Claros
Technologies

PFAS

WHAT ARE THEY AND WHAT CAN WE DO?

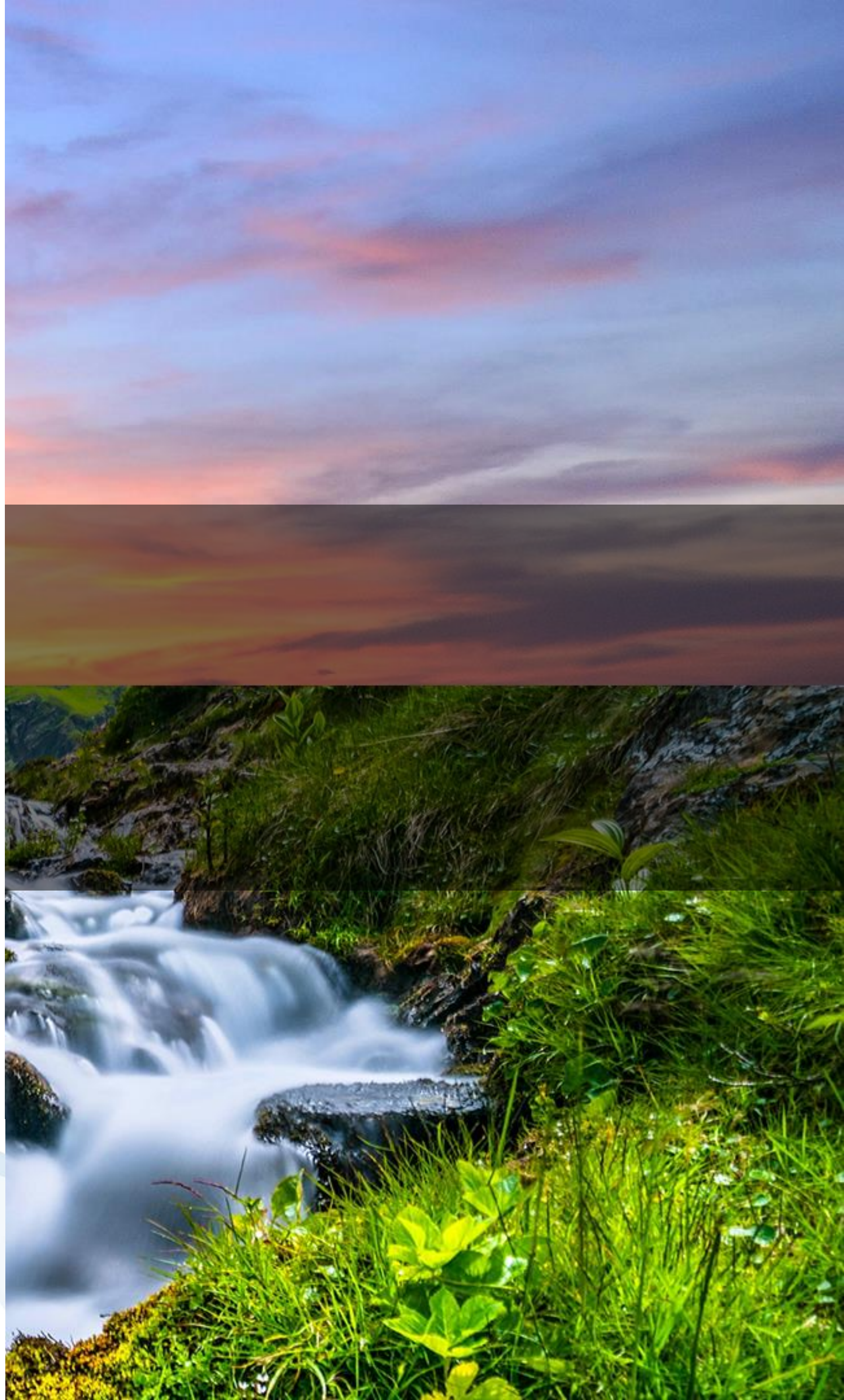
We founded Claros Technologies, Inc. because we believe that air, water, and other natural resources are limited and do not belong to one generation.

The mission of Claros Technologies is to use the latest advancements in science and engineering to innovate solutions that enable sustainable use, recovery, and reuse of these resources.

Minneapolis, MN
Proud to be founded in 2018 (spun out of the University of Minnesota) & HQ'd in the Midwest

Zachary Rogers
Account Executive

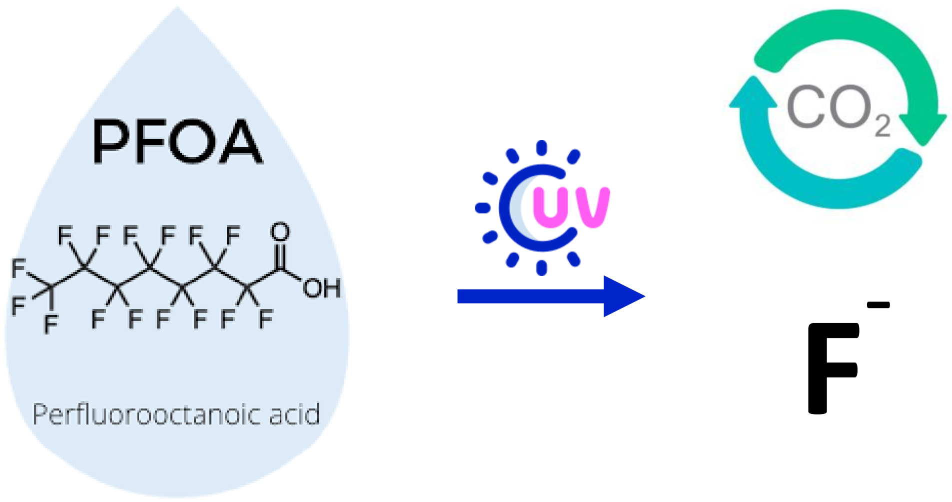
30+
Mission-driven scientists, business builders, and impact leaders committed to powering a circular economy



Learn more at https://clarostechnologies.com/

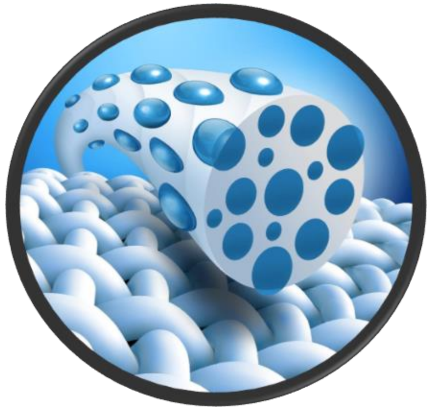
Technology and Business Focus

PFAS (Forever Chemicals) Destruction



- ✓ 99.99% destruction of all PFAS
- ✓ Rapid destruction times
- ✓ Low energy and cost beat other solutions
- ✓ Addressing global $100Bs market

Functional Materials



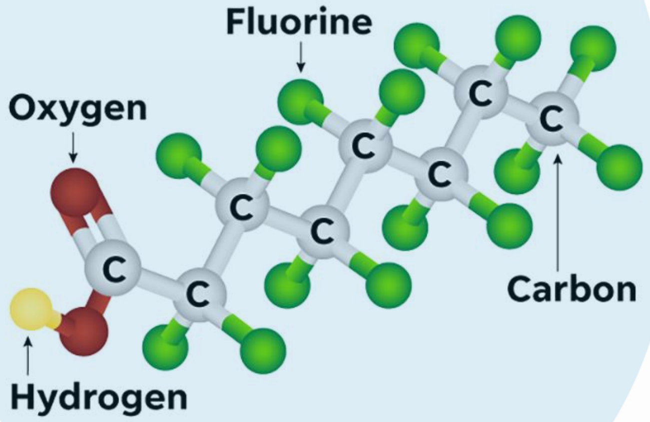
Functional Textiles
- Antimicrobial
- UV protective

Sorbent materials for
metal capture and
recovery from water
(e.g. Hg, Li)

- ✓ Improvement to traditional coating methods
- ✓ Creates lasting functionality throughout materials
- ✓ Countless potential applications

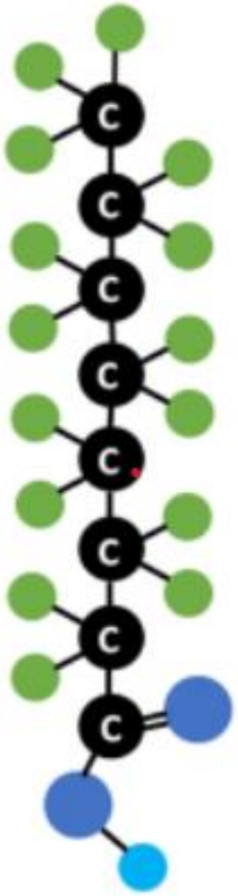
What are “PFAS” or “Forever Chemicals” ?

PFAS Compound



- PFAS stands for Per- and Polyfluoroalkyl Substances
- PFAS are a class of synthetic chemicals that contain a chain of carbon (C) atoms bound with fluorine (F) atoms
- PFAS compounds may also include hydrogen (H), oxygen (O), sulfur (S), or nitrogen (N) atoms
- PFAS are often called “Forever Chemicals” due to the strength of the C-F bond, making them persistent and resistant to natural degradation
- Although conversations often revolve around PFOA and PFOS, there are more than 14,000 PFAS compounds
- PFAS are useful due to their water-repellent and oil-repellent nature

What are "PFAS" or "Forever Chemicals ?



Long Chain PFAS → Carbon chain includes 8 or more carbon atoms (≥ C8)

- Includes PFOA and PFOS
- Most widely studied and regulated
- Demonstrated health impacts
- Persistent and bio cumulative

Short Chain PFAS → Carbon chain includes 4-7 carbon atoms (C4 – C7)

- Includes PFHxS and PFBA
- Some short chain PFAS are regulated
- Demonstrated health impacts
- Persistent and mobile

Ultra-Short Chain PFAS → Carbon chain includes 3 or less carbon atoms (≤ C3)

- Includes TFA
- Limited regulation
- Highly mobile and persistent
- Extremely difficult to capture

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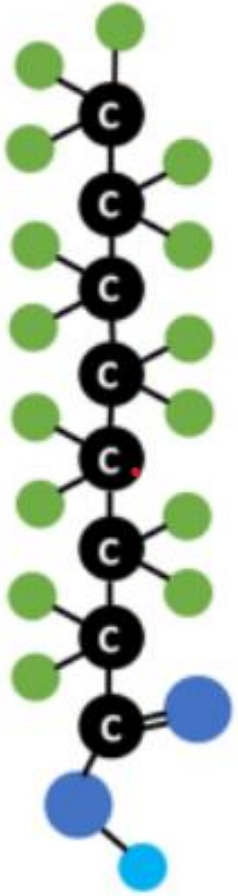

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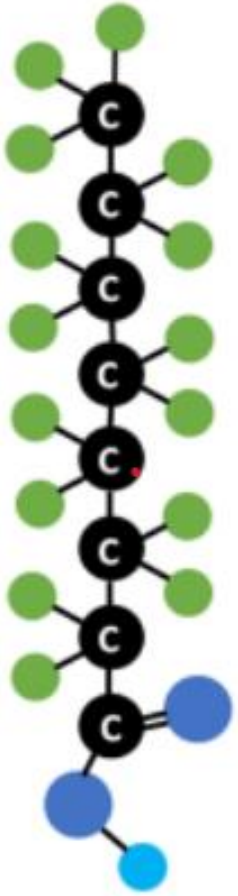

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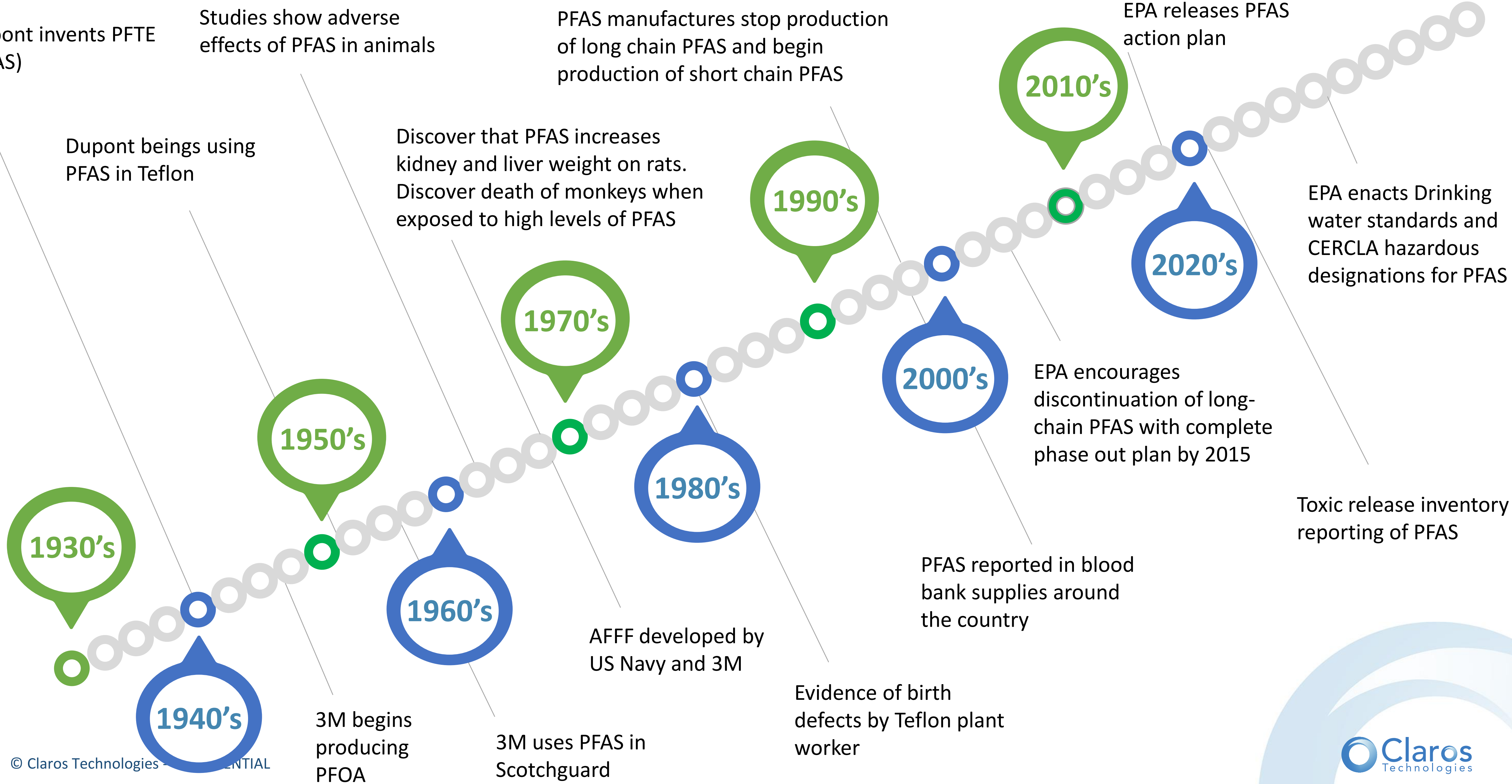
Brief History of PFAS in the U.S.



Dupont invents PFTE (PFAS)

1930's

Dupont beings using PFAS in Teflon

1940's

Studies show adverse effects of PFAS in animals

1950's

3M begins producing PFOA

1960's

3M uses PFAS in Scotchguard

Discover that PFAS increases kidney and liver weight on rats. Discover death of monkeys when exposed to high levels of PFAS

1970's

AFFF developed by US Navy and 3M

1980's

Evidence of birth defects by Teflon plant worker

PFAS manufactures stop production of long chain PFAS and begin production of short chain PFAS

1990's

2000's

PFAS reported in blood bank supplies around the country

EPA encourages discontinuation of long-chain PFAS with complete phase out plan by 2015

2010's

EPA releases PFAS action plan

2020's

EPA enacts Drinking water standards and CERCLA hazardous designations for PFAS

Toxic release inventory reporting of PFAS

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How are PFAS Used?

PFAS

PFAS are used in many different industries, often for stain-repellant and water-repellant properties

Fire Extinguishing Foam (AFFF)

Food Packaging

Dental Floss, Shampoo, and Cosmetics

Chrome Plating

Electronics

Cookware and Cleaning Products

Semiconductors

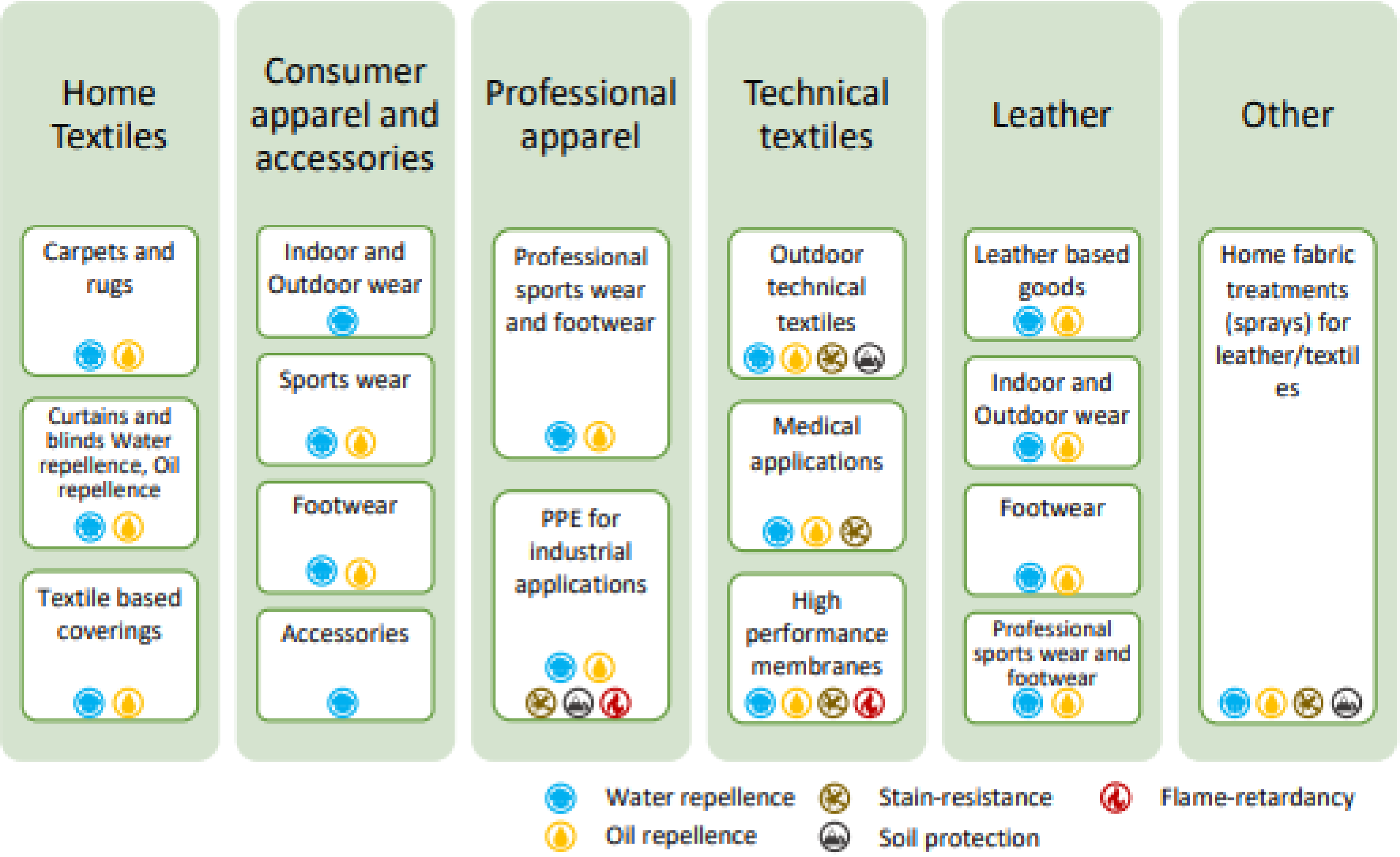
Carpets, Rugs, and Upholstery

Textile and Paper Manufacturing

Chip Manufacturing

PFAS in Textiles

The textile industry is the largest user of fluorotelomers, with an estimate 36% of the total market



Home Textiles
- Carpets and rugs 🔵 🟡
- Curtains and blinds Water repellence, Oil repellence 🔵 🟡
- Textile based coverings 🔵 🟡

Consumer apparel and accessories
- Indoor and Outdoor wear 🔵
- Sports wear 🔵 🟡
- Footwear 🔵 🟡
- Accessories 🔵

Professional apparel
- Professional sports wear and footwear 🔵 🟡
- PPE for industrial applications 🔵 🟡 🟤 ⚫ 🔴

Technical textiles
- Outdoor technical textiles 🔵 🟡 🟤 ⚫
- Medical applications 🔵 🟡 🟤
- High performance membranes 🔵 🟡 🟤 🔴

Leather
- Leather based goods 🔵 🟡
- Indoor and Outdoor wear 🔵 🟡
- Footwear 🔵 🟡
- Professional sports wear and footwear 🔵 🟡

Other
- Home fabric treatments (sprays) for leather/textiles 🔵 🟡 🟤 ⚫

🔵 Water repellence
🟡 Oil repellence
🟤 Stain-resistance
⚫ Soil protection
🔴 Flame-retardancy

PFAS in textiles has historically been used for:

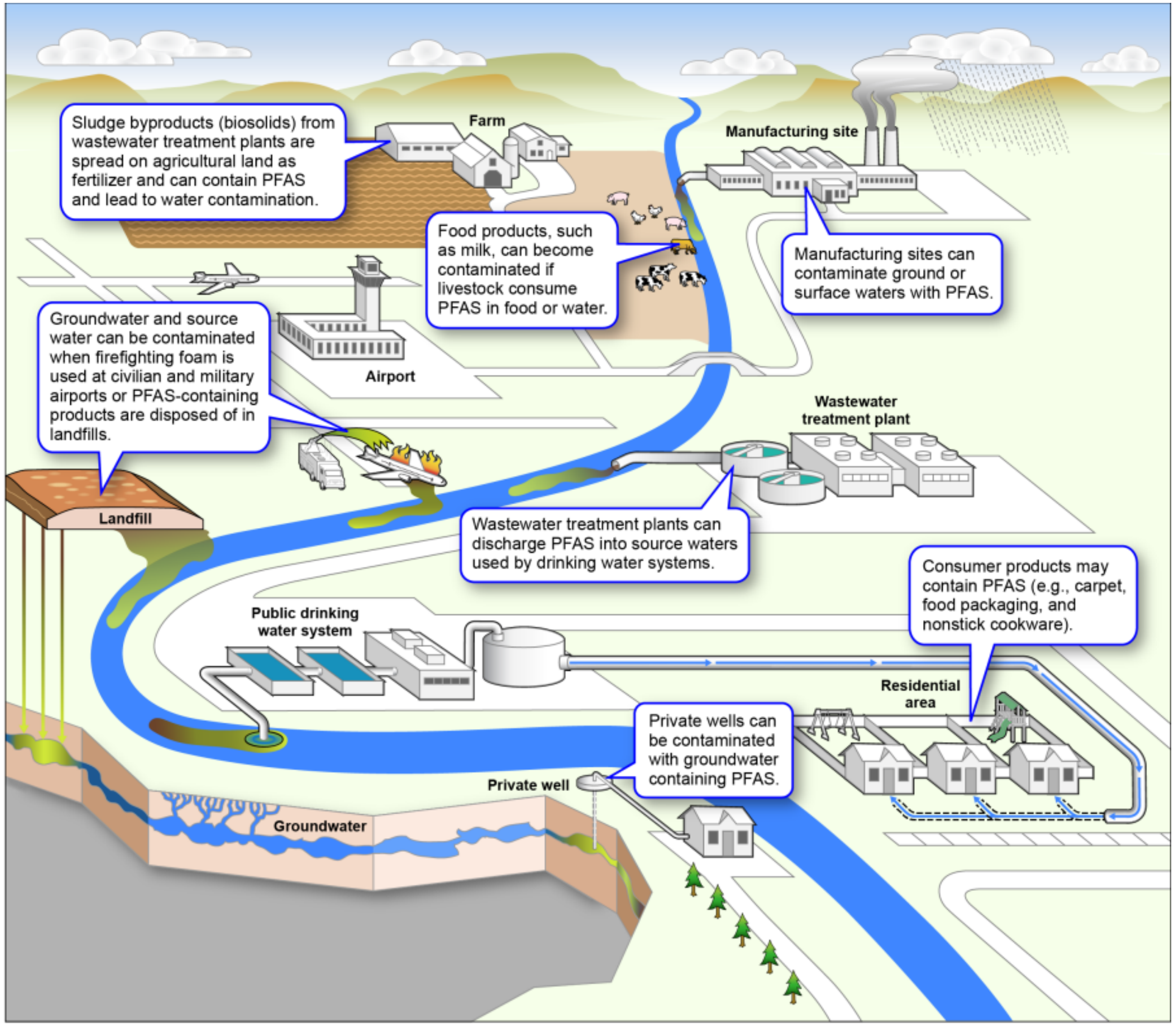
- Lubricants for weaving
- Wetting agents for dye deposition
- Dye ingredients
- Penetration aids for bleaches
- Antifoaming agents
- Emulsifying agents

PFAS are primarily released from textiles in three phases:

- Textile manufacturing
- Textile use
- Textile disposal

Source: SAIM 2021 Policy Brief

PFAS in the Environment



Sludge byproducts (biosolids) from wastewater treatment plants are spread on agricultural land as fertilizer and can contain PFAS and lead to water contamination.

Food products, such as milk, can become contaminated if livestock consume PFAS in food or water.

Manufacturing sites can contaminate ground or surface waters with PFAS.

Groundwater and source water can be contaminated when firefighting foam is used at civilian and military airports or PFAS-containing products are disposed of in landfills.

Wastewater treatment plants can discharge PFAS into source waters used by drinking water systems.

Consumer products may contain PFAS (e.g., carpet, food packaging, and nonstick cookware).

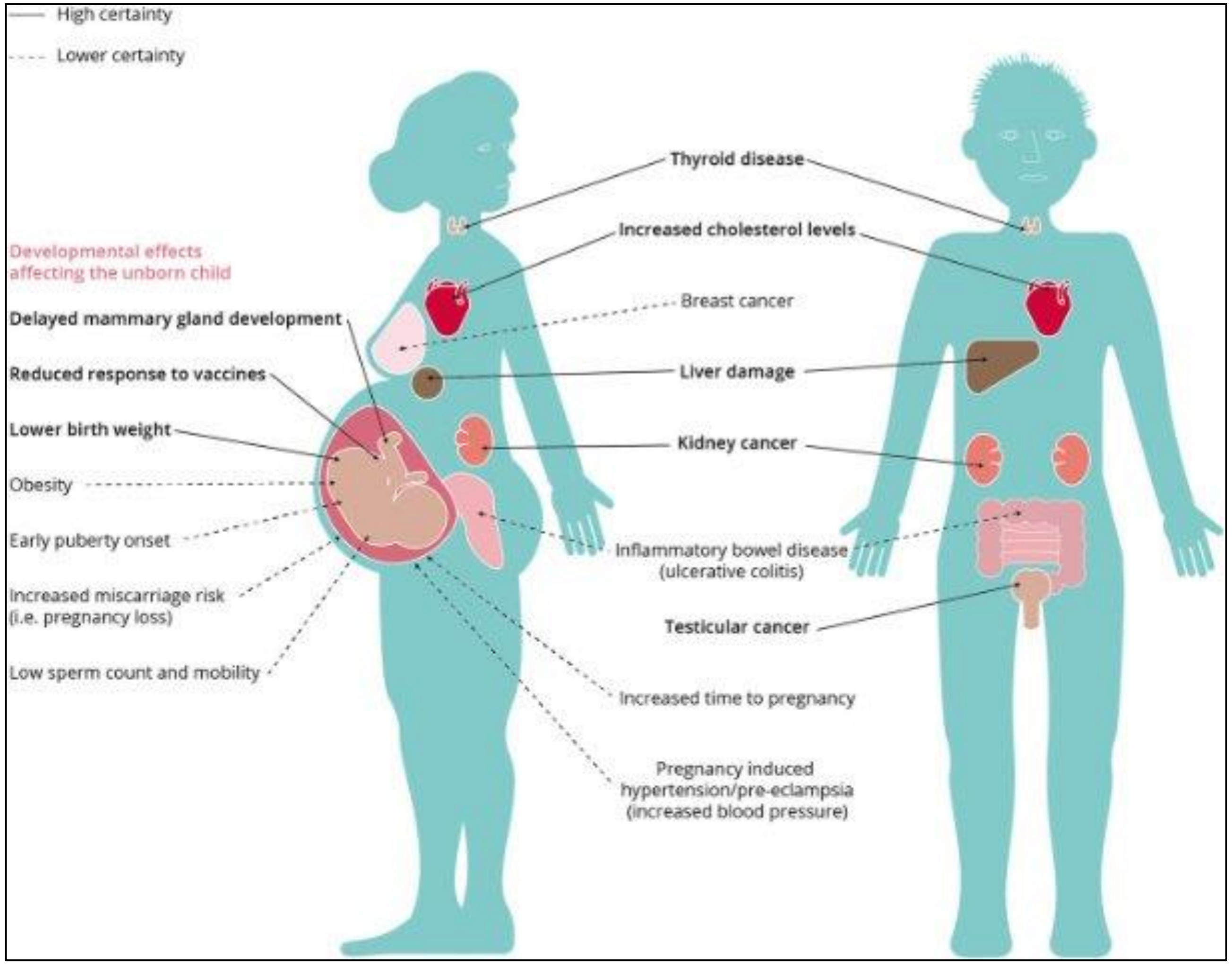
Private wells can be contaminated with groundwater containing PFAS.

Source: GAO | GAO-21-37

PFAS make their way into the environment in many different ways

- PFAS producers may contaminate water in their discharge or contaminate groundwater and surface water
- PFAS producers may contaminate landfill through their waste
- Wastewater treatment plants may discharge PFAS into source water systems
- Consumer products can cause PFAS buildup in landfills and public drinking water systems
- Groundwater and source water can be contaminated by AFFF
- Contaminated biosolids may be used as fertilizer

Human Exposure and Health Risks of PFAS



https://doi.org/10.1002/etc.4890

People may be exposed to PFAS in a variety of ways including:

- Contaminated drinking water
- Cookware and food packaging
- Clothing
- Dust and air contamination
- Contaminated food sources

Many studies have linked PFAS exposure to numerous health conditions including:

- Decreased fertility or high blood pressure
- Developmental delays and accelerated puberty
- Increased risks of cancer
- Hormonal changes
- Reduced immune responses

Impact of PFAS

Social / Economic

- Lack of access to clean drinking water
- Increased healthcare costs
- Annual disease burden and associated economic costs between $5-$63B in the US alone
- Devaluation of homes and businesses
- Loss of production and wages
- Reduce quality and duration of life
- Increased stress, anxiety, depression
- Erosion of public trust
- Environmental racism

Environmental

- Pollution in water, soil, solids, air
- Loss of ecosystem services
- Toxicity in flora and fauna
- Agriculture loss
- Contamination in remote parts of the world far from industrial sources
- Autoimmune disorders in animals such as alligators, sea turtles
- Bioaccumulative and biomagnified
- Contamination in animal tissue and blood and meat, milk, eggs

Societal cost of 'forever chemicals' about $17.5tn across global economy – report

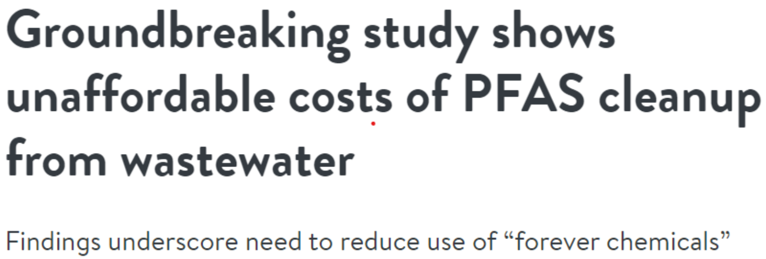
Chemicals yield profit of about $4bn a year for the world's biggest PFAS manufacturers, Sweden-based NGO found

New EPA limits on 'forever chemicals' in drinking water could cost $1.5 billion per year to implement

PFAS proposal would cost companies $1B; lacks limits and cleanup requirement

Daily Exposure to 'Forever Chemicals' Costs United States Billions in Health Costs

NYU Langone Researchers Link the Chemicals to Cancer, Thyroid Disease, Childhood Obesity & Other Medical Conditions



Groundbreaking study shows unaffordable costs of PFAS cleanup from wastewater

Findings underscore need to reduce use of "forever chemicals"

Regulatory Landscape

Following the voluntary phase out of PFOS by 3M between 2000 and 2002, the EPA began to issue regulations that are still progressing today

2002 - Toxic Substance Control Act Use Regulations of PFAS

2009 - EPA issues provisional health advisories for PFAS

2019 - EPA develops the PFAS Action Plan

2020 - Toxic Release Inventory Reporting of PFAS

2024- EPA releases Maximum Contaminant Limits for 6 PFAS in drinking water

2024 - EPA designates two PFAS as CERCLA Hazardous Substances

2021
California
Apparel and Textiles Bill

California prohibits the manufacture, distribution, or sale of apparel, textiles, and cosmetics that contain intentionally added PFAS starting Jan 2025

https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/risk-management-and-polyfluoroalkyl-substances-pfas

Regulation of PFAS in the Textile Industry

United States

- California prohibits the manufacture, distribution, or sale of apparel, textiles, and cosmetics that contain intentionally added PFAS starting Jan 2025
    - PFAS that a manufacturer has intentionally added to a product and that have a functional or technical effect in the product, including the PFAS components of intentionally added chemicals and PFAS that are intentional breakdown products of an added chemical that also have a functional or technical effect in the product.
    - The presence of PFAS in a product or product component at or above the following thresholds, as measured in total organic fluorine: 100 ppm by Jan 1st , 2025 -> 50 ppm by Jan 1st, 2027

Europe

- The Stockholm Convention on Persistent and Organic Pollutants (POPs) bans PFOS, PFOA, PFHxS and their related compounds
- REACH (Registration, Evaluation, Authorization and Restriction of Chemicals) restricts Perfluorinated carboxylic acids (C9-C14 PFCAs), their salts and precursors
    - Under European Parliament and council review: REACH restricts PFHxA, its salts and related substances
    - Under scientific committee review: REACH restricts over 10,000 PFAS compounds use in Europe
    - Compounds on the REACH candidate list of substances of very high concern (SVHC) PFOA, C9-C14 PFCAs, PFHxS, HFPO-DA, PFBS, PFHpA

EPA Drinking Water Regulations for PFAS

April 10th, 2024 - EPA announced the enforceable Maximum Contaminant Limits (MCL) for 6 PFAS in drinking water under the Clean Water Act

- Public water systems have 5 years to comply with the regulation
- Public water systems must monitor and notify the public of contaminations starting in 2027
- Municipalities must take action if monitoring shows levels that exceed the outlined MCL’s

PFAS Compound	MCL
PFOA	4 ppt
PFOS	4 ppt
PFNA	10 ppt
PFHxS	10 ppt
GenX	10 ppt
PFNA	1 (unitless) Based on Hazard Index (HI)
PFHxS	
PFBS	
GenX	

$$\text{HI} = \frac{\text{PFNA}}{10} + \frac{\text{PFHxS}}{10} + \frac{\text{PFBS}}{2000} + \frac{\text{GenX}}{10}$$

*Denominators based on the highest level of each compound determined not to have health risks

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EPA CERCLA Ruling for PFAS

April 19th, 2024 – EPA finalizes rule designating PFOA and PFOS as hazardous substances under the Comprehensive Environmental Response, Compensation & Liability Act (CERCLA)

- Pressure for PFAS polluters to pay for investigations and clean up of PFAS
- Defines PFOA and PFOS as “CERCLA” hazardous substances but does not define them as hazardous waste
- Does not define a requirement for treatment to be performed in a particular way or disposed in a particular type of landfill
- EPA will focus on holding those entities that have significantly contributed to the release of PFAS contamination into the environment responsible, including those parties that have manufactured PFAS or used PFAS in their manufacturing process
- Defines the reporting threshold for PFOA and PFOS as greater than 1 pound per 24 hours

Analytical Methods for PFAS

	Targeted Approach	Non-Targeted Approach
Pros	• Know the identity and concentrations of selective PFAS compounds are in a sample • Cover all compounds in US federal and state regulations	• Analyze PFAS a whole class in a sample without information about individual PFAS compounds • Suitable for blanket ban
Cons	• Only cover less than 1% total PFAS compounds available • Hard and expensive to expand the methods to cover more • Not suitable for blanket ban of PFAS	• Does not reveal any information about specific PFAS compounds • Hard to address the PFAS problem with a single number • Free fluoride could cause interferences

Key Takeaway

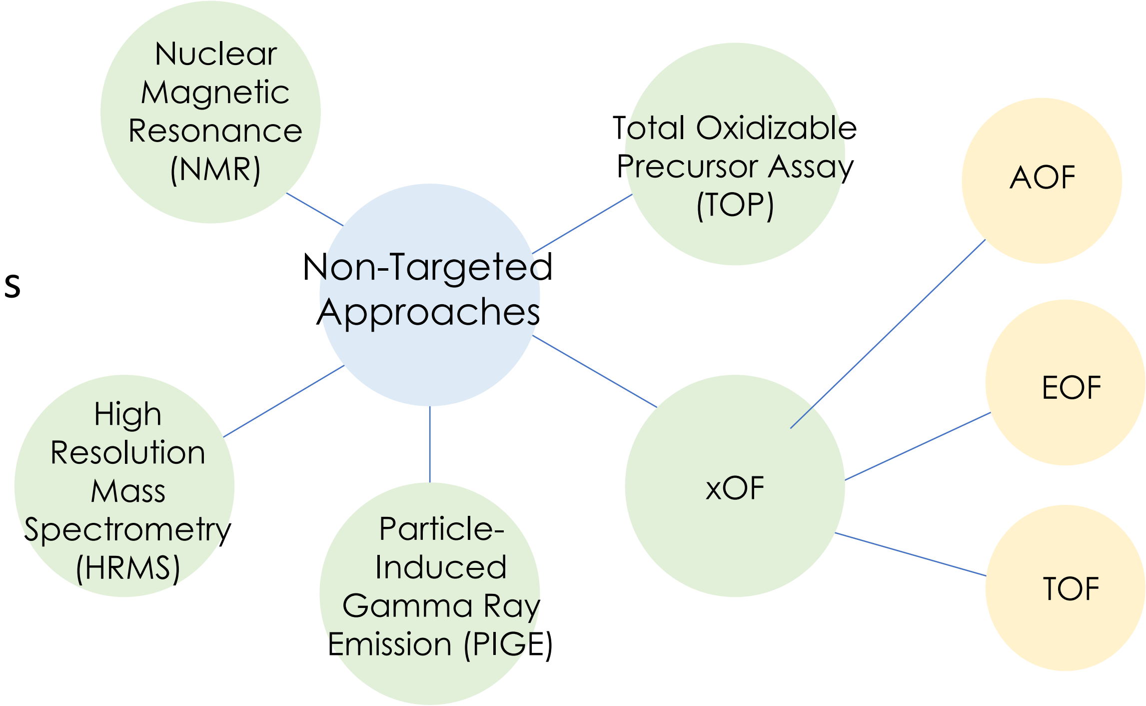
Targeted and non-targeted approaches are complementary to each other and results from both methods should be considered while addressing PFAS problems.

Analytical Methods for PFAS

- Almost all the targeted analysis method for PFAS is mass spectrometry (MS) based

- EPA, ASTM, and ISO have published some most popular standard methods for PFAS, such as
  - EPA 1633, 533, 537.1
  - OTM 45, OTM 50
  - ASTM D8421, D7979
  - ISO 21675

- Only standard methods existing for PFAS in textile are EU methods
  - One LCMS based method (EN 17681-1:2022)
  - One GCMS based method (EN 17681-2:2022)


Non-Targeted Approaches

Nuclear Magnetic Resonance (NMR)

Total Oxidizable Precursor Assay (TOP)

High Resolution Mass Spectrometry (HRMS)

Particle-Induced Gamma Ray Emission (PIGE)

xOF

AOF

EOF

TOF

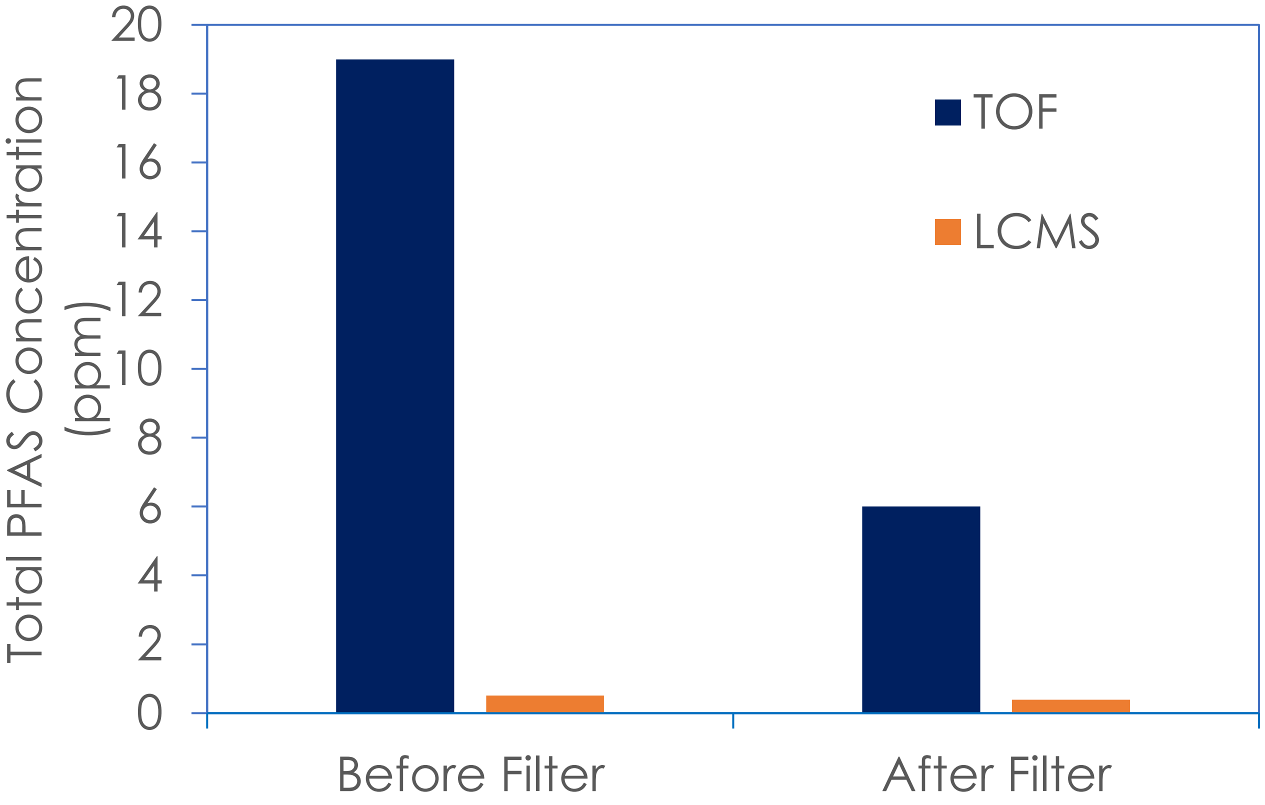
Key Takeaway

Targeted and non-targeted approaches are complementary to each other and results from both methods should be considered while addressing PFAS problems.

Analytical Methods for PFAS

Example Client Sample Analysis

LCMS – Targeted Analysis / TOF – Non-Targeted Analysis



- Client samples from a firefighting equipment testing lab's waste stream before and after a filtration treatment
- Samples are analyzed prior to and after a filtration process using TOF measurement and LCMS (EPA draft method 1633)
- **97.4% and 93.7% PFAS concentrations before and after the treatment, respectively, are not monitored by a standard LC-MS method**

PFAS in Textiles – Claros Approach

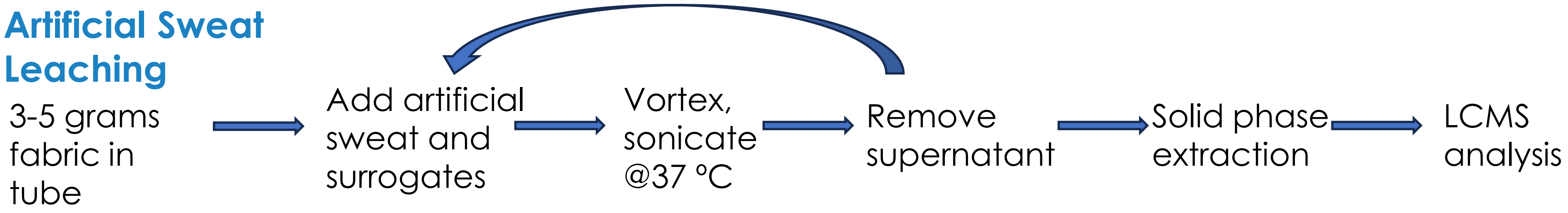
EXPERIMENT

Bought clothing from popular brands at the Mall of America that were not water resistant and branded as PFAS free

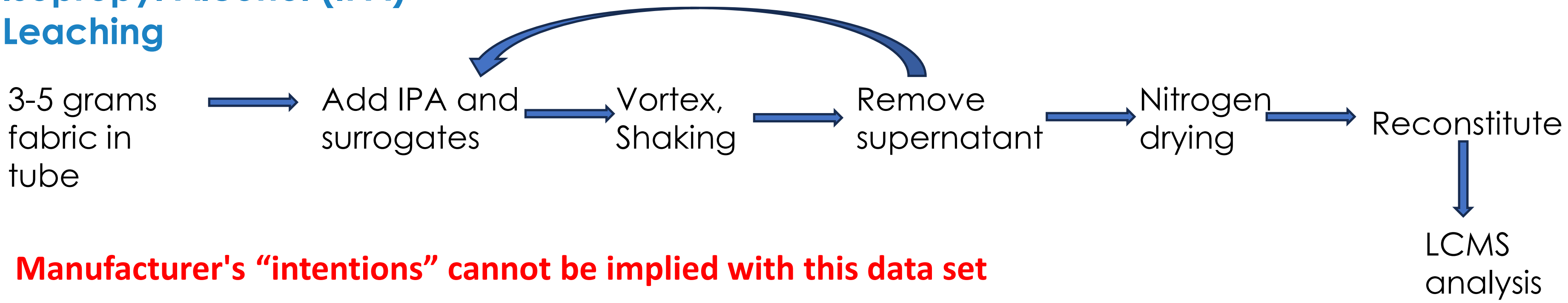
With consideration of current resources and equipment that we have access to:

- Targeted LCMS with EPA 1633 (40 PFAS compounds) panel with two different leaching methods
  - Leaching with artificial sweat
  - Leaching with Isopropyl Alcohol (IPA)
- Total fluorine with CIC

Artificial Sweat Leaching


3-5 grams fabric in tube → Add artificial sweat and surrogates → Vortex, sonicate @37 °C → Remove supernatant → Solid phase extraction → LCMS analysis

Isopropyl Alcohol (IPA) Leaching


3-5 grams fabric in tube → Add IPA and surrogates → Vortex, Shaking → Remove supernatant → Nitrogen drying → Reconstitute → LCMS analysis

Manufacturer's "intentions" cannot be implied with this data set

RESULTS

Artificial sweat: PFPeA and PFHxA were found in all samples. PFOS was detected in one sample

IPA: HFPO-DA and PFHxA were found in all samples. Many more PFAS compounds were detected compared to the results from artificial sweat

Targeted PFAS analysis only counts for a fraction of the total fluorine from textiles

No textiles surpassed the regulatory level for intentionally added PFAS:

Total fluorine is at ppm level. Specific PFAS compounds are at ppb level even simply using artificial sweat.

Comparing to Clean Water Act of 4 ppt specific PFAS, 1 ppb is 250 times of 4 ppt and 1 ppm is 250,000 times of 4 ppt

PFAS Remediation Methods Overview

MOST EXISTING CONTAMINATION METHODS CREATE REPEATED CYCLES OF CONTAMINATION

Separation

Processes that separate PFAS into a smaller volume

- Most PFAS remediation processes include a capture / separation / concentration phase
- This is a **pre-disposal** step, and requires a destruction method on the backend
- Includes activated carbon, reverse osmosis, and ion exchange filter methods; "reactivation" of filters also transport harmful PFAS back into the environment

Disposal

Landfill / Ground Injection

- Concentrated batches of PFAS waste/sludge sent to landfill usually after a separation technology is applied
- Post-consumer PFAS waste: 140M pounds of municipal solid waste that includes PFAS-containing consumer items also sent to landfill
- PFAS easily leaks into the air or out of the lining systems and into ground and water
- Extremely expensive
- Landfills refusing PFAS-waste due to liabilities and permit and required processes challenges

Incineration

- PFAS burned at high temperature
- Not a true "destruction" method
- Fails to destroy all of chemicals
- Remaining ash is sent to landfill, PFAS pollution enters air
- Method banned by the Department of Defense and multiple states in the US
- Full-wide ban expected

Destruction

Degradation of specific PFAS compounds, breaking carbon-carbon bonds

- Can create additional toxic byproducts or other types of PFAS
- All technologies still in pilot phase, not commercially available
- Typically struggle to remove short chain and ultra-short chain PFAS
- Popular methods include supercritical water oxidation, electrochemical oxidation, hydrothermal alkaline treatment, UV and plasma treatment

Defluorination

Breaking of the carbon fluorine bond

- Demonstrated with complete fluorine mass balances showing mineralization of PFAS to non-PFAS end products
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Technologies for PFAS

Destruction

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Technologies

Super Critical Water Oxidation (SCWO)

Water is heated to above 374˚C and to above 3000PSI to oxidatively destroy PFAS

Technology Readiness	• Commercial Scale
Advantages	• Short treatment time • No chemical additions needed • Less sensitive to co-contaminants • Can be used on solids
Disadvantages	• Less effective on short chain PFAS • High energy consumption • Potential for harmful byproduct generation • Difficult system design

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Hydrothermal Alkaline Treatment (HALT)

Water is heated and pressurized under alkaline environments to destroy PFAS

Technology Readiness	• Commercial Scale
Advantages	• Short treatment time • Less sensitive to co-contaminants • Can be used on solids
Disadvantages	• Less effective on short chain PFAS • CapEx can be expensive • Potential for harmful byproduct generation • Chemical intensive

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Electrochemical Oxidation (EO)

Destroys PFAS oxidatively through the application of an electric current into water

Technology Readiness	• Pilot Scale
Advantages	• Ambient conditions • Minimal chemical additions needed
Disadvantages	• Less effective on short chain PFAS • CapEx and electrode materials can be expensive • Potential for harmful byproduct generation • Slow process

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Plasma

Ionized gas destroys PFAS by promoting powerful reduction and oxidation reactions

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Technology Readiness	- Pilot Scale
Advantages	- Short treatment time - Less sensitive to co-contaminants
Disadvantages	- Formation of shorter chain PFAS byproducts - Plasma reactors are challenging to scale economically

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UV Photochemical

Application of UV light and photocatalysts to destroy PFAS in water

Technology Readiness	Pilot Scale
Advantages	Ambient conditions with low energy consumption Utilizes existing UV supply chain for scalability Effective on long and short chain PFAS
Disadvantages	Not effective on solids Reduced performance with UV absorbing co-contaminants Dependent on UV transmittance through the waste

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