PFAS - The (Rapidly) Evolving Technical and Legal Landscape

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October 26, 2021

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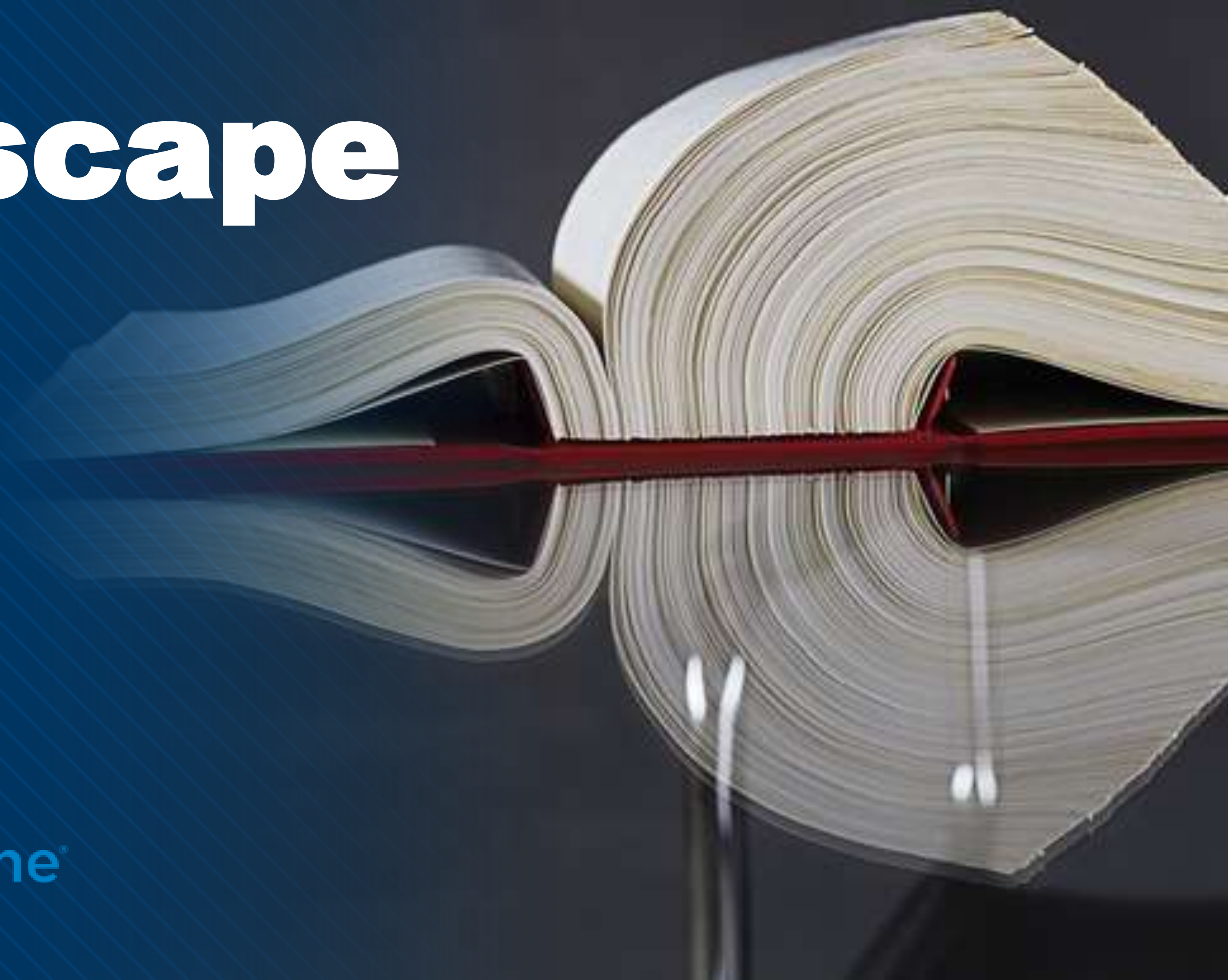
Legal Landscape



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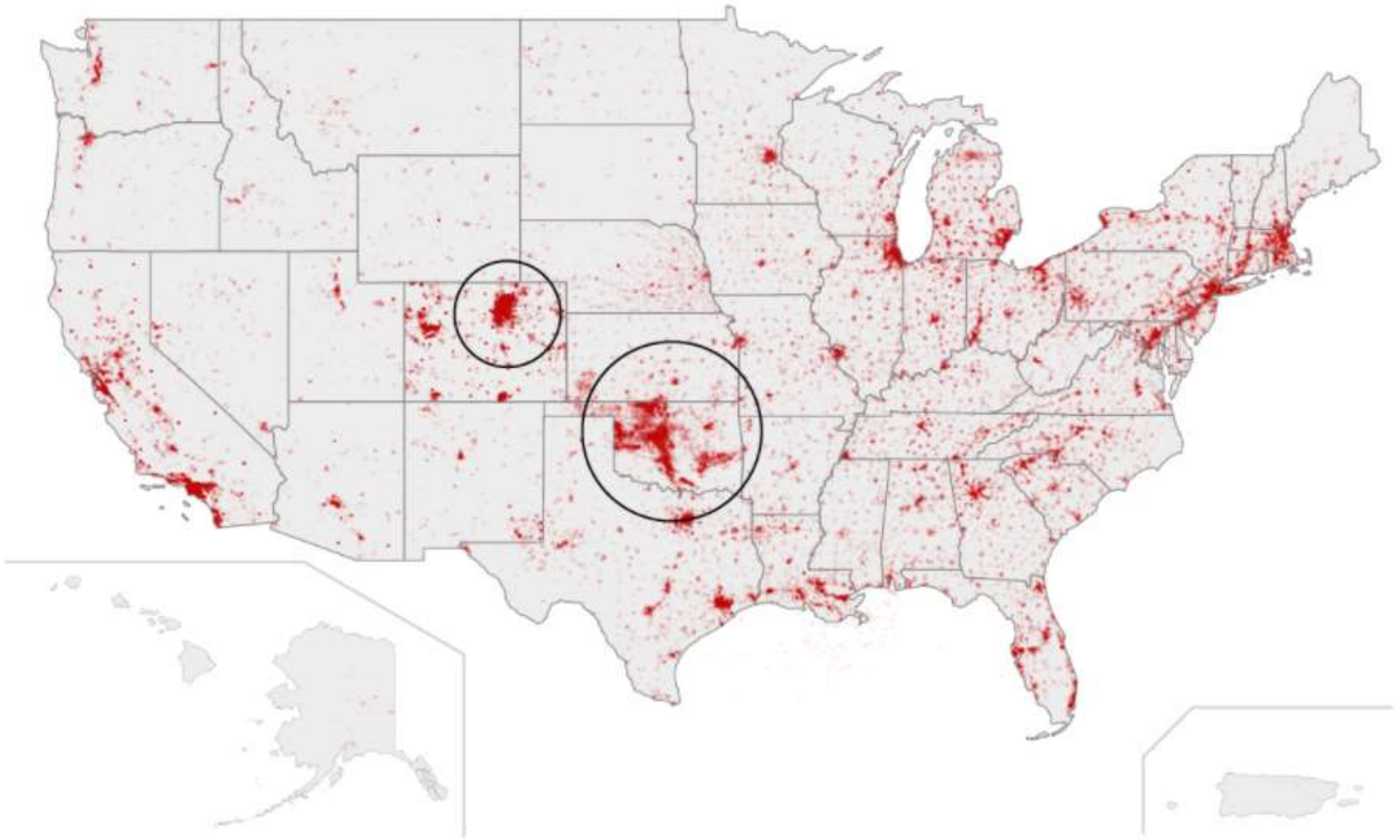
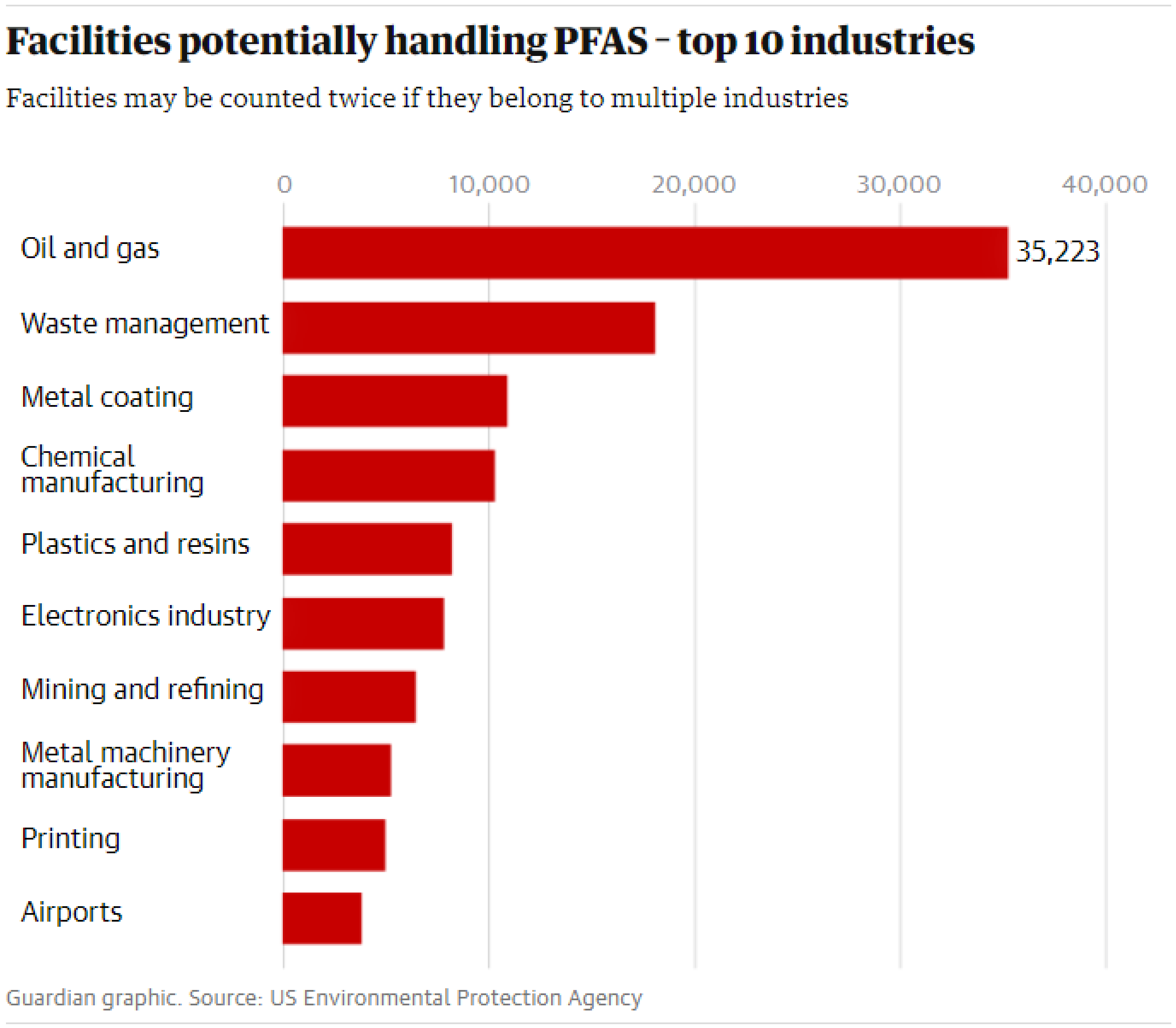
The EPA identified more than 120,000 facilities that may expose people to PFAS

The biggest clusters of facilities are in Oklahoma and Colorado



Guardian graphic. Source: US Environmental Protection Agency


Facilities potentially handling PFAS – top 10 industries
Facilities may be counted twice if they belong to multiple industries
0
10,000
20,000
30,000
40,000
Oil and gas
35,223
Waste management
Metal coating
Chemical manufacturing
Plastics and resins
Electronics industry
Mining and refining
Metal machinery manufacturing
Printing
Airports
Guardian graphic. Source: US Environmental Protection Agency

Even More Data on the Way

- Expanded TRI Reporting
- TSCA Section 8 Reporting
- Nationwide Drinking Water Monitoring
- Multi-laboratory Validated Analytical Method for 40 PFAS
- Update PFAS Analytical Methods for Drinking Water
- Monitor Fish Tissue for PFAS

Effluent Guidelines and Risk Assessments

- Primary Drinking Water Regulation for PFOS and PFOA
- Effluent Limitation Guidelines for PFAS Discharge
- NPDES Permit Limits
- Water Quality Standards
- GenX, PFBS and other toxicity assessment and health advisories
- Risk Assessment for PFOA and PFOS in Biosolids

CERCLA Listing and Remediation

- Certain PFAS as CERCLA Hazardous Substances
- Consideration of Precursors as Hazardous Substances
- Guidance on Destruction and Disposal

Identification

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Focus on Expanding Analytical Capabilities

- Target Methods
  - EPA Method 531.1 – 18 PFAS in Drinking Water
  - EPA Method 533 – 29 PFAS in Drinking Water
  - Modified Methods – 75 PFAS
  - Draft EPA Method 1633 – 40 PFAS in Waste Water, Surface Water, Groundwater, Soil, Biosolids, Sediment, Landfill Leachate, and Fish Tissue

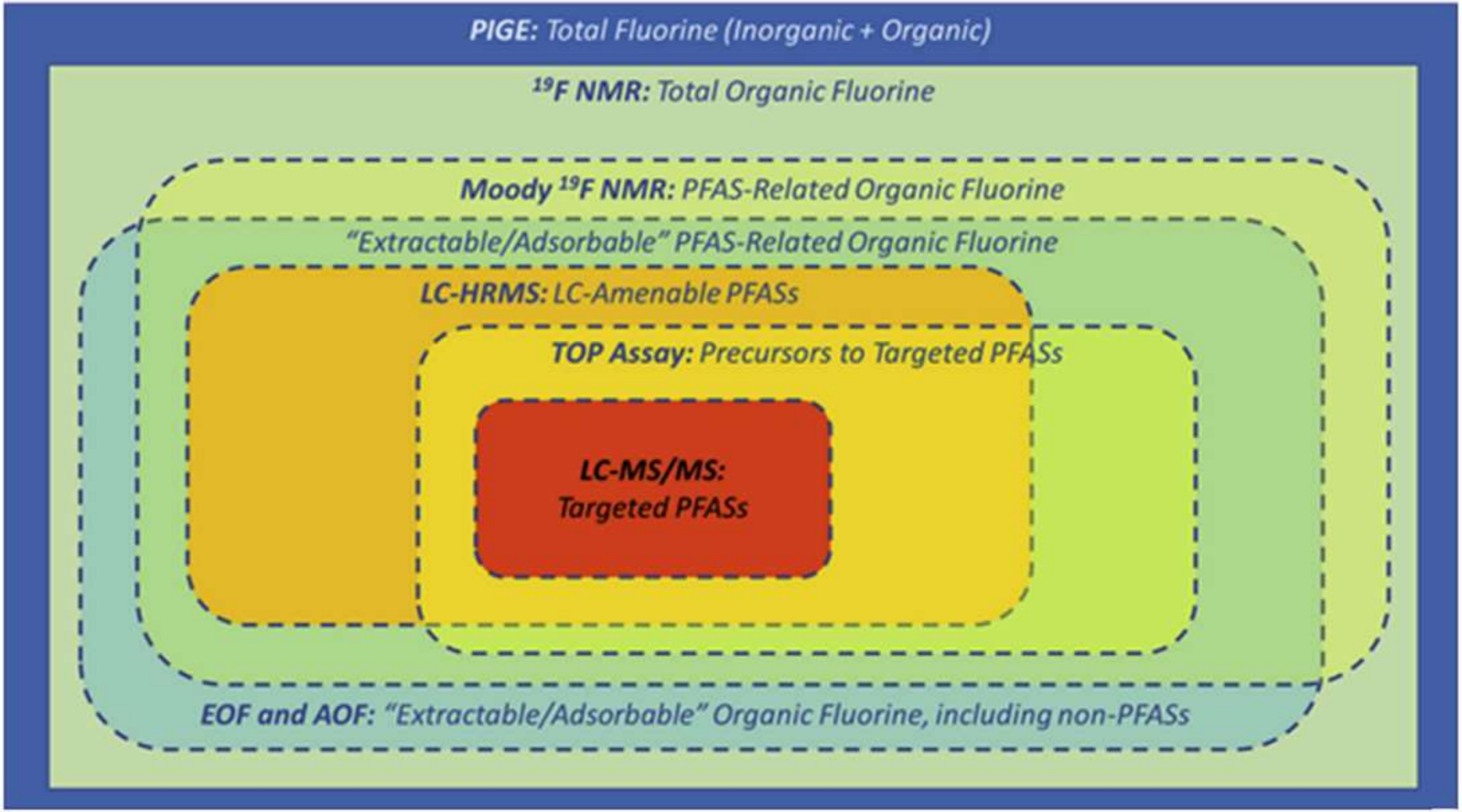
- Total oxidizable precursor (TOP) assay [ppt]
  - Oxidation of precursors to detectible byproducts
  - Commercially Available

- Estimates as high as 8,000 PFAS
- 241 commercially relevant PFAS (Buck et al., 2021, IEMA)
- Clear gap in analytical capabilities

- EPA commitment to update analytical methods (Fall 2024)
- Calls to manage PFAS as a class of chemicals

Total PFAS via Organofluorine Measurement

- Extractable organic fluorine (EOF) / adsorbable organic fluorine (AOF) [ppt/ppb]
  - Sample prepared to isolate organofluorine
  - combustion ion chromatography (CIC) to mineralize and measure organic fluorine
  - CIC does not differentiate between organic fluorine and fluoride, nor does it offer any structural details about the detected compounds.
  - Commercially Available
- Particle-induced gamma ray emission (PIGE) [ppb]
  - Generally Nondestructive
  - Surface analysis technique for quantification of elemental fluorine
  - Beam of protons excites 19F nuclei, emits Gamma rays
  - Best suited for solid-phase samples.
  - Currently in R&D stage (SERDP/ESTCPER19-1142)
- Fluorine-19 nuclear magnetic resonance spectroscopy [ppb]



McDonough, Guelfo, Higgins, 2019

Current Opinion in Environmental Science & Health

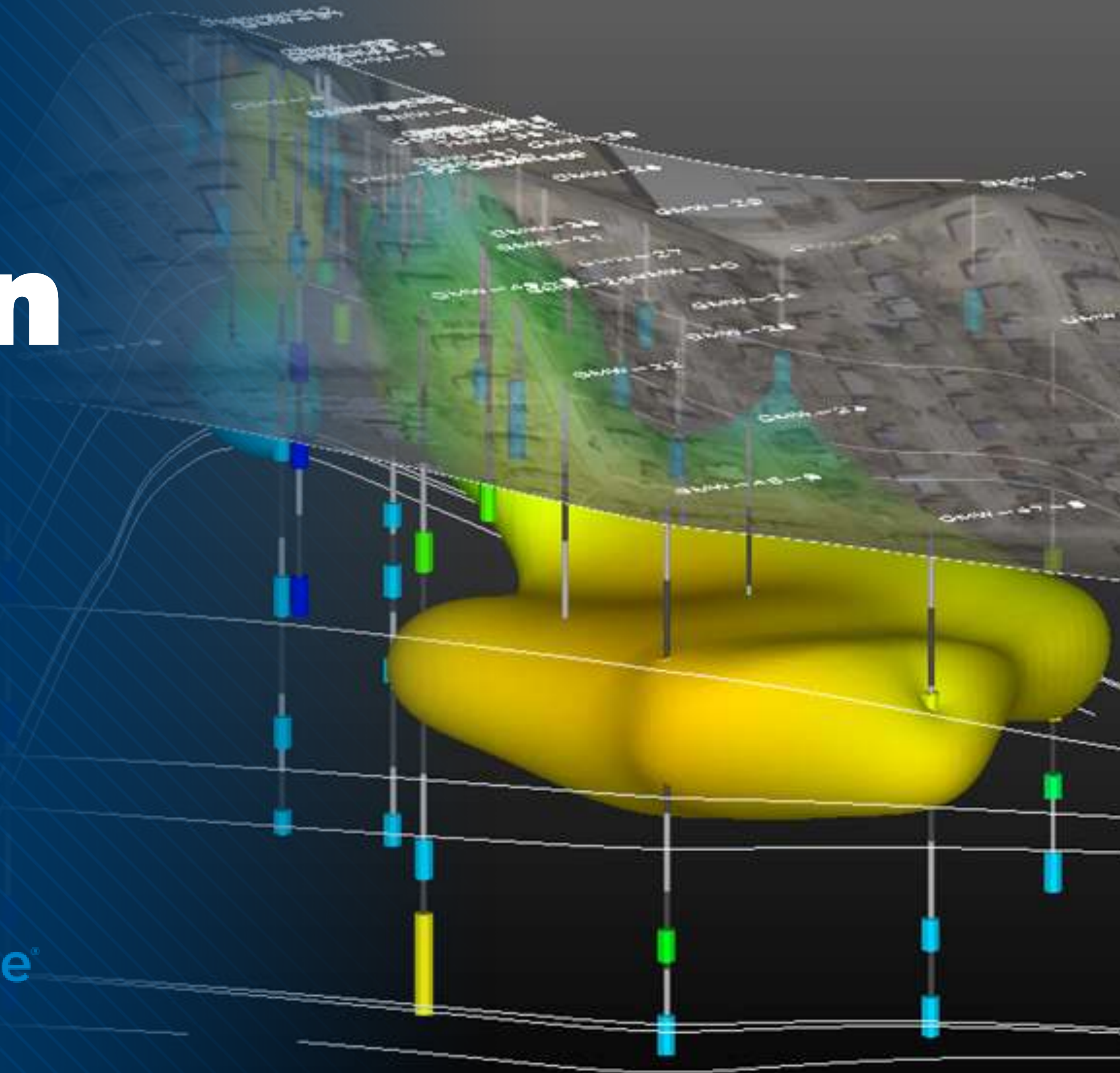
Applications of TOF methods

- Screening Methods
  - Presence or Absence of PFAS in products, wastes, etc.
- Remediation / Treatability
  - Closing mass balance
  - Performance monitoring
  - Influent / effluent mass balance
- Risk Management
  - Are there PFAS in this waste, soil, biosolids?
- Consumer Product Verification
  - Demonstration of “PFAS Free”

Non-Target Analysis - LC/MS-qTOF (quadrupole time of flight mass spectrometry)

- Higher Cost
- Comparison of peaks to library
- Quantitative results for hundreds of non-target PFAS
- Qualitatively identify many more PFAS
- More comprehensive understanding of sample than target-methods. But, some limitations in interpretation.
- When to use?
  - Forensic evaluations – Is this my PFAS?
  - Due diligence – Document conditions at the time of sale/purchase
  - Mass balance assessments

Investigation



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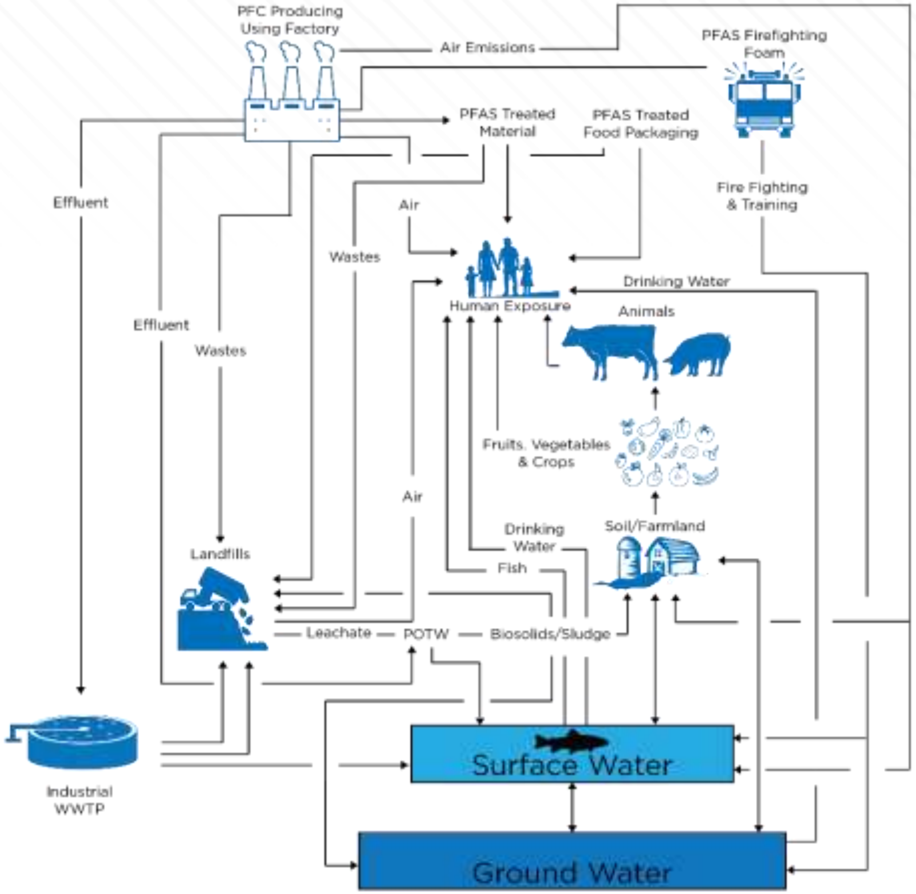
PFAS Characterization Challenges

Complex Interactions/Transport Behavior



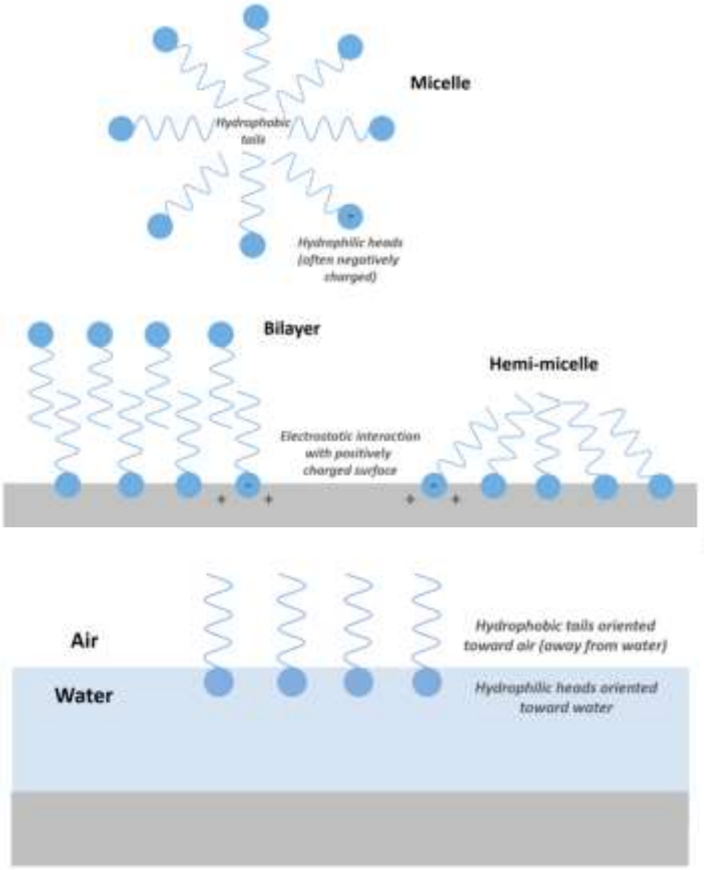
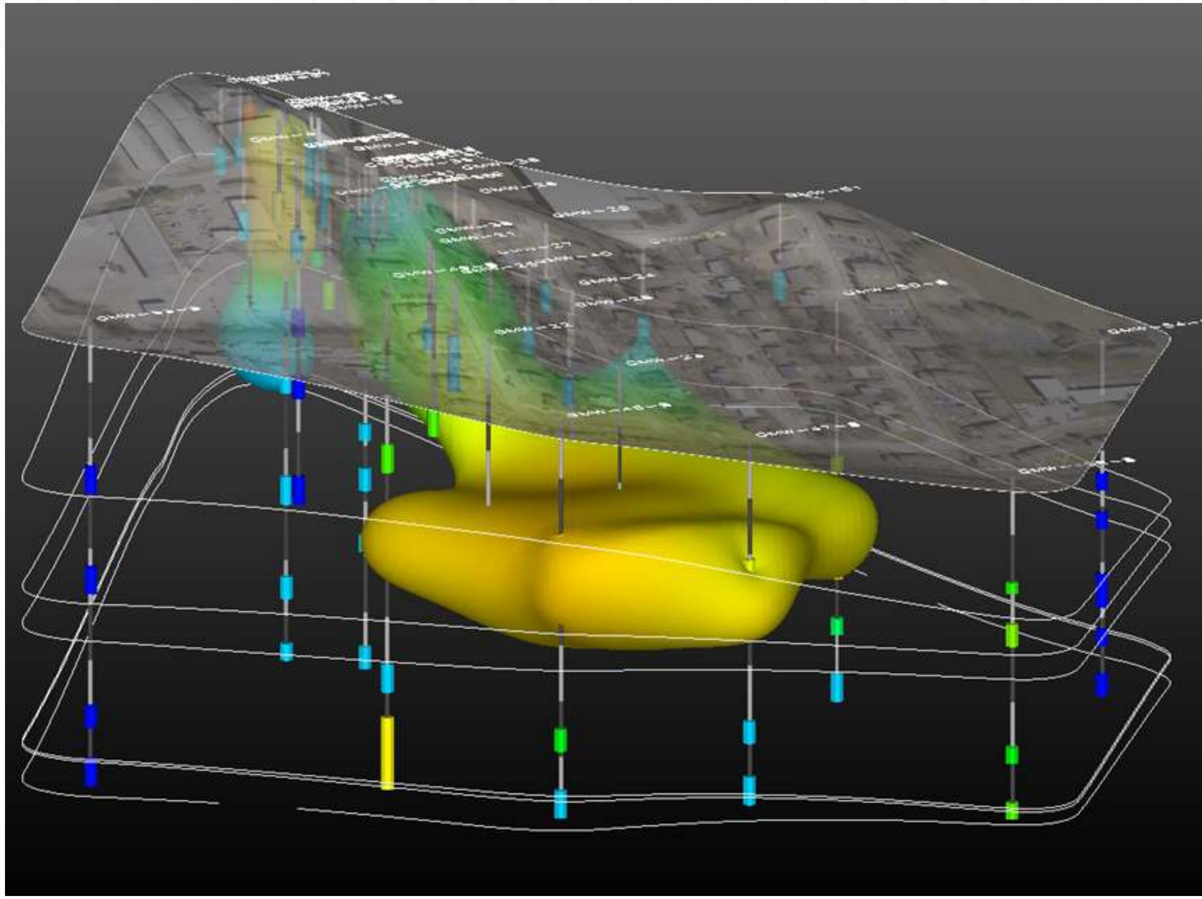


Image from ITRC, 2020

PFAS Characterization Challenges

Long Plumes

- Generally low but also variable (depending on the PFAS chain length and class) adsorption affinity
- High solubility
- High recalcitrance (terminal PFAS are not biodegradable)
- Surfactant behavior (attracted to air-water interface)
- Susceptibility to electrostatic forces (due to ionic form in solution)



Treatment

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Adsorption **Based Technologies**

- Activated Carbon (Granular, Powder, Colloidal)
- Ion Exchange Resin
- Others
  - Fluorosorb
  - RemBind
  - PQ-Osorb
  - Puraffinity
  - Biochar
  - Graphene
  - Zeolite
  - Pryolyzed Cellulose
  - Flocculation (PerfluorAd)

Relative effectiveness is based upon influent chemistry / presence of co-contaminants

Competition for receptor sites

Selectivity of adsorption media

(e.g. – PFAS selective ions)

Compatibility of treatment media / technology with application (e.g. – certain resins are not compatible with DW)

Treatment Objectives – Which PFAS are targeted?

Potential to Regenerate

Vessel Size

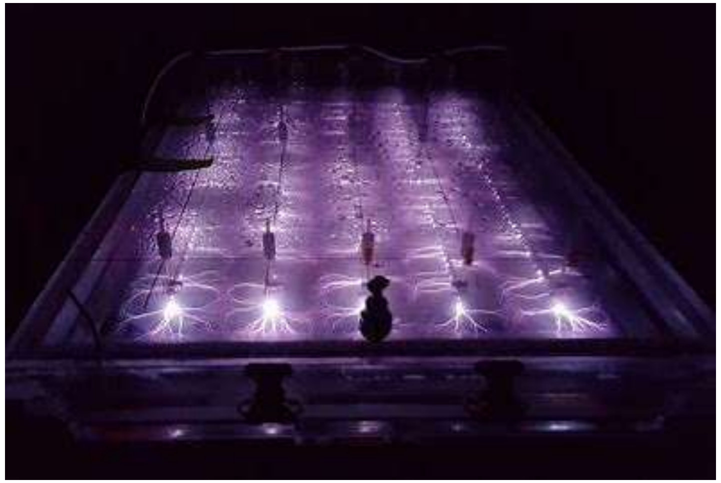
Separation

- Reverse Osmosis
- Engineered Membranes
- Foam Fractionation

- Pros
  - Effective at removing wide rage of PFAS.
- Cons
  - Management of rejects / concentrates
  - Maintenance

Destruction

- Incineration
- Sonolysis
- Smoldering
- Electrochemical Oxidation
- Non-Thermal Plasma
- Super Critical Water Oxidation
- UV Radiation of Sulfite
- Chemical Oxidation
- Thermal Oxidation
- Chemical Reduction
- Photolysis
- Electron Beam
- Biological Enzymatic Defluorination



Sequestration

- Landfills
  - Subtitle D
  - Subtitle C
  - Leachate Management

- Class I disposal wells
  - Considered suitable for PFAS-containing wastes
  - Reduces risk of exposure to wastes
  - Little potential for air emissions

Goals in Managing / Disposing of PFAS-Containing Soil

- Inherent risks associated with waste management

  - Shorter Term Risks
    - Preventing spread of contamination
    - Dust / Runoff-control
    - Account for worker exposures
    - Transportation risks
    - Regulatory compliance

  - Long Term Risks
    - Future Releases
      - Leachate to SW
      - Leachate to GW
      - Air Emissions
      - Transport to receptor

Future of PFAS Treatment

- Strategies for concentration and destruction
  - Sorption / Separation (e.g. - Regenerable IX / Fractionation) → Destruction (e.g. - incineration / non-thermal plasma)

- Need to overcome in-situ treatment challenges
  - Current technologies limited to colloidal carbon
  - Sorption / “PFAS Sink”
  - Current focus / advancements – in situ application of other proven ex situ technologies
  - Need to destroy PFAS in situ

- Need to demonstrate complete destruction – limited by analytical capabilities