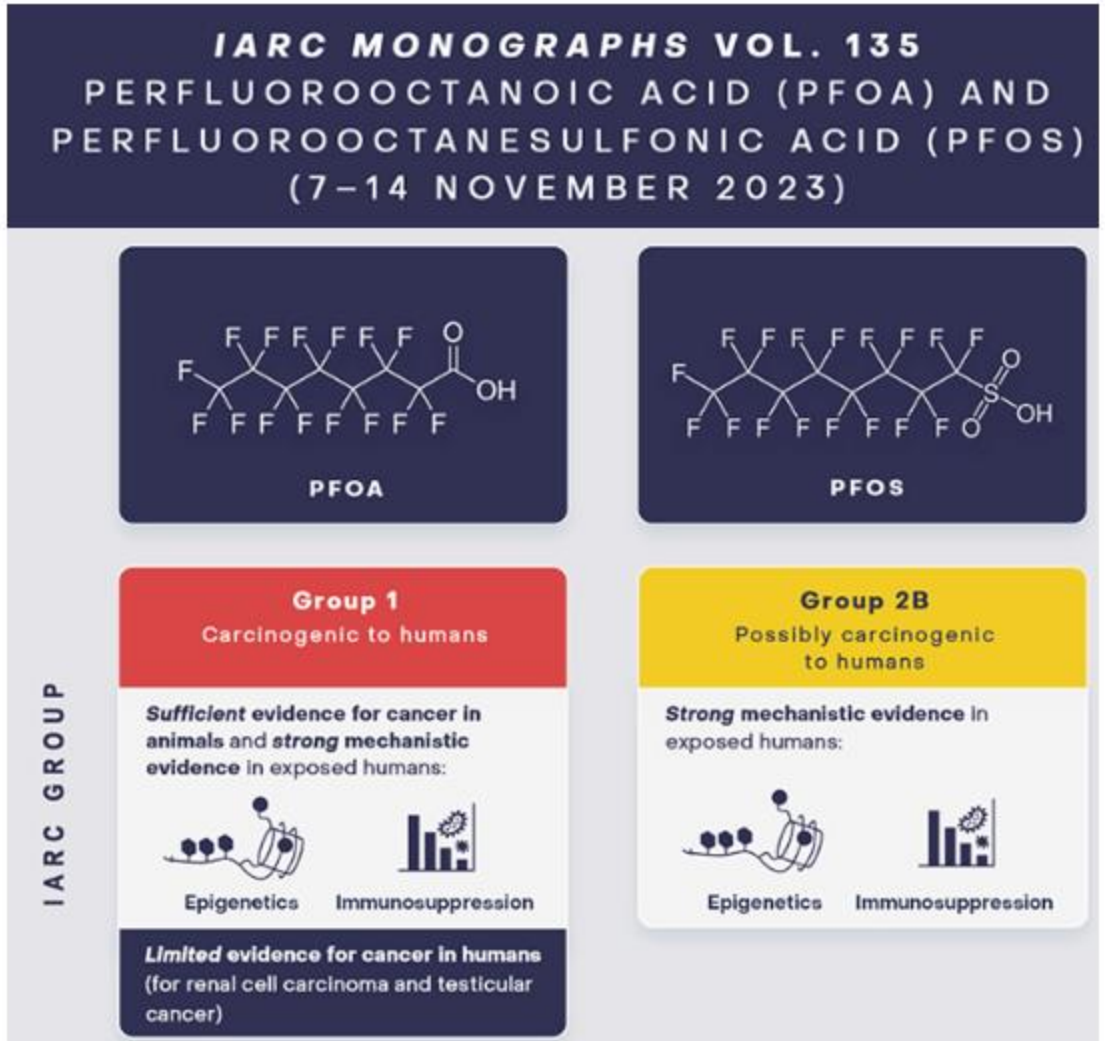
International Agency for Research on Cancer

World Health Organization

Table 1. Summary of classifications in *IARC Monographs* Volume 135

Agent	Evidence stream			Overall evaluation
	Cancer in humans	Cancer in experimental animals	Mechanistic evidence (key characteristics of carcinogens)	
Perfluorooctanoic acid (PFOA)	*Limited* (renal cell carcinoma and testicular cancer)	*Sufficient*	*Strong* in exposed humans (KCs 4, 7), human primary cells (KCs 5, 7, 8), experimental systems (KCs 4, 5, 7, 8, 10)	Group 1
Perfluorooctanesulfonic acid (PFOS)	*Inadequate*	*Limited*	*Strong* in exposed humans (KCs 4, 7), human primary cells (KCs 5, 7, 8), experimental systems (KCs 4, 5, 7, 8, 10)	Group 2B

KCs, key characteristics of carcinogens; KC4, induces epigenetic alterations; KC5, induces oxidative stress; KC7, is immunosuppressive; KC8, modulates receptor-mediated effects; KC10, alters cell proliferation, cell death, or nutrient supply.



Hazard Conclusions Across EPA PFAS Assessments

Health outcome	PFAS Assessments[a,b,c]						
	PFNA (this assessment)	PFHxA U.S. EPA (2023h)	PFBA U.S. EPA (2022b)	PFBS U.S. EPA (2018b)	Gen X chemicals U.S. EPA (2021a)	PFOA[d] U.S. EPA (2016b)	PFOS[d] U.S. EPA (2016a)
Thyroid	+/-	+	+	+	ND	Human: + Animal: +/-	Human: +/- Animal: +/-
Liver	+	+	+	-	+	Human: + Animal: +	Human: - Animal: +
Developmental	+	+	+	+	+/-	Human: + Animal: +	Human: + Animal: +
Reproductive	Male: + Female: -	-	-	-	+/-	Human: - Animal: +/-	ND
Immunotoxicity	+/-	-	-	-	+/-	Human: + Animal: +	Human: +/- Animal: +
Renal	-	-	-	+	+/-	Human: +/- Animal: +/-	ND
Hematological	-	+	-	ND	+/-	ND	ND
Ocular	ND	ND	-	ND	ND	ND	ND
Serum lipids	+/-	ND	ND	-	ND	Human: + Animal: +	Human: +
Hyperglycemia	ND	ND	ND	ND	ND	Human: - Animal: -	Animal: +/-
Nervous system	+/-	-	ND	ND	ND	Human: - Animal: -	Animal: +/-
Cardiovascular	+/-	ND	ND	-	ND	ND	ND
Cancer	-	-	-	-	+/-	+/-	+/-

EPA Promulgates Regulations on 6 PFAS in Drinking Water – April 10,2024!

- PFOA and PFOS
  - MCLGs = 0
    - Carcinogenic
    - No safe level
  - MCLs = 4 ppt (ng/L)
    - Based on technological, economic, and sociological considerations
- PFHxS, PFNA, GenX –
  - MCLG=MCL
  - 10 ppt each
- PFBS, PFHxS, PFNA, GenX
  - Hazard index for mixture of 2 or more = 1
- 3 years (2027)to complete initial monitoring
  - followed by compliance monitoring and
  - must notify public of PFAS levels
- 5 years (2029) to implement solutions to
  - reduce PFAS <MCLs, and
  - if violate must take action and notify public

April 19, 2024 – PFOA and PFOS designed as hazardous under Superfund and the polluter will have to pay to remediate!

Other Federal Regulations on PFAS

FDA – removed from food packaging (2024)
DOD – No PFAS in AFFF in practice/training (2020); total by 10/2024
FAA – No PFAS required in domestic airports after 10/4/2021

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****April 2025 – EPA Revises Regulations****

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What is Happening in our States?

WATER

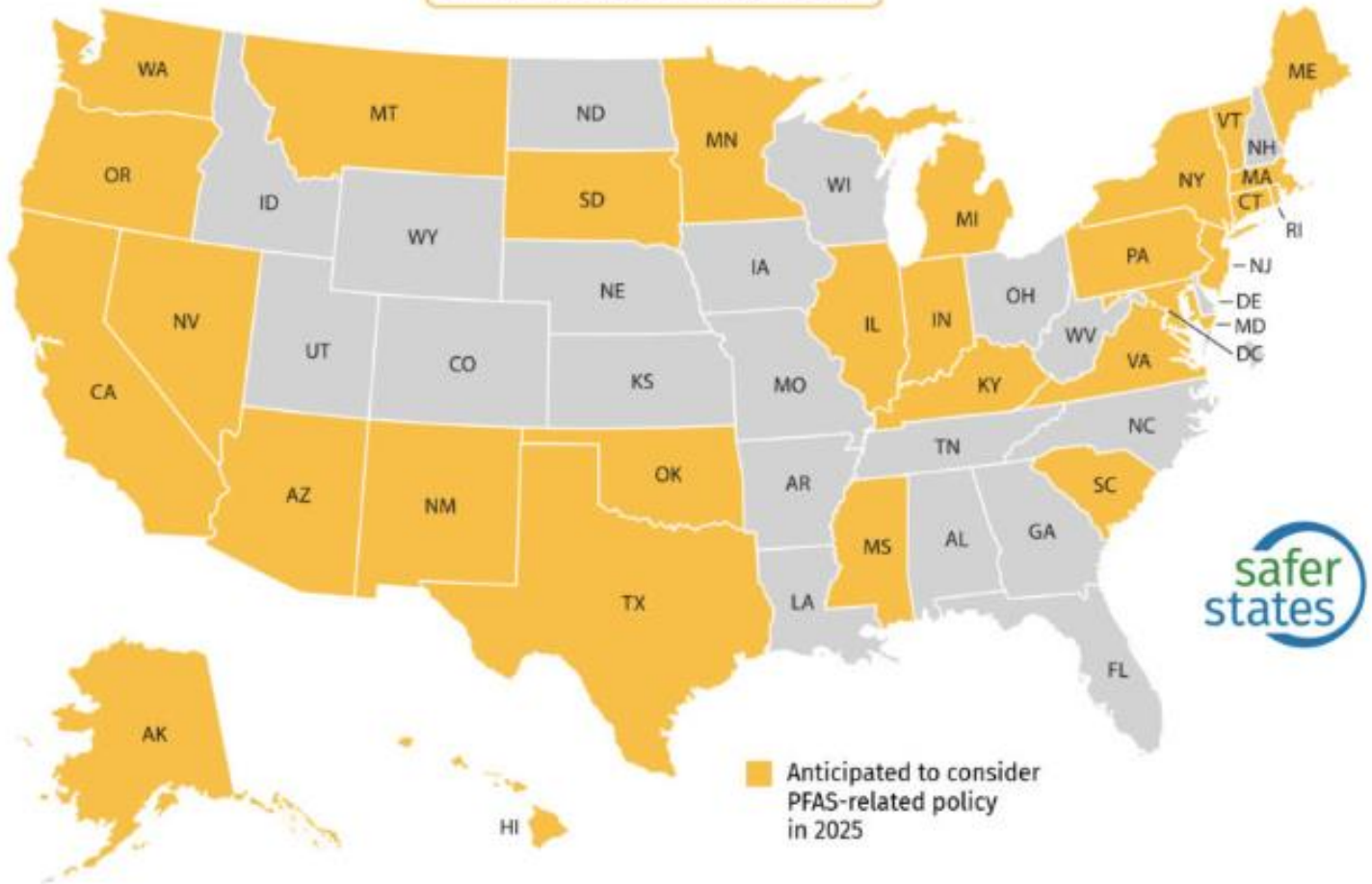
- 30 states – DW, GW, surface water
- 8 states have MCLs (>EPA's)
  - MI, NH, NJ, NY, PA
  - Sum
    - VT – Σ 5
    - MA, ME, RI – Σ 6
  - 6 more states are developing MCLs
- 2 states guidelines <EPA's proposed MCLs
  - Il, VT – 2 ppt
- 23 states look at more than just PFOA and PFOS

AFFF, Food, Textiles

- 36 states in process of banning or restricted PFAS-containing AFFF
- Food Contact Materials
  - 14 states banning in progress
  - Major grocery and restaurants chains eliminating PFAS
  - Banned in Denmark in 2020
- Textiles and Furnishings
  - CA, NY, etc.…

STATES EXPECTED TO TAKE ACTION IN 2025

PFAS "Forever Chemicals"



PFAS Exposure, Testing, and Clinical Follow-Up (NASEM, 2022)

- Sufficient Evidence
  - decreased **antibody response** (in adults and children)
  - **dyslipidemia** (in adults and children),
  - decreased **infant and fetal growth**,
  - increased risk of **kidney cancer** (in adults).
- Limited Evidence
  - increased risk of **breast cancer** (in adults),
  - **liver enzyme** alterations (in adults and children),
  - increased risk of **pregnancy-induced hypertension** (gestational hypertension and preeclampsia),
  - increased risk of **testicular cancer** (in adults),
  - **thyroid disease** and dysfunction (in adults), and
  - increased risk of **ulcerative colitis** (in adults).

Clinical Follow-up and Care for PFAS Exposure

(NASEM, 2022)

- PFAS blood concentration below 2 ng/mL (ppb) are not expected to have adverse health effects.
- PFAS blood between 2 and 20 ng/mL may face the potential for adverse effects
  - encourage reduction of PFAS exposure
  - prioritize screening for dyslipidemia, hypertensive disorders of pregnancy, and breast cancer
- PFAS blood above 20 ng/mL may face a higher risk of adverse effects
  - screening for dyslipidemia
  - conduct thyroid function testing
  - assess for signs of kidney and testicular cancer and of ulcerative colitis

ATSDR Issues Clinical Guidance on PFAS, January 18, 2024

Testing Patients for PFAS

- Testing is available, but with limitations
  - Testing for 40 PFAS available through US laboratories
    - E.g., Quest Diagnostics - ~$350/sample for 9 PFAS
  - Cost usually born by patient
  - Consensus and guidelines lacking
- NASEM suggest stratified response
  - <2 ng/ml – don't expect adverse effects
  - 2-20 ng/ml – potential for adverse health effects
  - >20 ng/ml – increased risk
- Use existing standard of care and promote mitigation measures
  - Assess metabolic, liver, renal, and thyroid function tests
  - Further screening for thyroid, kidney, and testicular cancer
- Implement strategy to reduce exposure
- Repeat testing after 1-2 years to assess efficacy of exposure reduction measure

Zuccaro et al., Cleveland Clinic J. Med. 92(2025)
Environ. Sci. Technol. 2025, 59, 17, 8368-8379

Avoiding PFAS

Food
- Cut back on fast food and greasy carryout food
- Avoid most freshwater fish
- Pop popcorn the old-fashioned way
- Store food in glass or stainless-steel containers

Consumer Products
- Chose personal care products without “PTFE” or “Fluoro” Ingredients
- Be wary of all fabrics labeled stain or water repellent
- Avoid PTFE-based nonstick pans and kitchen utensils
- Avoid water-resistant cosmetics

Water
- Install a certified filtration water system

Gardening
- Avoid sludge-based fertilizers and PFAS-pesticides for gardening

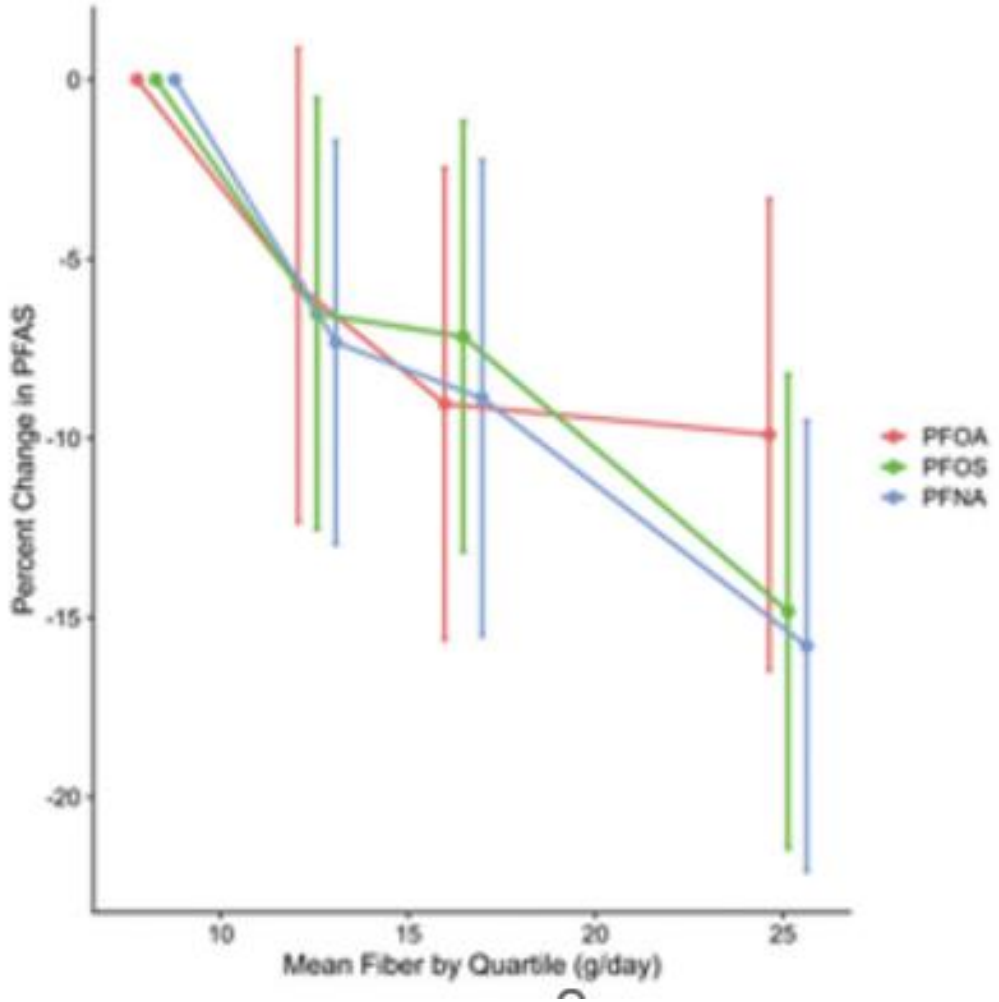
Half-Lives of Common PFAS

PFAS	Half-Life
• PFOA	• 2-10 years
• PFOS	• 3-27 years
• PFHxS	• 5-35 years
• PFNA	• 2-4 years
• PFBS	• ~ I month
• PFBA	• ~ 3 days

Shorter half-lifes:
- females 20-50 yrs
- young age
- better kidney function
- gut inflammation

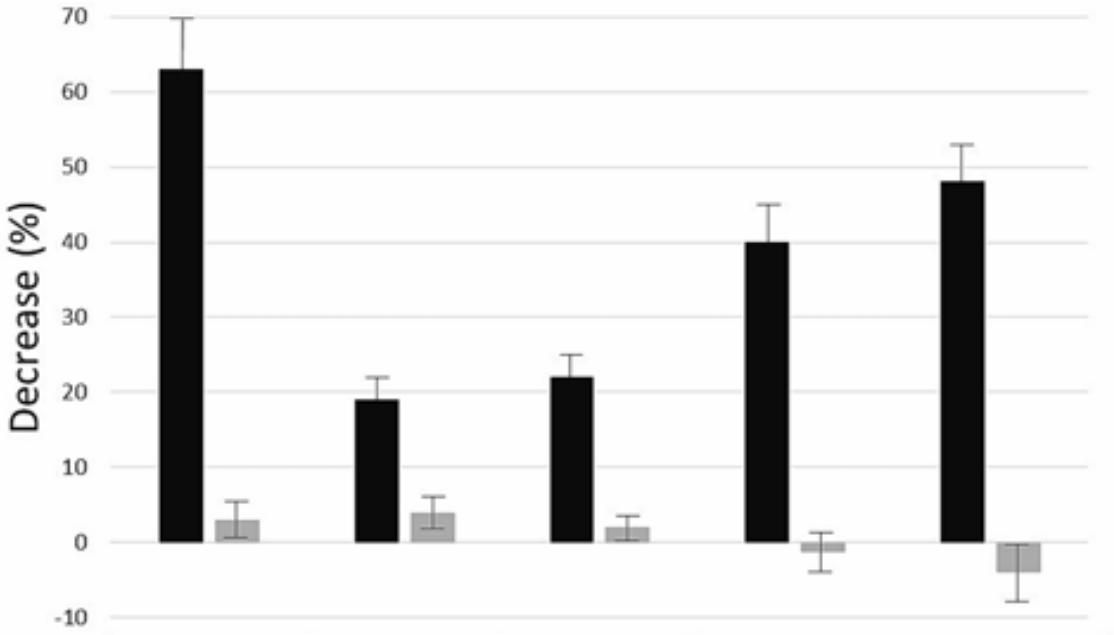
Li et al, 2018

Dietary Fiber Increases PFAS Excretion



Pizzorno, Integrative Medicine • Vol. 22, No. 6 • January 2024

Relative Elimination of PFAS after 12 Weeks of Treatment with an Anion Exchange Resin



	PFOS	PFHxS	PFOA	PFNA	PFDA
Treatment period	63 (57 to 70)	19 (16 to 22)	22 (19 to 25)	40 (35 to 45)	48 (43 to 54)
Observation period	3.3 (1.0 to 5.6)	3.5 (1.4 to 5.6)	2.4 (0.7 to 4.0)	-1.3 (-3.9 to 1.3)	-4.0 (-7.8 to -0.1)

Moller et al., Env Intl (2024)

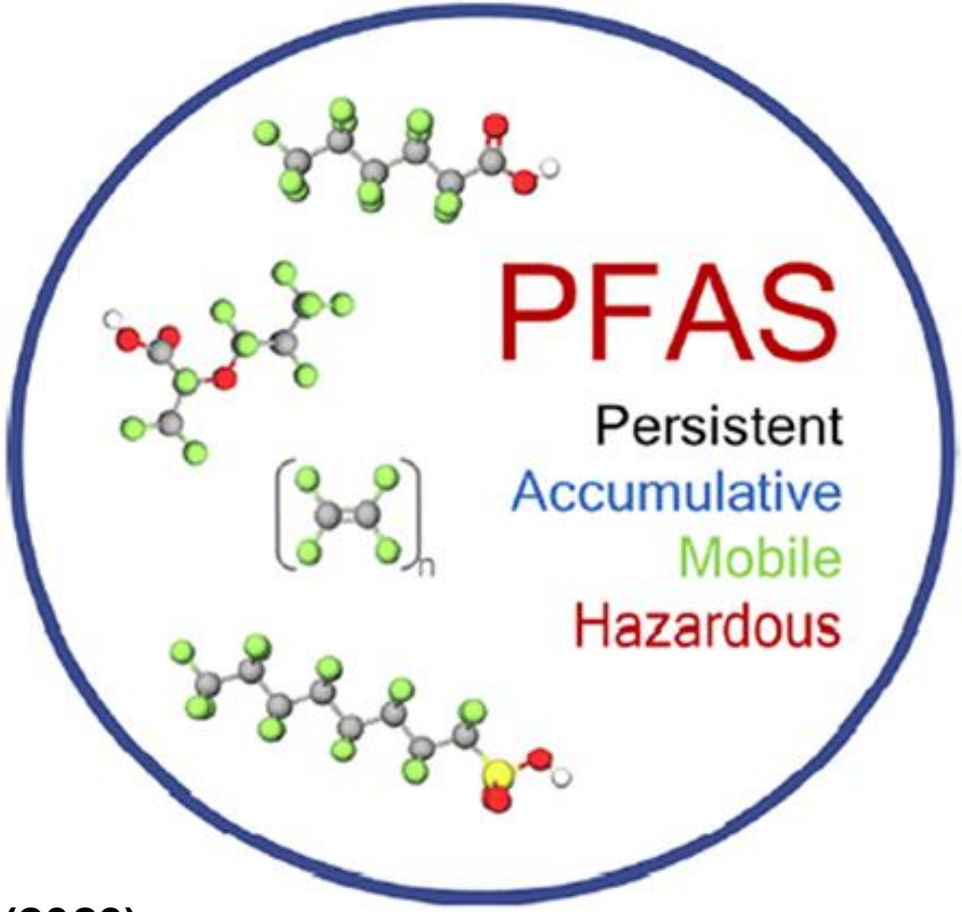
Scientific Basis for Managing PFAS as a Chemical Class

Chemicals Strategy for Sustainability Towards a Toxic Free Environment **European Commission – October 10, 2020**

PFAS[62]

The Commission will:

- ban **all PFAS** as a group **in fire-fighting foams** as well as in **other uses**, allowing their use only where they are essential for society;
- address PFAS with a **group approach**, under relevant legislation on water, sustainable products, food, industrial emissions, and waste;
- address PFAS **concerns on a global scale** through the relevant international fora[63] and in bilateral policy dialogues with third countries;
- establish an EU-wide approach and provide financial support under research and innovation programmes to identify and develop **innovative methodologies for remediating PFAS contamination** in the environment and in products;
- provide research and innovation funding for safe **innovations to substitute PFAS** under Horizon Europe.



EU proposed ban on all nonessential, unintentional uses of PFAS (2023)

Kwiatkowski et al, ES&T Lett 2020

Thank You!

Questions???