International Water Resources Association

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PFAS Health Effects, Current Global Policies, & Emergent & Existing Destruction Technologies

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PFAS are Present Everywhere in Surface Water, Groundwater & Air

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Objectives of Presentation:

Where is PFAS Used & What are the Health Risks?

What are Current Global Policies & Established & Emerging Regulations?

What are the Current and Emerging Destruction Technologies?

Main Takeaways from the Presentation

PFAS is ubiquitous in the environment, carcinogenic, and globally is likely reducing female fertility and male sperm counts

PFAS regulations in Europe, African nations, and the United States are beginning to restrict use of PFAS in consumer products, but so far there is relatively little regulatory action prohibiting the use of PFAS.

PFAS destruction in drinking water, is routinely treated through adsorption using granular activated carbon (then incineration). **Photoactivated Reductive Defluorination and Supercritical Water Oxidation may emerge as lower cost alternatives.**

PFAS Background

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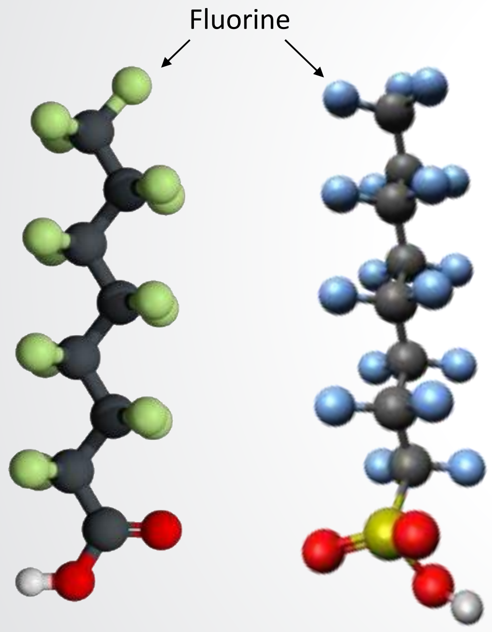
EPA

Per- & Polyfluoroalkyl Substances (PFAS)



PFOA *PFOS*

- **A very large class of synthetic chemicals**
  - **Chains** of carbon (C) atoms surrounded by fluorine (F) atoms, with different terminal ends
  - **Complicated chemistry** – thousands of different variations exist in commerce
  - **Widely used** in industrial processes and in consumer products
  - **Mobile** via multiple air, water pathways
  - **Some** PFAS are known to be **PBT:**
    - **Persistent** in the environment
    - **Bioaccumulative** in organisms
    - **Toxic** at relatively low (ppt) levels

PFAS Health Effects; Product Types

- Examples are non-stick coatings (Teflon), textiles (Gore-Tex), stain resistant carpets and sofas, and aqueous firefighting foams to engulf flames (AFFF). PFAS water pollution has been confirmed in the European Union, Asia, Australia, the Middle East, and the USA, and in most countries, protective regulations are inadequate or completely lacking.
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- As with polychlorinated biphenyls (PCBs), PFAS are also toxic, resistant to environmental degradation, and distributed throughout the food chain and bioaccumulate in humans, and marine and terrestrial organisms. Currently the most important and best understood classes of PFAS are **PFOS** (perfluorooctane sulfonate: C8HF17O3S) and **PFOA** (perfluorooctanoic acid: C8HF15O2), which are prevalent in AFFF and metal plating liquids.

Reproductive Health Effects

Many studies, some evaluating 40 years of data, provide strong evidence **linking PFAS to reduced female fertility and declining male sperm counts.**

The evidence is from peer-reviewed epidemiological studies, meta- analyses, & government/non-Governmental Organizations reports

Regarding Reproductive Adverse Effects:

The reduced sperm counts and lowered female fertility are attributable to these factors:

-Mimic or block sex hormones (estrogen, testosterone);

-Interfere w/ ovarian follicle development;

-Damage sperm DNA & impair motility;

-Reduce testosterone production

Policy Considerations – European Union

European Commission (EC) has not halted all manufacturing and use of per- and polyfluoroalkyl substances (PFAS).

But it has implemented significant restrictions targeting specific applications due to health and environmental concerns.

Recent EU Legislation

- The European Commission finally published in October 2025 the REACH restriction for the use of PFAS **in fire-fighting foams** by amending annex XVII of this Regulation.
- It provides for a gradual ban of 'forever chemicals' **in this application**. The text includes **transition periods of up to 10 years** for certain extreme fires. This restriction is the result of years of preparatory work by ECHA, examinations by the Commission and a vote by Member States..
- Fire-fighting foams are leading to massive contaminations of drinking water resources close to fire drill sites such as **airports or military sites across Europe**. In the past, this led to the exposure of consumers to high PFAS levels in their drinking water in a number of locations.

Policy Considerations - EU

- As of September 2024, the EC adopted measures to restrict the use of undecafluorohexanoic acid (PFHxA) in consumer textiles (e.g., rain jackets), food packaging (e.g., pizza boxes), certain cosmetics, waterproofing sprays, & some firefighting foams.

- The restriction does not apply to PFHxA used in semiconductors, batteries, or fuel cells for green hydrogen.

- These restrictions will take effect between 2026 and 2029.

Policy Considerations - EU

- The European Chemicals Agency (ECHA) is evaluating a broader restriction covering a wide range of PFAS substances, following a 2023 proposal by five EU member states: Denmark, Germany, the Netherlands, Norway, and Sweden. This proposal aims to address the entire PFAS group, but its implementation is still under assessment.
- The Packaging and Packaging Waste Regulation, adopted in December 2024 and effective from February 2025, restricts PFAS in food contact materials, setting specific concentration limits.

Policy Considerations – EU
Industry Concerns

- The proposed comprehensive PFAS ban has raised concerns in various industries. The European Federation of Pharmaceutical Industries and Associations (EFPIA) warns that **such a ban could jeopardize the production of over 600 essential medicines in Europe, as PFAS are integral to pharmaceutical manufacturing** processes.
- Similarly, the **semiconductor industry faces challenges due to the reliance on PFAS in manufacturing** processes. While some companies have ceased PFAS production, the industry is exploring alternatives to comply with potential future regulations

Policy Considerations – African Nations

- Several African countries have taken steps to regulate or ban the manufacture and use of certain PFAS
- While these actions are commendable, **many African nations still lack comprehensive regulations on PFAS.**
- PFAS contamination is widespread across the continent, with hotspots identified in South Africa, Kenya, Nigeria, Uganda, Ghana, Ethiopia, Mozambique, Tanzania, Zambia, Mali, and Tunisia.
- The Bamako Convention, an African Union treaty, prohibits the import of hazardous wastes, including certain PFAS compounds, into Africa. However, this convention primarily addresses the transboundary movement of hazardous wastes rather than the domestic production and use of PFAS.

Policy Considerations – African Nations
Countries with PFAS Restrictions

- **South Africa**: Has prohibited the use of PFOS & PFOA in firefighting foams & established guidelines for acceptable PFAS levels in drinking water & soil.
- **Kenya**: Restricted use of PFASs in industrial processes & consumer products, such as non-stick cookware and stain-resistant fabrics.
- **Uganda**: Banned both the import & production of certain PFAS-containing products.
- **Nigeria**: Set limits on PFAS concentrations in wastewater discharges from industrial facilities.

Policy Considerations – African Nations Conclusions

- While some African countries have implemented measures to regulate or ban specific PFAS compounds, **comprehensive and harmonized regulations across the continent are still developing.**
- Continued research, public awareness, and **regional cooperation are essential to address PFAS contamination effectively.**

Policy Considerations –USA
Federal Law Holds Primacy, But States Can Establish More Stringent Laws

- **PFAS are *not* fully banned at the federal level**—only six compounds are regulated in drinking water.
- **No federal ban exists yet** on PFAS in consumer products, though proposed legislation could change that.
- **Many states have already imposed bans or restrictions** covering cookware, cosmetics, textiles, food packaging, firefighting foam, menstrual products, and more.

Policy Considerations -USA

State-Level Action

While federal bans are limited, **many states** are actively banning or restricting PFAS in various products:

State	Notable Actions
Maine	Full ban on added PFAS in all new products by 2030, with some earlier restrictions time.com+15stateline.org+15wired.com+15.
Minnesota	Banned PFAS in cookware, cosmetics, juvenile products, textiles by Jan 2025; full class ban by Jan 2032.
California	Bans in cosmetics (from Jan 2025), children's products (July 2023), textiles/apparel (Jan 2025).
New Mexico, **Colorado**, **Vermont**, **Washington**, **New York**, **Connecticut**, **Hawaii**, **Massachusetts**, **Oregon**, others	Various bans on PFAS in food packaging, textiles, cosmetics, firefighting foam, menstrual products. Most roll out between 2024–2028.
Firefighting foam	15+ states (e.g., Washington in 2018) have restricted PFAS-based foam.

Comparison of PFAS Destructive Treatment Technologies

3 Most Common Treatment Technologies

3 Most Common PFAS Treatment Technologies

ADSORB OR SEPARATE PFAS

Activated carbon
- Granular, powder - *ex situ*
- Liquid (PlumeStop) - *in situ*

Anion exchange (AIX) resins - *ex situ*

Membrane treatment - *ex situ*
- Reverse osmosis (RO)
- Nanofiltration

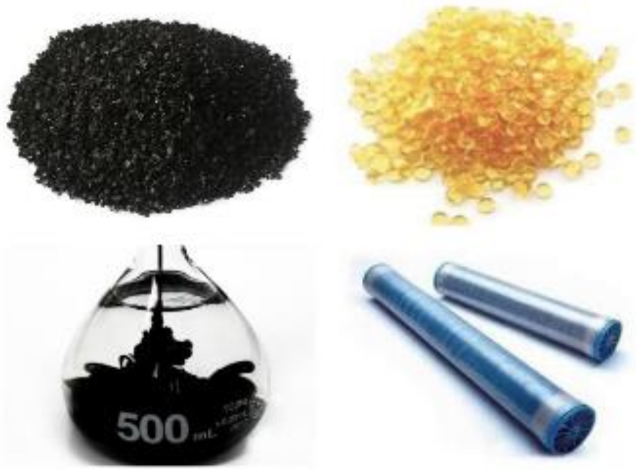

Image: Mineralization of PFAS-A Permanent Solution; Air and Waste Management Association Ramboll, February 2020

Advantages/Disadvantages of 3 Most Common Treatment Technologies

- All 3 technologies effectively capture PFAS
- Destruction of PFAS follows and media is regenerated for reuse
- ADVANTAGES: Efficient capture followed by high T incineration
- DISADVANTAGES: Very high cost

Prominent Technology in Use

Granular Activated Carbon is the Most Widely Used Technology

Prominent Technology in Use

Tank w/ Granular Activated Carbon is Most Widely Used Technology

Prominent Technology in Use

Supercritical Water Oxidation (SCWO)

- Foam fractionation is 1st applied to concentrate PFAS compounds:

PFAS are surface-active compounds that are attracted to the air-liquid interfaces of rising air bubbles.

Foam is created at the top of a column where the PFAS is harvested.

- SCWO is a single-step wet oxidation process that transforms organic matter, at 400-600 Degrees C, into water, carbon dioxide, and sometimes an inert mineral solid residue .

- **ADVANTAGE: Complete defluorination; trailer-mounted unit is effective**
- DISADVANTAGE: Relatively high energy costs

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Mobile Supercritical Water Oxidation

Battelle's PFAS Annihilator™

Bench Scale

- Proof of concept of destruction to < 5 ppt with minimal residence time and no harmful by-products
- Optimization of input parameters
- Demonstration success with real-world samples

Field Scale

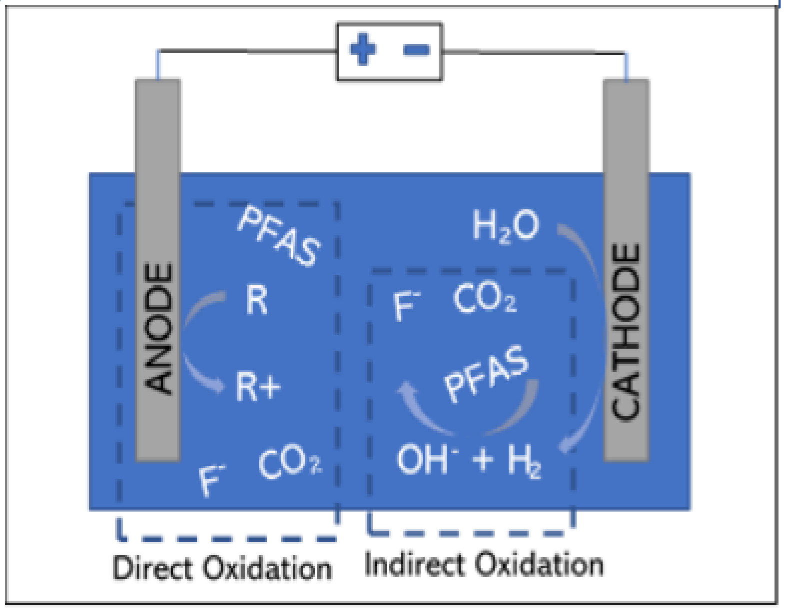
- Mobile system for treatment of finite volumes of PFAS-contaminated water (e.g., investigation derived waste (IDW))
- >500 gallons/day
- Planned deployments at DoD sites in fall 2020

Prominent Technology Under Development

- **Electrochemical Oxidation**

- **A water treatment technology that uses electrodes, where electrical currents are passed through a solution to oxidize PFAS**
- **ADVANTAGES: Low energy costs, operation at Std T, operability in a mobile unit, no chemical oxidants or additives**
- **DISADVANTAGES: Incomplete defluorination, generation of toxic byproducts, expensive electrodes**

Image: Research Brief, EPA January 2021



Prominent Technology Under Development

Sonolysis

Uses ultrasonic waves to degrade or completely destroy PFAS compounds,

Bubbles are created in a liquid, which then grow & collapse, causing localized high T & ionization of H_2O and gases (a.k.a. acoustic cavitation)

Creates T > 5,000^{o}C

Advantages: Can achieve full defluorination of some PFAS compounds;
Can be used in a treatment train with GAC polishing to achieve cleanup levels

Disadvantages: Relatively high energy costs

Prominent Technology Under Development

Microbial Destruction

- Certain bacterial strains, often indigenous to a cleanup site, can achieve partial defluorination
- Advantages: Low cost to implement;
- Can be used in a treatment train such as GAC to achieve cleanup levels
- Disadvantages: Microbial strains have not been identified as capable of surviving in a natural environment & achieve complete defluorination

- Strains that achieve partial degradation (not even defluorination) have been shown to recombine into similar PFAS compounds
- The Future: Research to date indicates that full defluorination can be achieved by **custom enzymes (proteins)……**

Prominent Technology Under Development

Photoactivated Reductive Defluorination (PRD)

- Patented ultraviolet light + proprietary nontoxic reagents
- PRD is facilitated by adding a cationic surfactant to form a surfactant micelle cage that traps PFAS
- Foam fractionation is applied first to optimize process

- Winner of the US EPA, DoD 2021 Award “Innovative Ways to Destroy PFAS” in 2021.

- ADVVANTAGES: Complete defluorination; relatively low energy requirements
- DISADVANTAGES: Application may need more than one iteration to achieve cleanup levels

Prominent Technology Under Development

- **Hydrothermal Alkaline Treat (HALT)**

- HALT, or Hydrothermal Alkaline Treatment, uses high pressure (~25 Mpa), high temperature (350 ^{o}C), and high pH (>14) liquid water to break down the strong carbon-fluorine bonds in PFAS and convert them into benign salts

- The addition of the alkaline compound sodium hydroxide amendment is a key ingredient

- Foam fractionation is applied first to optimize process

- ADVANTAGES: **Complete defluorination**
- DISADVANTAGES: **Very high energy costs**

What are the Most Promising Technologies?

- SCWO and PRD hold the most promise to supplant GAC (& Ion Exchange or Reverse Osmosis) as lower cost alternatives

- Both technologies destroy PFAS and avoid incineration of GAC (or IEx resins or RO membranes) and regeneration of carbon/resins/membranes

- SCWO is farther along at scaling up with commercial demonstrations, e.g., processing 6M gallons H_2O/day at Orange Co Sanitation District

- Smaller scale demonstrations of PRD suggest the possibility that PRD can achieve complete destruction of PFAS compounds ***by using less energy than SCWO***

Conclusions

- PFAS is ubiquitous in the environment, carcinogenic, and globally is likely reducing female fertility and male sperm counts
- PFAS regulations in Europe, African nations, and the United States are beginning to restrict use of PFAS in consumer products, but so far there is relatively little regulatory action prohibiting the use of PFAS.
- PFAS destruction in drinking water, is routinely treated through adsorption using granular activated carbon (then incineration). Photoactivated Reductive Defluorination and Supercritical Water Oxidation may emerge as lower cost alternatives.

Questions?

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