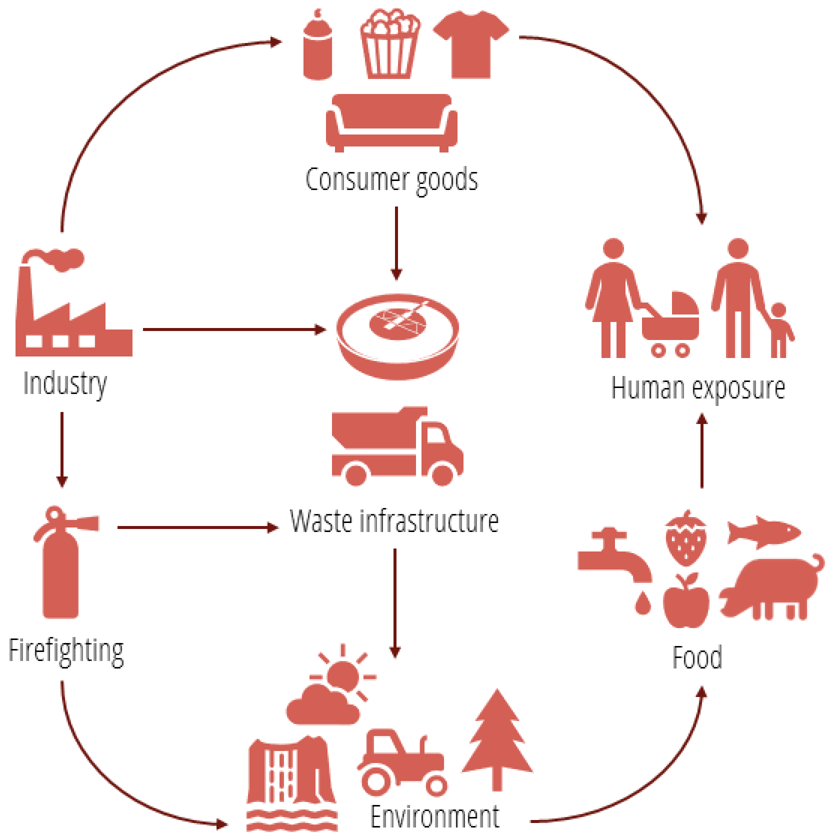

PFAS in Drinking Water & Wastewater:

A Comprehensive Review of Occurrence, Risks, and Treatment Strategies

Presented by:

Swaroop C Puchalapalli, PE (TX, NY & CT)

Outline

- PFAS Overview
- Regulatory Overview
- Treatment
- Emerging Treatment Technologies
- Funding
- Case Studies

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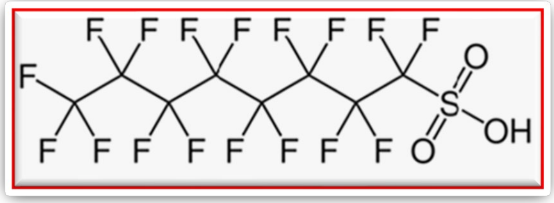
PFAS Overview

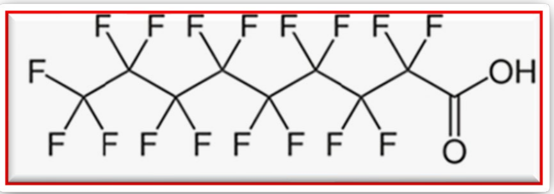
What are PFAS?

- Per- and Polyfluoroalkyl Substances
- Carbon – Fluorine bonds
- PFOS and PFOA
- 3M, Dupont (Chemours)

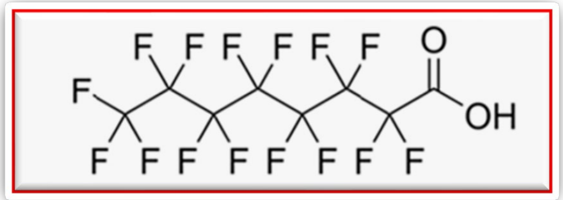
Perfluorooctanoic Sulfonic Acid (PFOS)



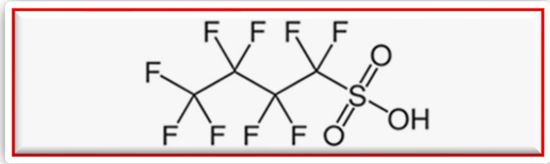
Perfluorononancanoic Acid (PFNA)



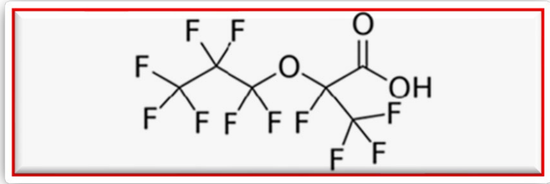
Perfluorooctanoic Acid (PFOA)



Perfluorobutane Sulfonic Acid (PFBS)



Hexafluoropropylene Oxide Dimmer Acid (GenX)



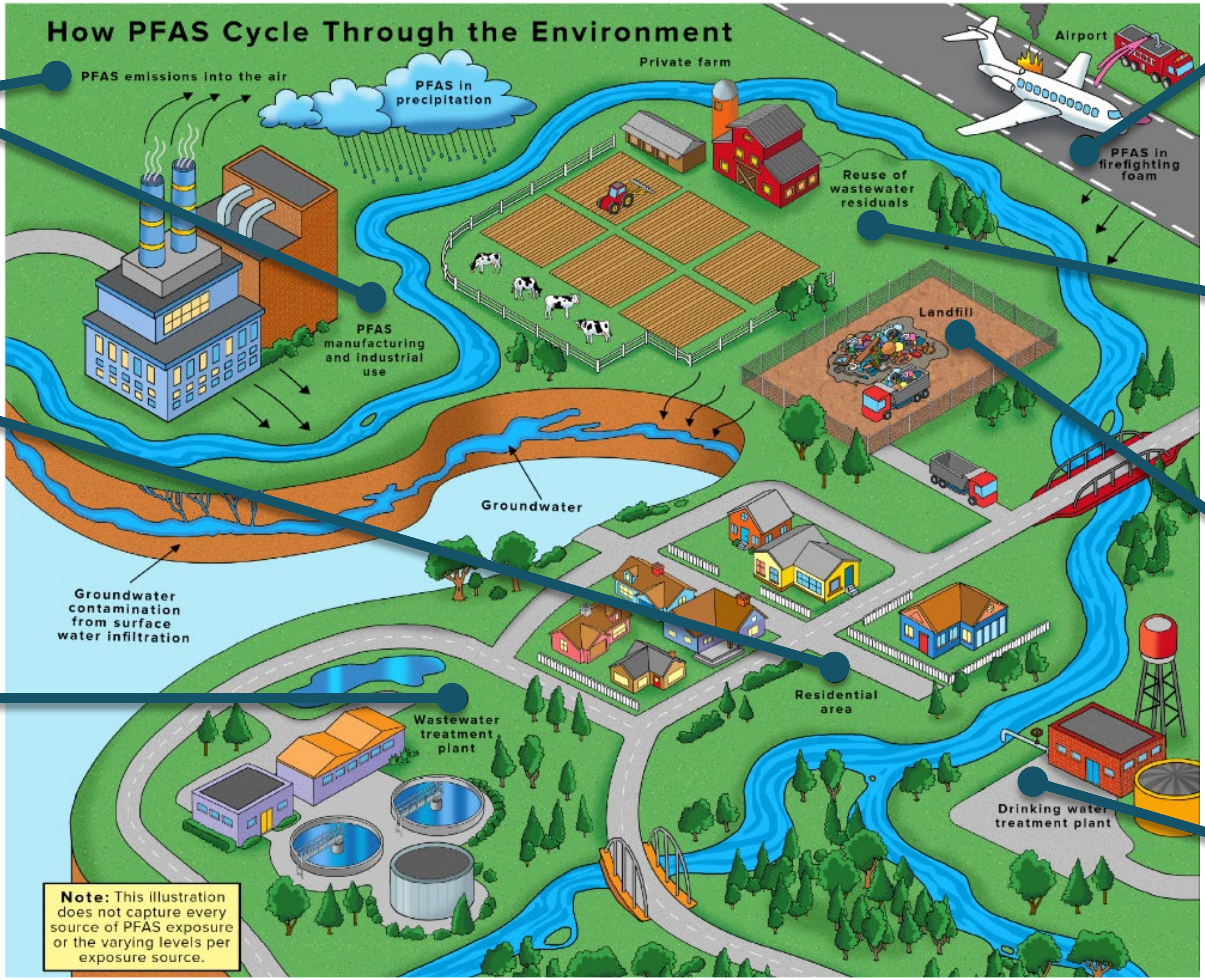
PFAS in Products

PFAS Cycle Infographic

Industrial Discharges

Household Products

WWTP Discharges



Firefighting Foam

Land Applied Biosolids

Landfills

Drinking Water Treatment Plants

Source: AWWA

Regulatory Overview

PFOA Stewardship Program

UCMR 3
PFOS PFOA
PFNA PFHxS
PFHpA PFBS

Updated Lifetime Health Advisories
PFOA : 0.004 ng/L, PFOS: 0.02 ng/L+ PFBS: 2000 ng/L
GenX Chemicals: 10 ng/L

PFAS Action Plan

2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023

PFOS Phased Out

Short-term Provisional Health Advisories
PFOA: 400 ng/L
PFOS: 200 ng/L

Lifetime Health Advisories
PFOA + PFOS: 70 ng/L

Preliminary Regulatory Determination
PFOA
PFOS

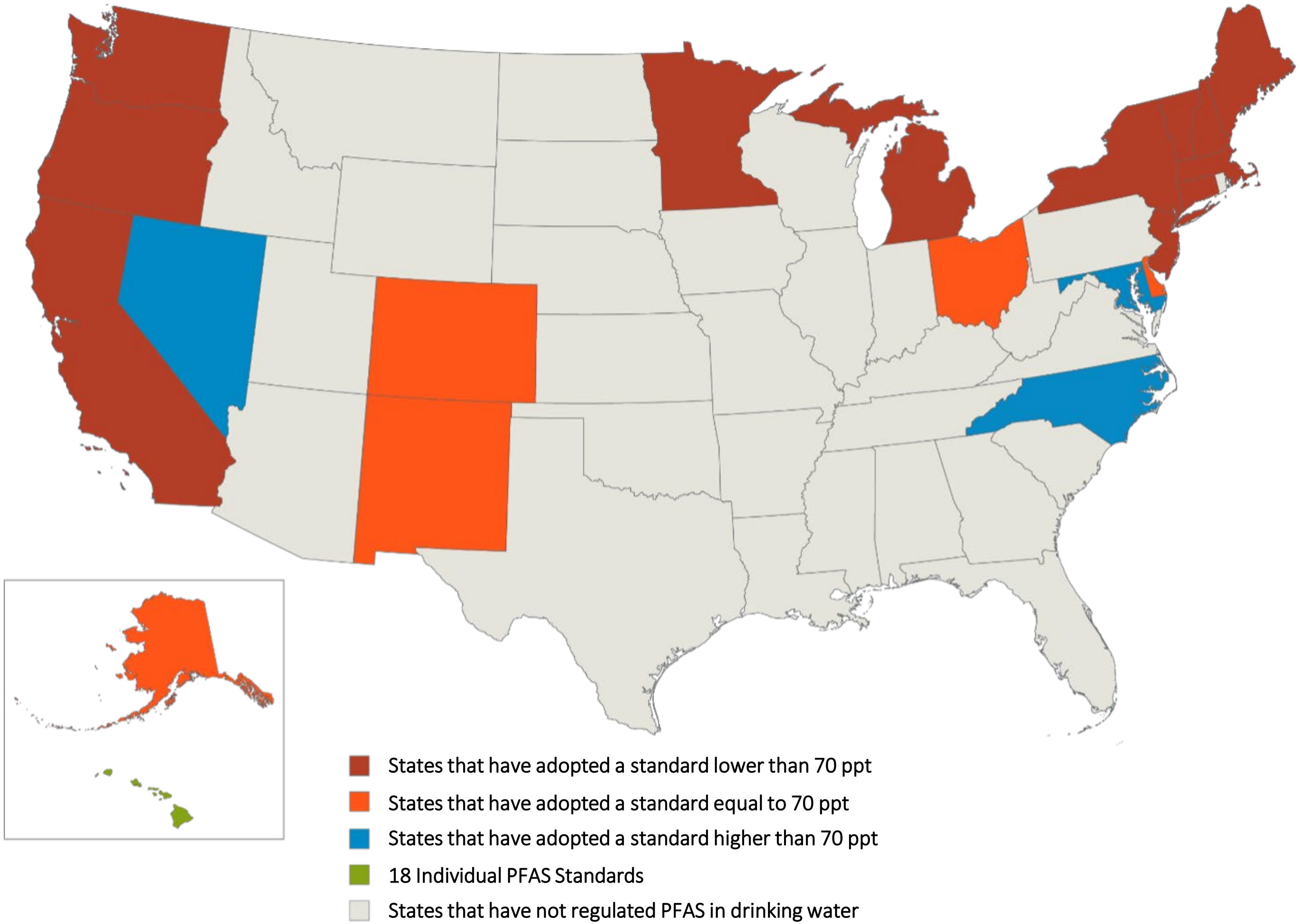
National Primary Drinking Water Regulation Proposed on March 2023

Strategy for PFAS in NPDES Permits

Oct 2021 PFAS Strategic Road Map

PFOA and PFOS as Hazardous Substances Under CERCLA and Plan 15

PFAS Drinking Water Regulations



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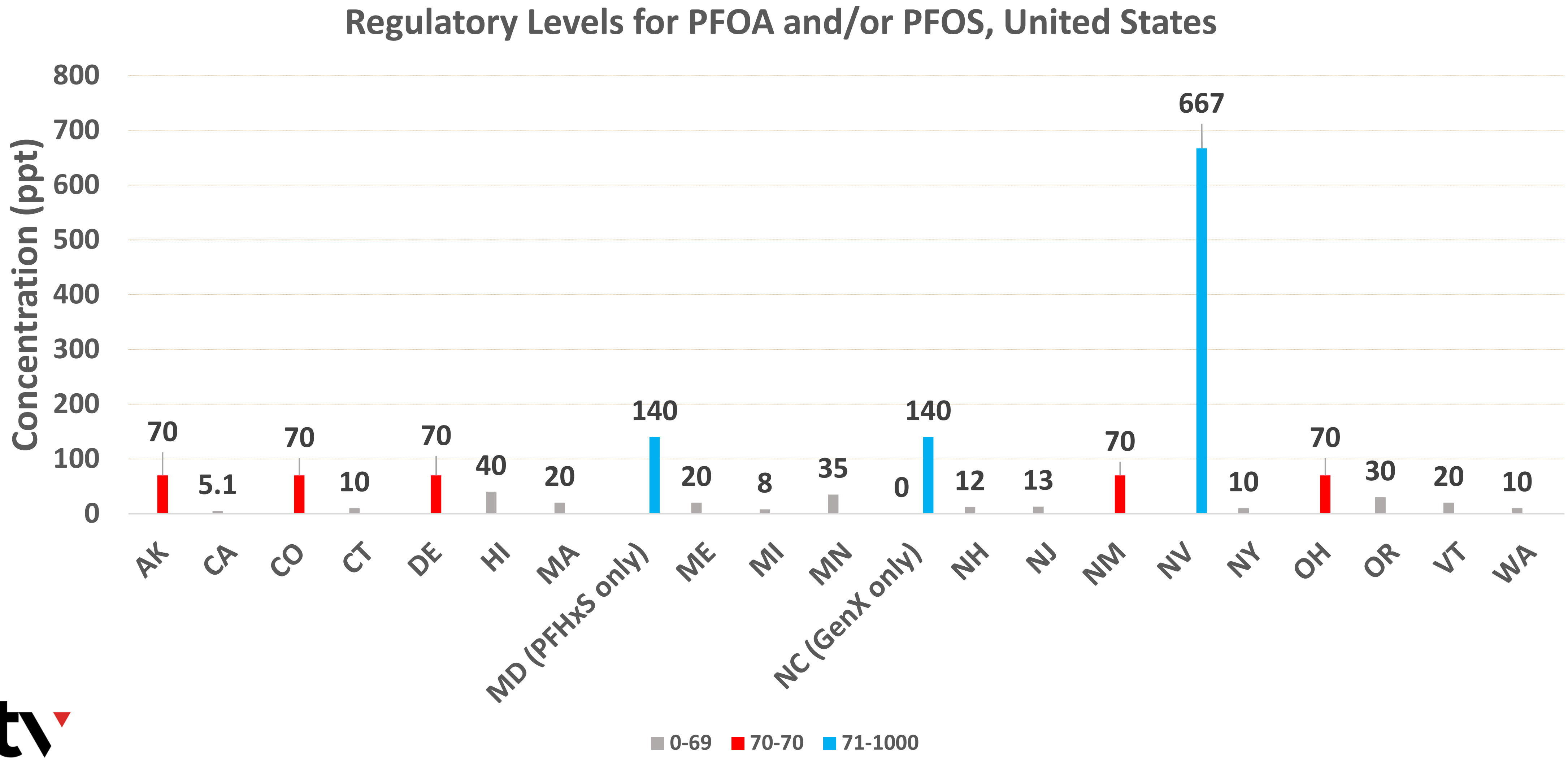
PFAS Drinking Water Regulations



Proposed Maximum Contaminant Level (MCL)

- National Primary Drinking Water Regulation (NPDWR)

PFAS Compound	Proposed MCLG (Goal)	Proposed MCL (Enforceable Levels)	Rule Trigger Level
PFOA	Zero	4.0 ppt*	1.3 ppt*
PFOS	Zero	4.0 ppt*	1.3 ppt*
PFNA	1.0 (unitless) Hazard Index**	1.0 (unitless) Hazard Index**	0.33
PFHxS			
PFBS			
HFPO-DA (GenX Chemicals)			

**ppt = parts per trillion (also expressed as ng/L)*
***Hazard Index is a tool used to evaluate potential health risks from exposure to chemical mixtures*

Hazard Index

- The Hazard Index (HI) is used to understand health risks
- Measured level compared to Health Based Water Concentration (HBWC)

$$HI = \frac{GenX_{Water}}{GenX_{HBWC}} + \frac{PFBS_{Water}}{PFBS_{HBWC}} + \frac{PFNA_{Water}}{PFNA_{HBWC}} + \frac{PFHxS_{Water}}{PFHxS_{HBWC}}$$

Monitoring and Reporting Requirements

- Groundwater >10,000 customers and All Surface Water Systems

  - Initial monitoring
    - Quarterly
    - Each point of entry
    - 12-month period

  - Initial below trigger level
    - Two samples
    - Each point of entry
    - All regulated PFAS
    - Minimum 90 days apart
    - One calendar year

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Monitoring and Reporting Requirements

- Groundwater ≤10,000 customers

  - Initial monitoring
    - Two samples
    - Each point of entry
    - All regulated PFAS
    - Minimum 90 days apart
    - 12-month period
  - ≤3,300 customers below initial trigger level
    - One samples
    - Each point of entry
    - All regulated PFAS
    - Minimum 90 days apart
    - One calendar year
  - >3,300 customers below initial trigger level
    - Two samples
    - Each point of entry
    - All regulated PFAS
    - Minimum 90 days apart
    - 12-month period

Determining a Violation

- After one complete year of quarterly sampling
- Running annual average exceeds MCL
- Calculating Running Annual Average
  - IF sample concentration below MCL
  - THEN its default value = Zero for that quarter
- Previous UCMR 5 Monitoring Data
- Previous State-Led Monitoring Data
- If systems have multiple years of data, the most recent data must be used

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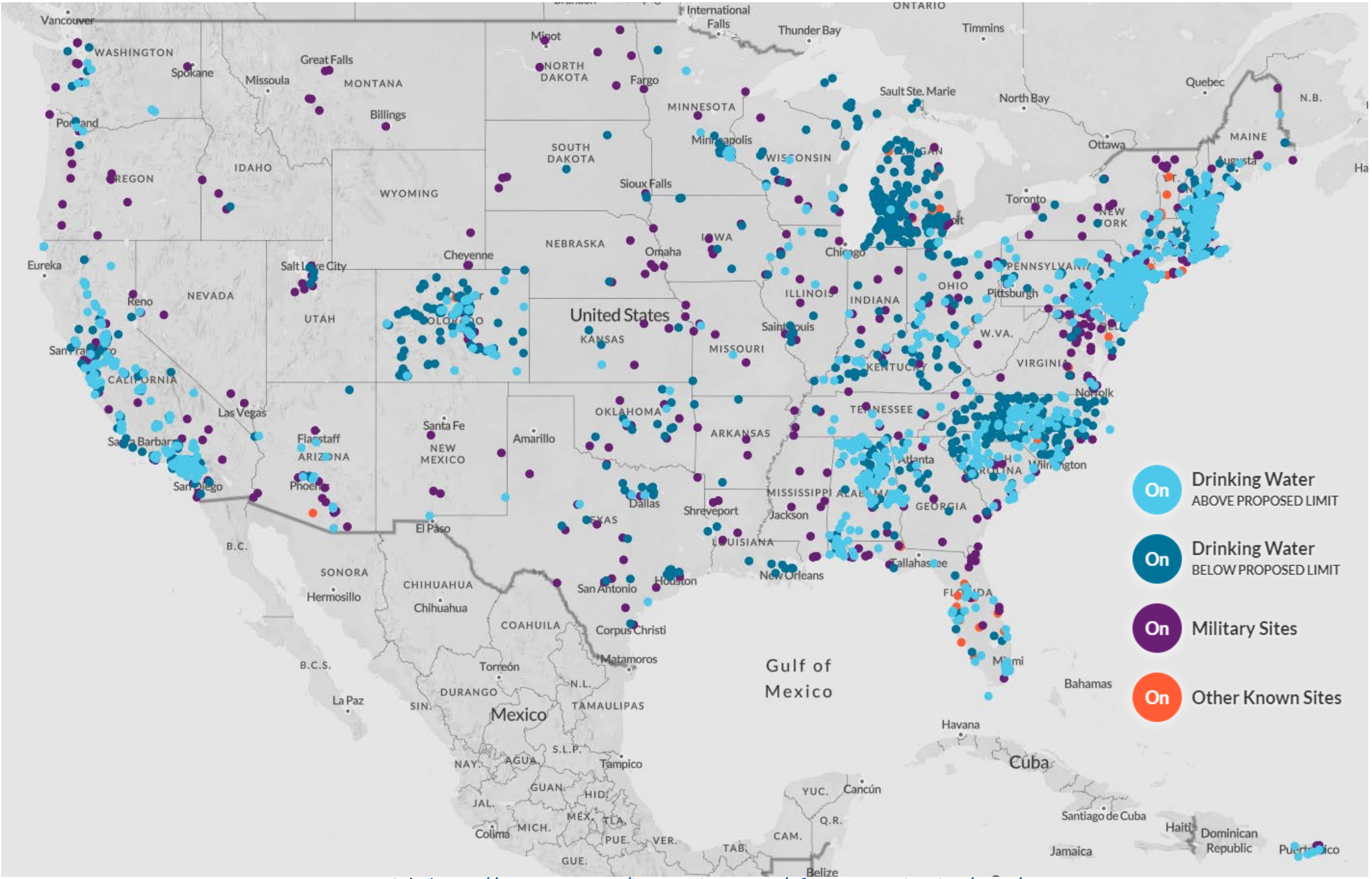
EPA NPDWR Webinar - March 2023

- Public water systems
  - Monitoring
  - Public reporting
  - Treatment
- ~66,000 water systems
- ~5-10% (~3,400-6,300) expected to exceed at least one MCL

PFAS Drinking Water Map



Source: ewg.org *Link: https://www.ewg.org/interactive-maps/pfas_contamination/map/*

Impacts on Water Utilities

Provide Treatment?

Blend Existing Sources?

Develop Alternate Sources?

Purchase Water?

Treatment

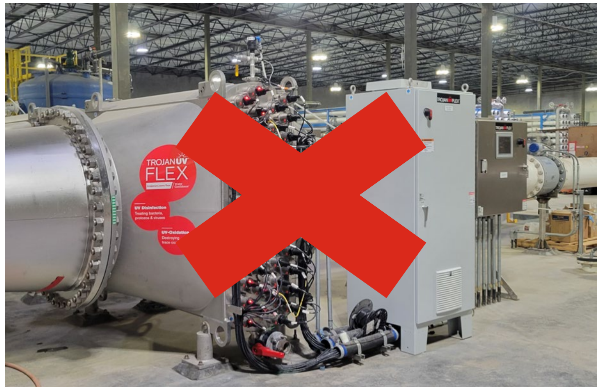
PFAS Treatment Overview:

Focus on Drinking Water

Best Available Technologies

"Conventional" Pretreatment

Air stripping / aeration



UV Advanced Oxidation Process (AOP)

Membrane Filtration

Physical separation with concentrated waste stream

Activated Carbon (GAC & PAC)

Adsorption

Ion exchange

Ion exchange and adsorption

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Treatment Technologies

- **Nanofiltration/ Reverse Osmosis**
  - Pretreatment
  - Post treatment to control corrosivity
  - PFAS waste stream
  - Complex operation
  - High capital cost
  - High operating cost
  - Treats co-contaminants

Treatment Method	Potential Removal[1]	Costs	Considerations	
			Pros	Cons
Membrane Filtration	PFOA: 47-99% PFOS: 93-99% PFBA: 99.9% PFBS: 99.8% PFHxA: 99.2% PFHxS: 99% PFHpA: 99% PFHpS: 99% PFNA: 99%	$$$	• Excellent, broad spectrum removal of PFAS • Reasonable for groundwater systems	• Reject water must be treated before discharging • High capital expense with high energy demands • Susceptible to fouling and may require pre-treatment • Reverse osmosis is preferable to nanofiltration due to better removal efficiency but higher operating costs

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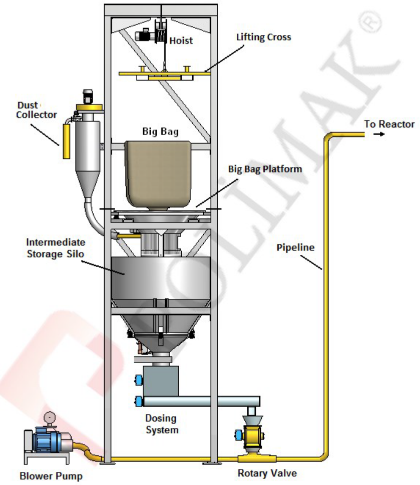
Treatment Technologies

- **Powdered Activated Carbon (PAC)**
  - Surface water
  - PAC pretreatment
  - Moderate removal
  - PFAS residuals



- **Activated Carbon**
  - Many full-scale installations
  - Adsorption
  - Good removal capacity
  - Removes organics/ co-contaminants
  - GAC can be reactivated or incinerated

Treatment Method	Potential Removal[1]	Costs	Considerations	
			Pros	Cons
Activated Carbon	PFOA: 40-99% PFOS: 18-98% PFBA: 99% PFBS: 98% PFHxA: 95% PFHxS: 90% PFHpA: 90% PFHpS: 82% PFNA: 93%	$$	• Widely used for PFAS removal, high removal rates possible • Powder activated carbon is useful for responding to spills	• Lower removal rates for perfluoroalkyl acids and short-chain PFAS • Possibility of competitive adsorption with other compounds present, such as TOC • Low rate of adsorption in GAC may result in long mass transfer zones and adjustment of associated operating requirements • Requires thermal regeneration of GAC; regenerated GAC may not be as effective as virgin GAC • Creates waste residuals to dispose of exhausted carbon and potential opportunity for pollution

- ***Types of GAC:***
  - Bituminous coal
  - Coconut shell
  - Lignite
  - Wood

Treatment Technologies

- **Ion Exchange Resin**
  - Newer technology
  - Several full-scale installations
  - Ion exchange and adsorption
  - Higher removal capacity
  - PFAS selective, Not chlorine tolerant
  - Single use (for drinking water), incinerated

Pre-filter

- *Ion Exchange Resin Types for PFAS Removal:*
  - Gel resin
  - Macroporous resin

Treatment Method	Potential Removal[1]	Costs	Considerations	
			Pros	Cons
Anion Exchange	PFOA: 77-97% PFOS: 90-99% PFBA: 97% PFBS: 98% PFHxA: 97% PFHxS: 99% PFHpA: 94% PFHpS: 99% PFNA: 98%	$$	• Sorption rates depend on the resin and porosity • Can partially remove PFOA, PFNA, and PFOS • Resin can be specialized for specific PFAS and allows IX to have a higher capacity than activated carbon	• Costs are similar to activated carbon but depend greatly on resin and treatment system • Rate of exchange will depend on many factors, including influent PFAS concentration, design of the IX, solution ionic strength and bead material • Surface water supplies may need clarification/filtration before treatment • Range of efficacy for long and short-chain PFAS

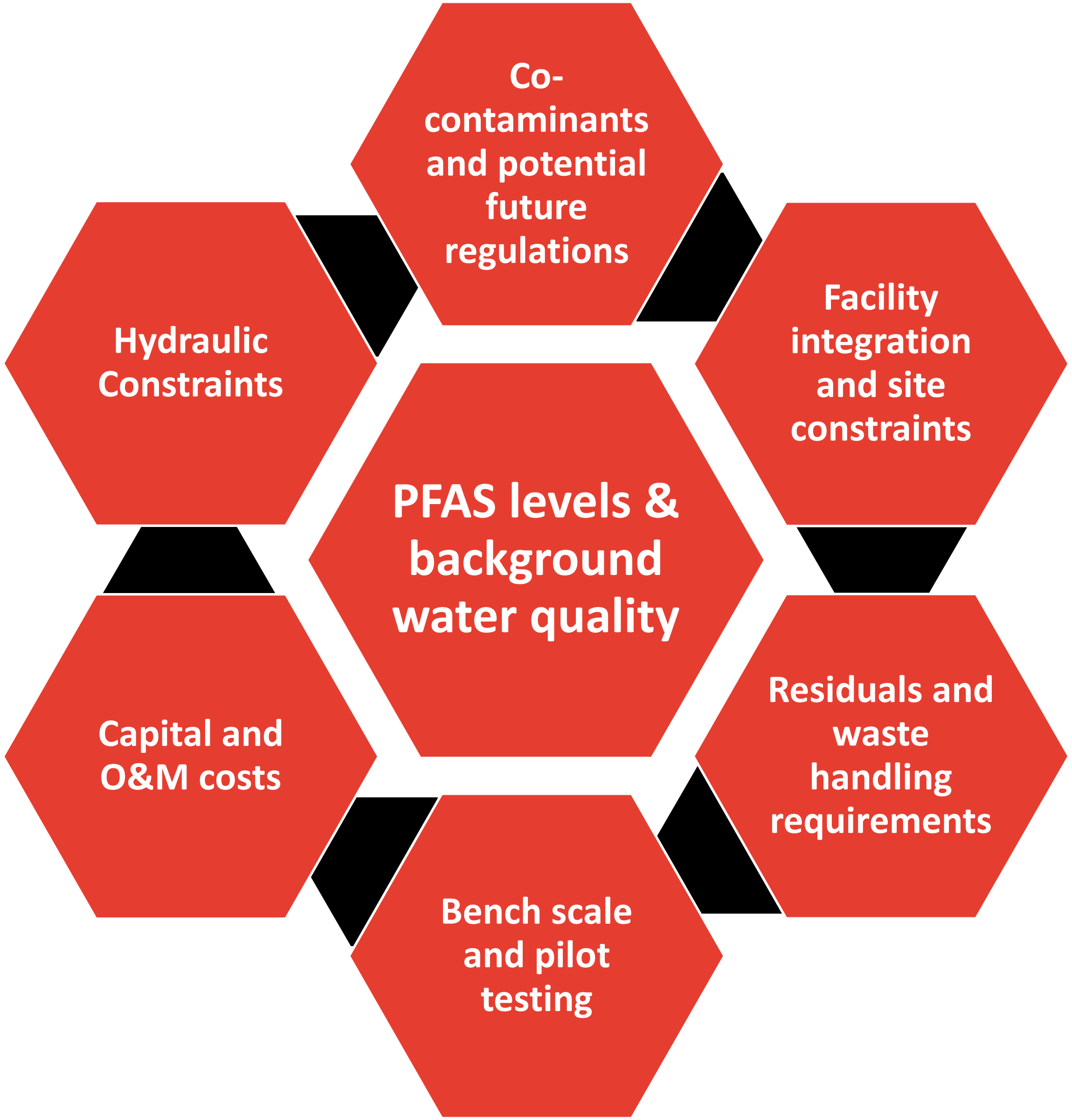
- Purolite: Purofine PFA694E
- Calgon: Carbon CalRes 2301
- Dupont: AmberLite PSR2 Plus
- ECT2: Sorbix Pure LC
- ResinTech: ResinTech SIR-110-HP

Preliminary Space Planning & High-Level Costs

- Preliminary Space Requirements
  - Nano Filtration or RO - ~ 15 to 20 SF per 1000 Gallons
  - GAC - ~ 35 to 45 SF per 1000 Gallons
  - AIX - ~ 30 to 40 SF per 1000 Gallons
- High-Level Costs
  - Nano Filtration or RO - ~ $1 per 1 Gallon and O&M of $0.5
  - GAC - ~ $0.6 per 1 Gallon and O&M of $0.3
  - AIX - ~ $0.7 per 1 Gallon and O&M of $0.35

These costs include superstructure, all associated appurtenances and prepared in accordance with an AACE Class 4 estimate (-30% to -50% budget level estimate)

Treatment Selection Considerations



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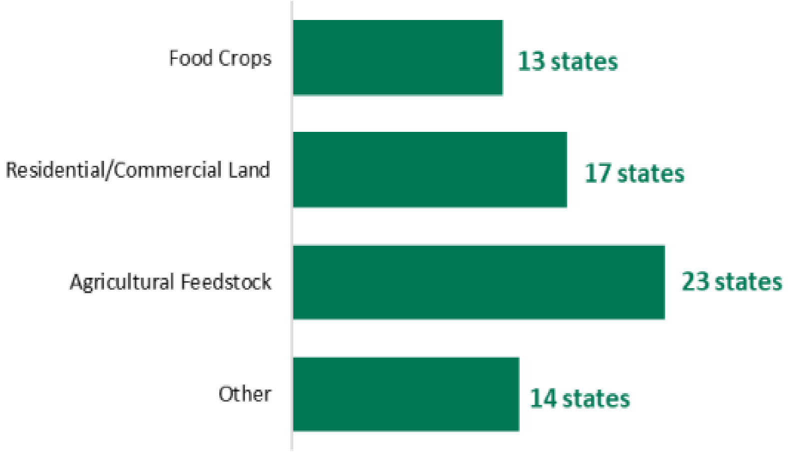
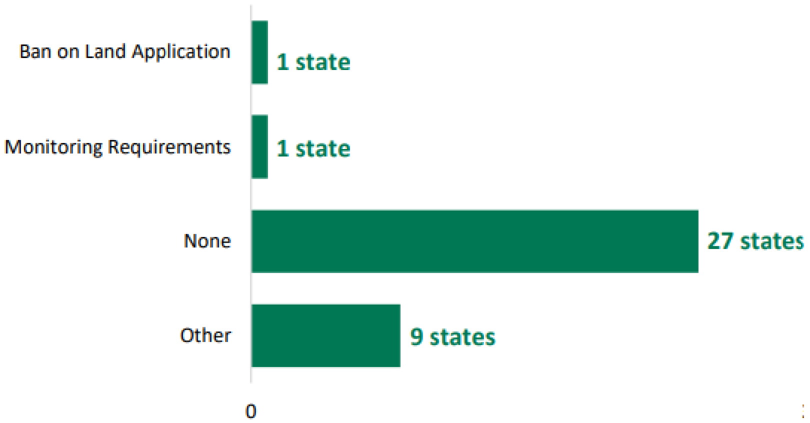
PFAS in Wastewater

What Other States are Doing

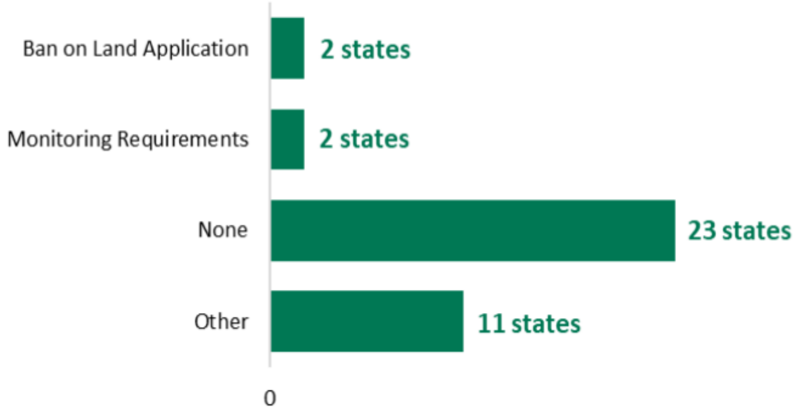
Allowable Uses for Land-Applied Biosolids



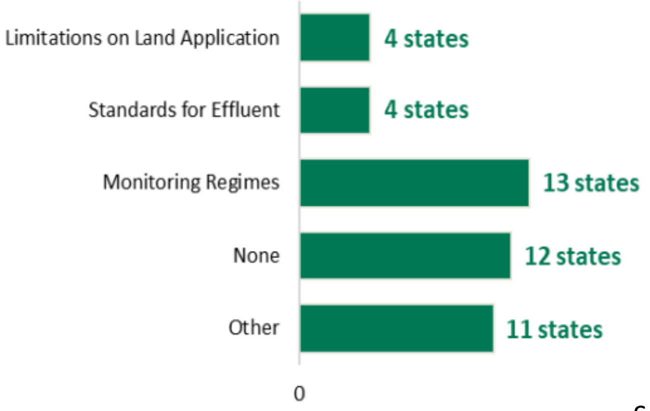
Number of States With Enacted or Proposed Legislation on PFAS in Biosolids



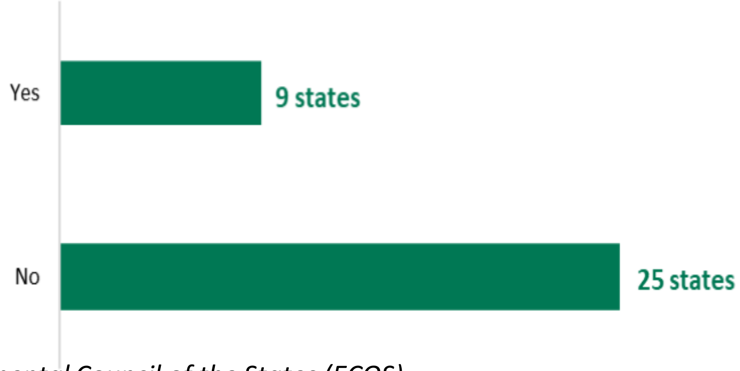
Number of States Considering Legislation on PFAS in Biosolids



Regulatory Actions States Have Taken or Are Considering



States that Have Jurisdictions with Established Standards, Bans, Monitoring Regimes, etc. Related to Biosolids Disposal or Land Application



Source: Environmental Council of the States (ECOS)

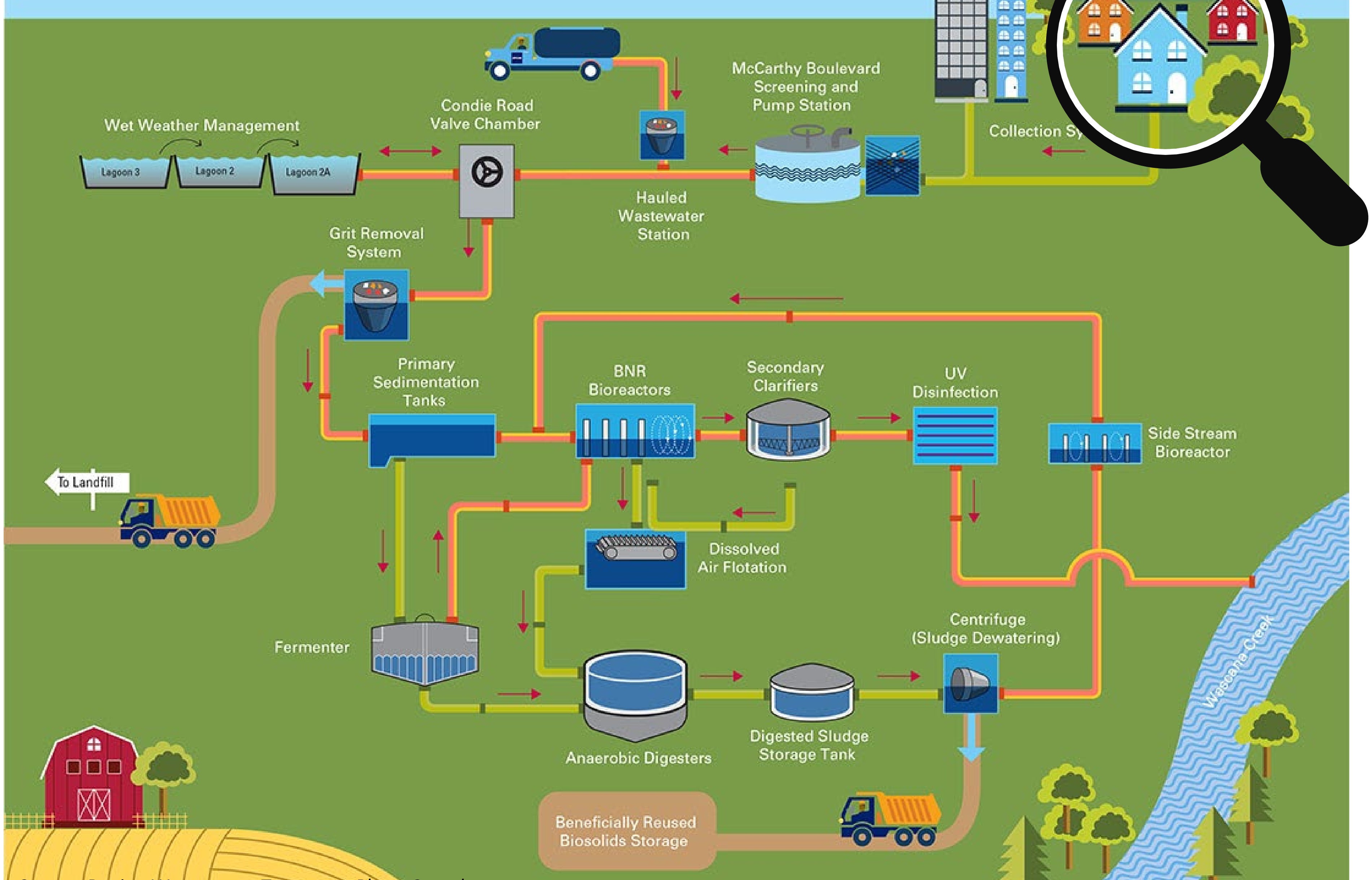
PFAS In Wastewater

Source: Regina Wastewater Treatment Plant, Canada

- Sampling
  - Various Point in the process, Influent, effluent and sludge
  - Characterize PFAS discharge and sources

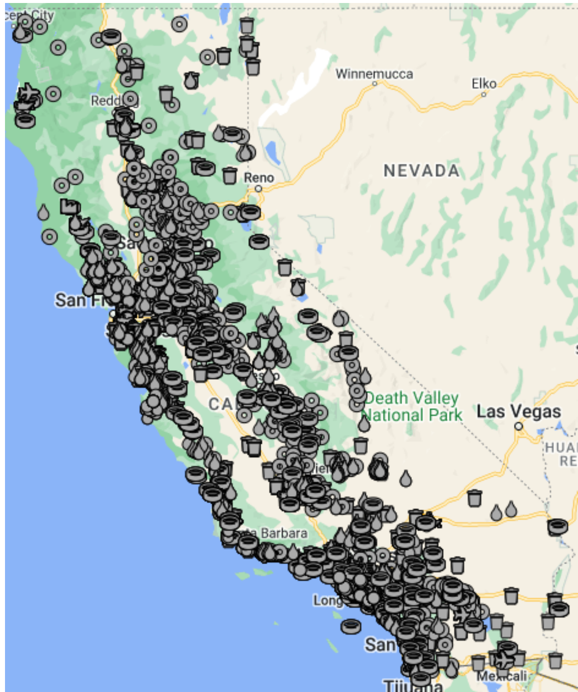
70% ends up at outfall and the remaining 30% either escapes or end up in biosolids

Source Identification



Source: Regina Wastewater Treatment Plant, Canada

- Source Identification
  - Data collection and assessment to identify PFAS source
  - Industrial facilities, landfills and airports etc.
  - Through site inspections and review of facility records



Treatment for PFAS in Wastewater

- Reclaimed Water

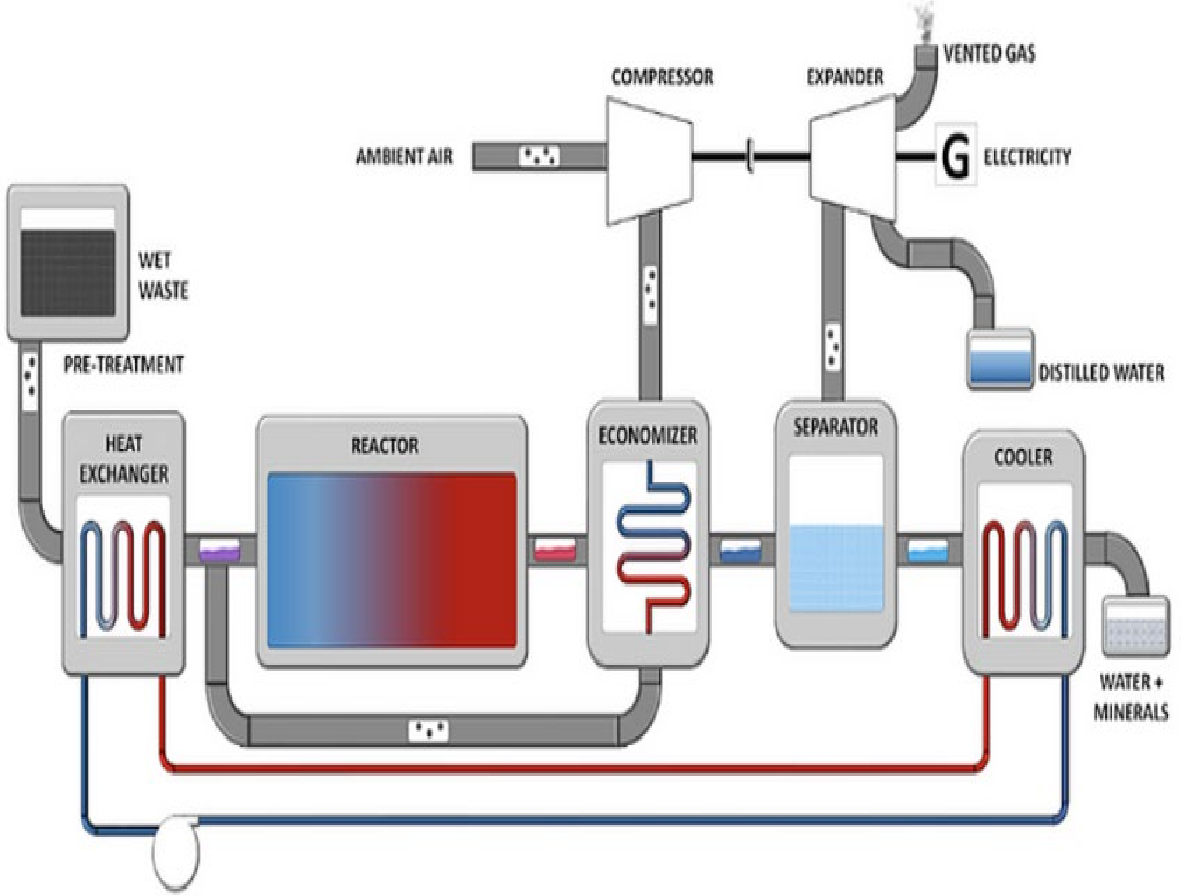
Membrane Filtration
Physical separation with concentrated waste stream

Activated Carbon (GAC & PAC)
Adsorption

Ion exchange
Ion exchange and adsorption

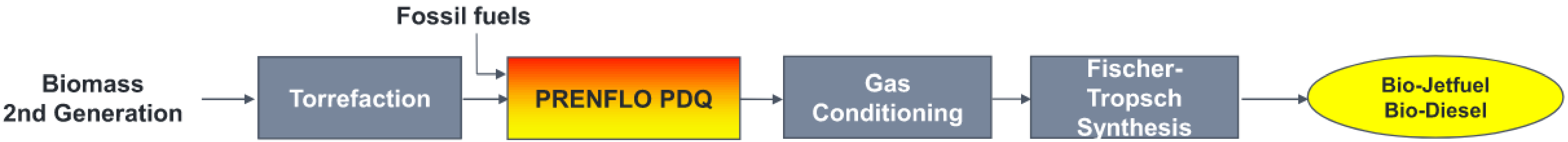
Treatment for PFAS in Wastewater

- Biosolids
  - Source Reduction
  - Incineration
  - Pyrolysis/Gasification
  - Supercritical Water Oxidation



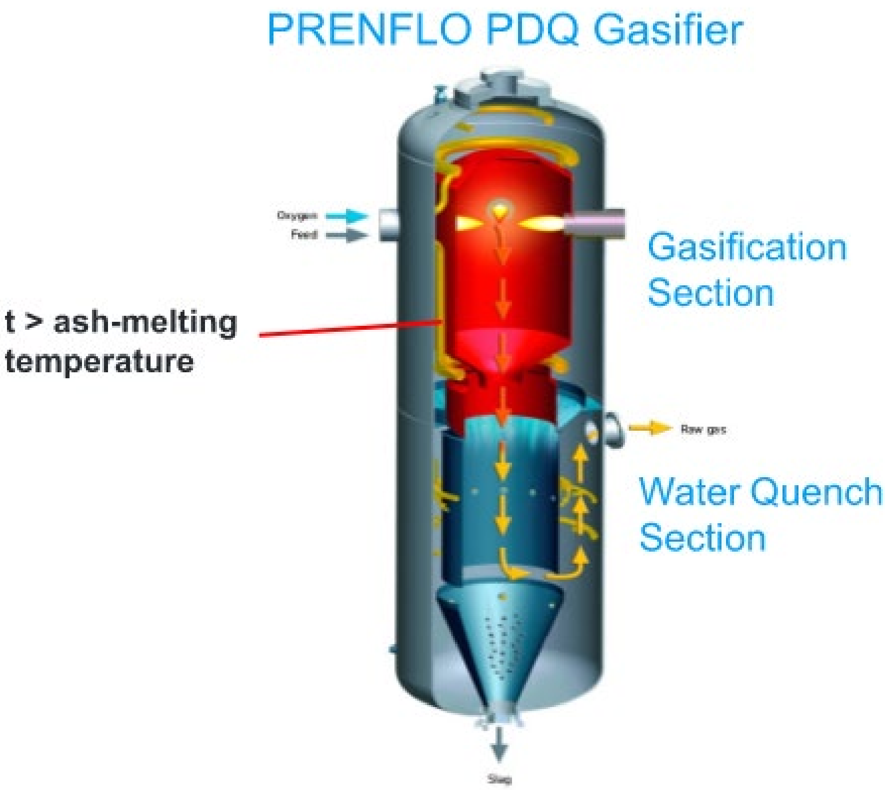
Source: Web 374 Water

Alternative Uses of Biosolids



- Synthetic Gas and Lubricants
- Renewable Compressed Natural Gas
- Sustainable Aviation Fuel

Source: Biotfuel



Emerging Technologies

Adsorbent Media

cyclopure

DEXSORB+

FLUORO-SORB® 400

Pump & Treat, Permeable Reactive Barrier (PRB)

FLUORO-SORB® 100

In-Situ Solidification & Stabilization (ISS)

FLUORO-SORB® 200

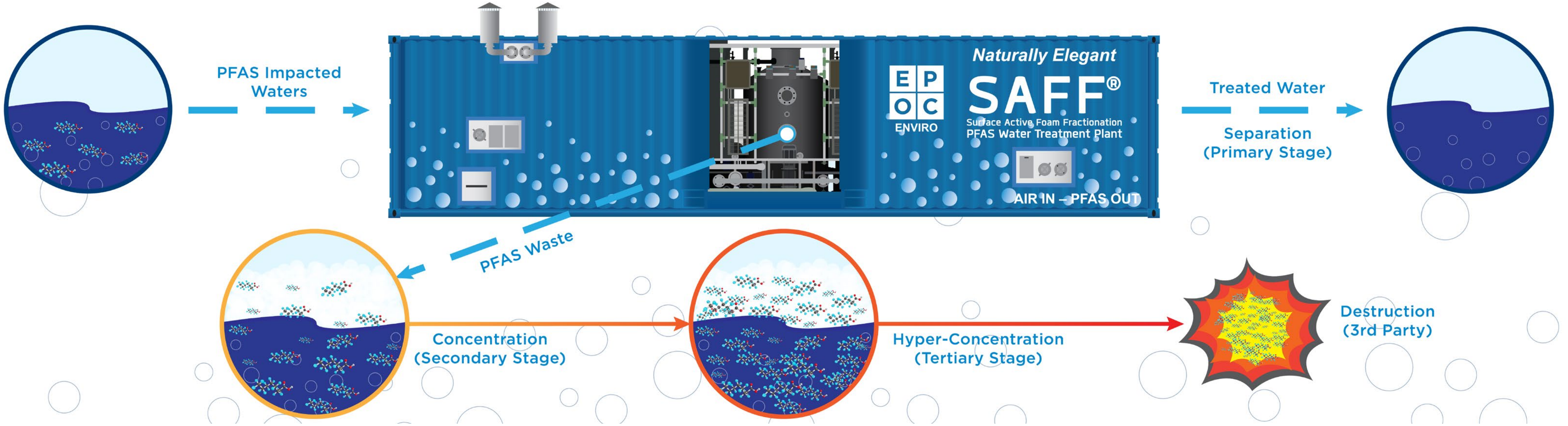
Pump & Treat, Permeable Reactive Barrier (PRB)

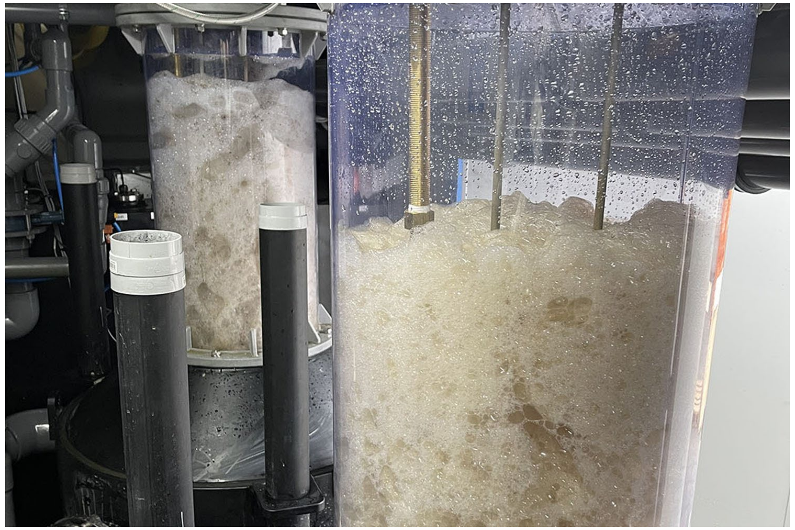
FLUORO-SORB® 300

High Organics Wastewater Treatment

https://youtu.be/HGKawPAMULA

Surface Active Foam Fractionation (SAFF)

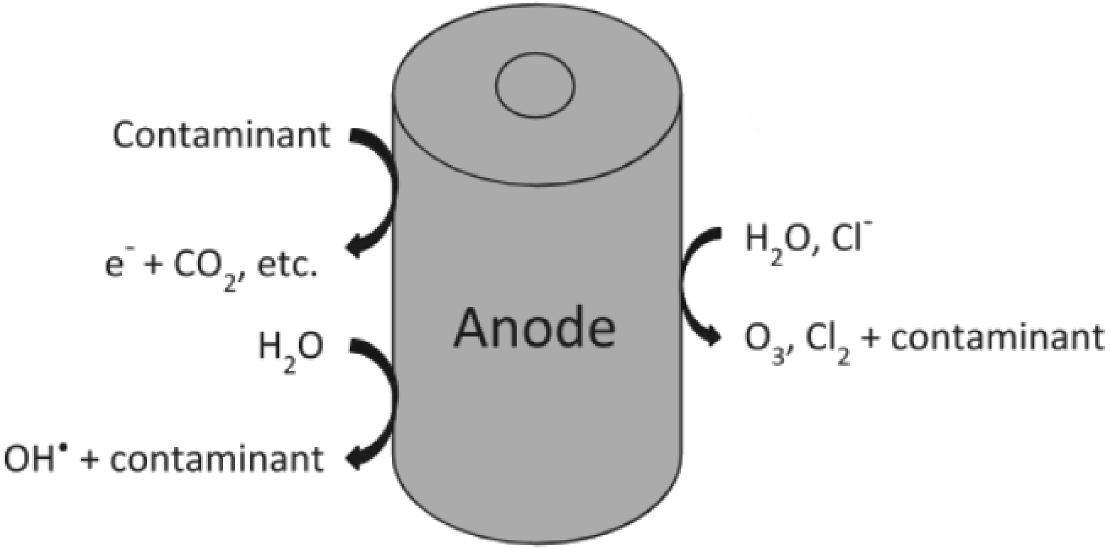




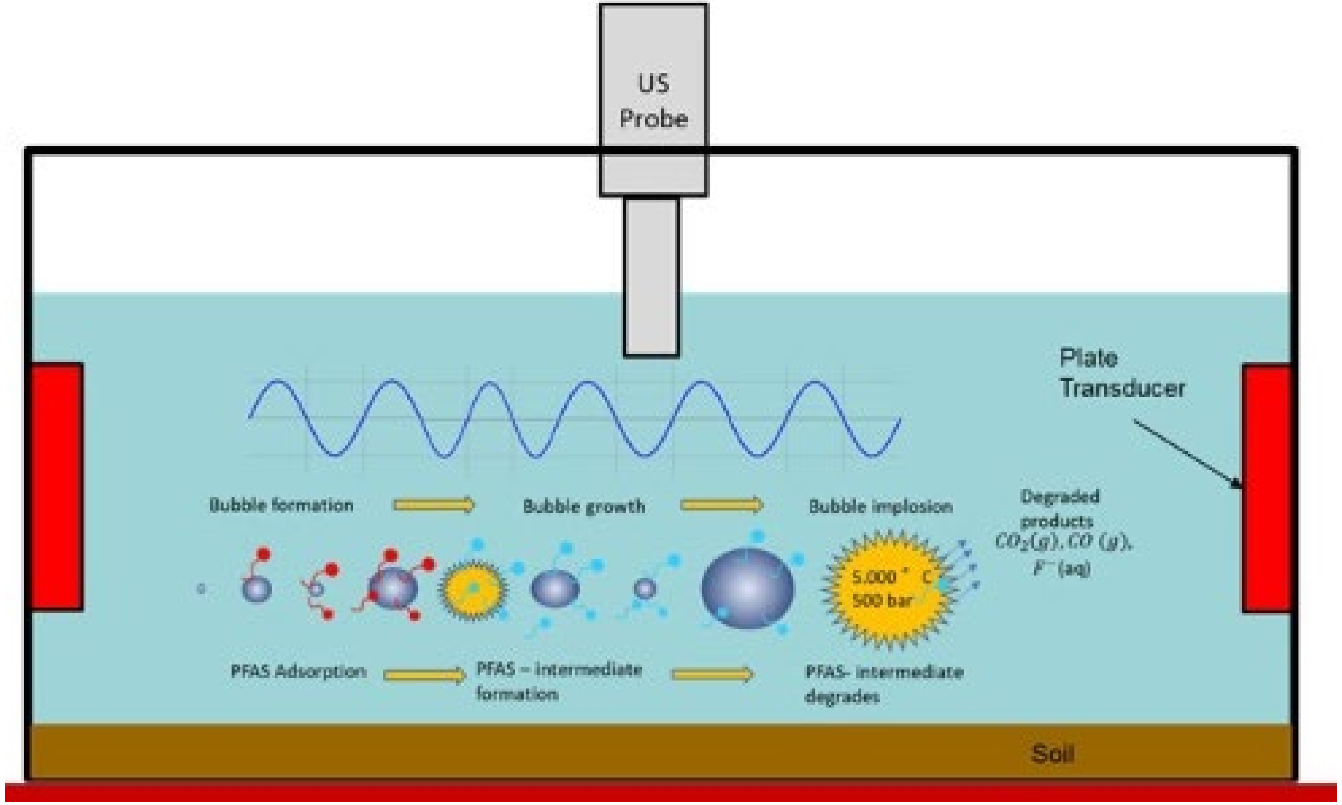
https://youtu.be/uUutrt3VFYU

Electrochemical Advanced Oxidation Processes (eAOPs)

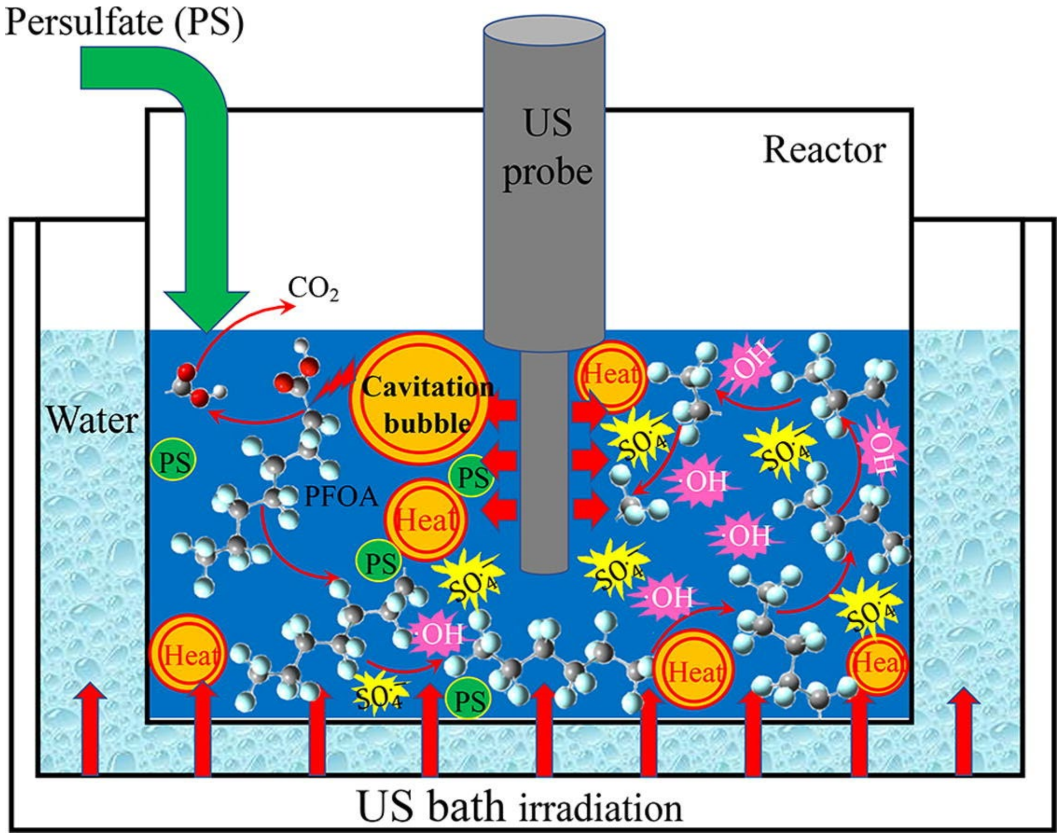
Aclarity



Sonochemical Oxidation/Ultrasound



Source: NJIT



Source: Synergistic degradation of PFAS in water and soil by dual-frequency ultrasonic activated persulfate by Yong

- Acoustic waves in liquids at frequencies ranging from 20 kHz to 1,000 kHz
- Process produces high temperatures and pressures

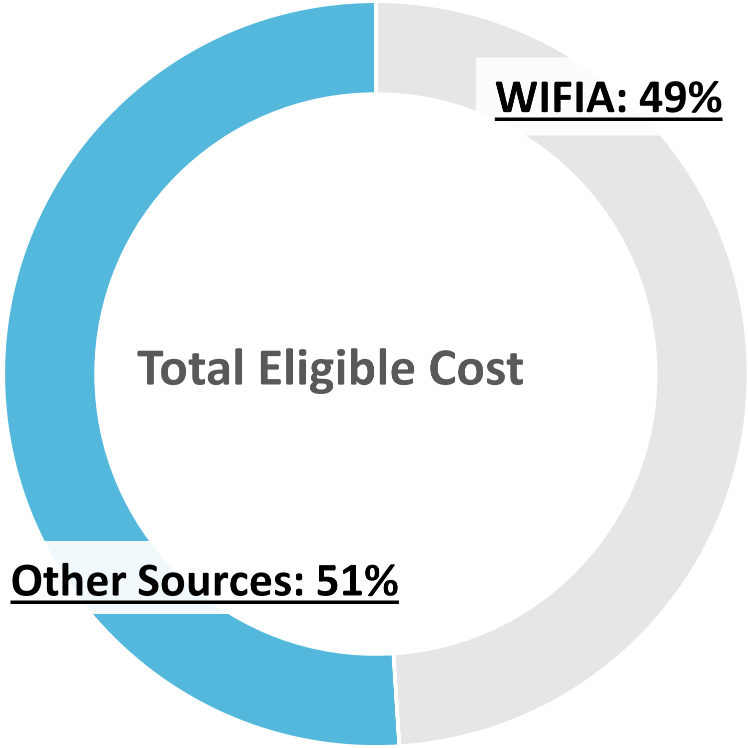
PFAS Funding Opportunities

Bipartisan Infrastructure Law (BIL)

- $21 billion
  - $9 billion for PFAS and other emerging contaminants
    - $4 billion - Drinking Water State Revolving Fund (DWSRF)
    - $5 billion - Small/Disadvantaged Communities Grant Program
  - $12 billion - BIL DWSRF funds earmarked for drinking water safety

Water Infrastructure Investment & Jobs Act (WIFIA)

- EPA program for water & wastewater infrastructure financing
  - Administered directly by EPA: no TWDB involvement
  - Finances 49% of total costs at Treasury SLGS rate (AAA)
  - $20 million minimum project cost for populations serving >25k population
  - PFAS projects are eligible and have already been funded
  - Popular program under-utilized in Texas



Case Studies

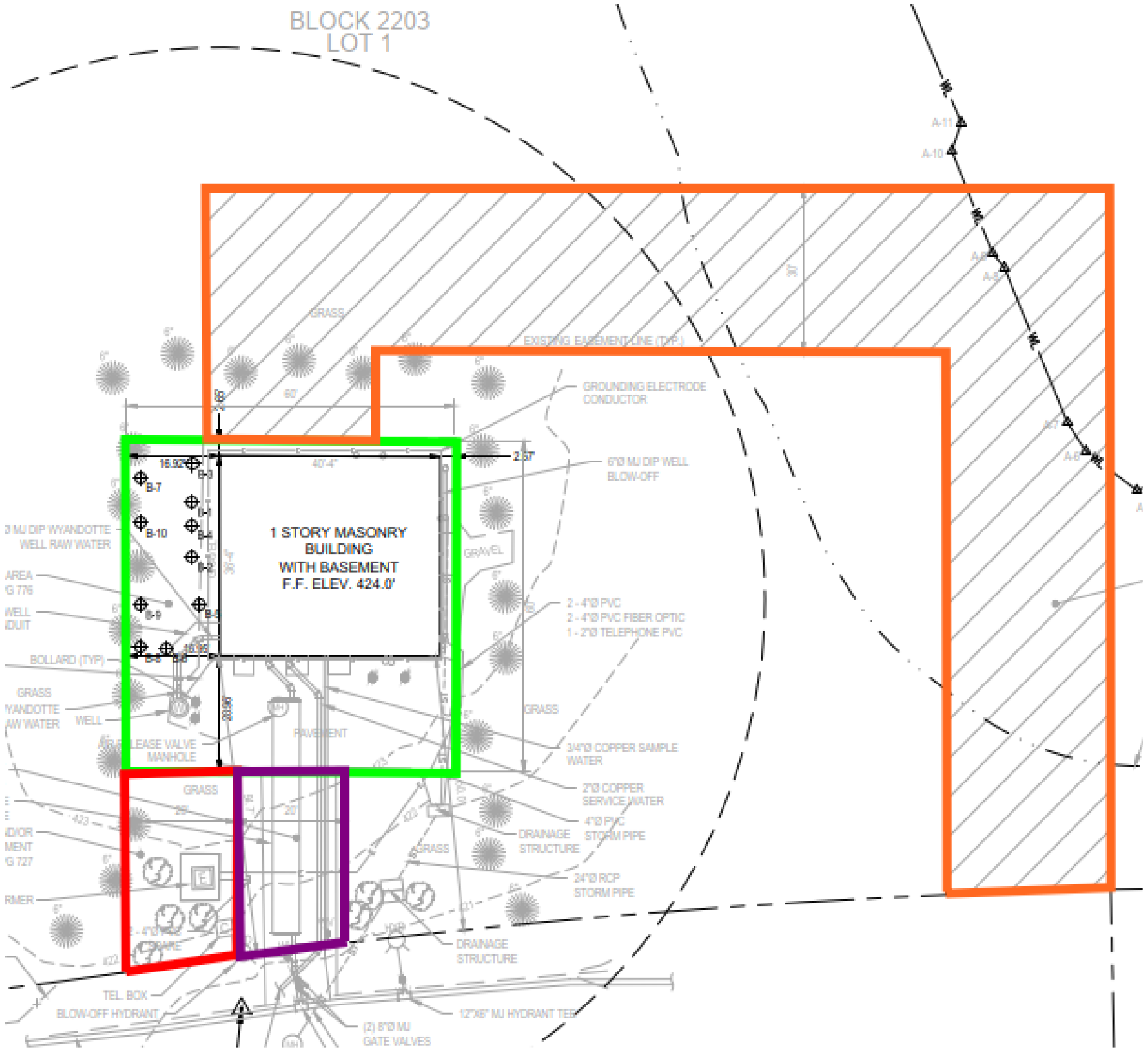
Project 1:
Water Treatment Plant with Challenging Site

Study Phase Started in July 2020

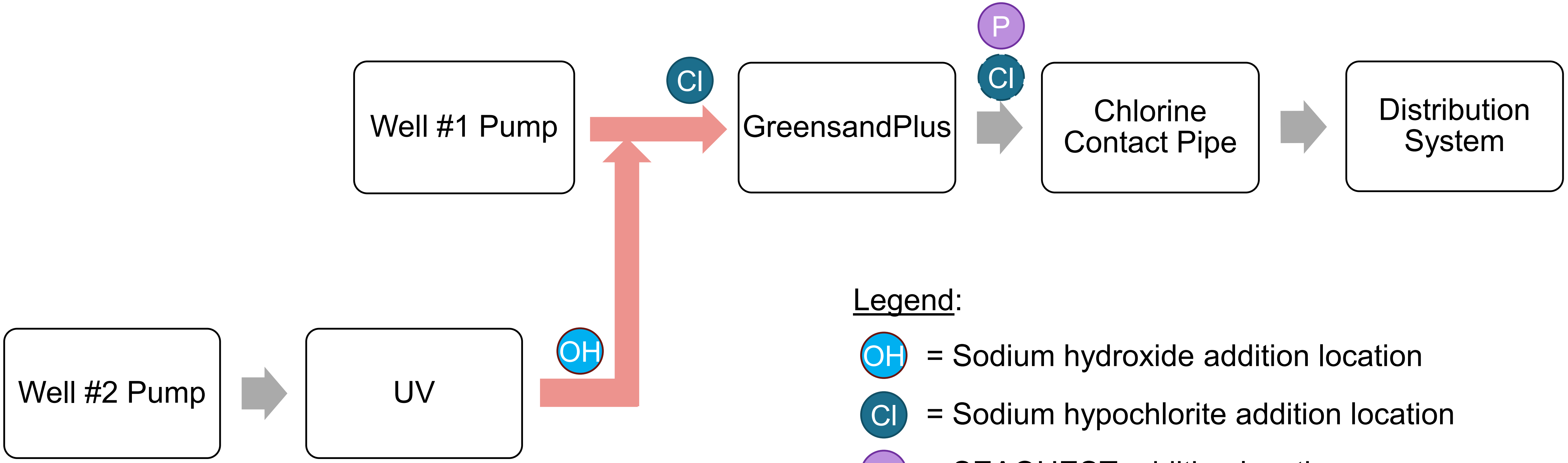
Construction Completed by March 2023

Project 1: Background

- 1050 gpm
  - Well #1 750 gpm
  - Well #2 300 gpm
- Within park, opposite country club
- Under MCL, but elevated
- Treats Manganese with GreensandPlus Filters
- Drivers
  - Site constraints
  - Pressure drop concern
  - PFAS levels
  - Background water quality
  - Capital and O&M costs



Project 1: Existing Process Flow Diagram



Legend:

- OH = Sodium hydroxide addition location
- Cl = Sodium hypochlorite addition location
- P = SEAQUEST addition location

Project 1: Treatment Technology Selected

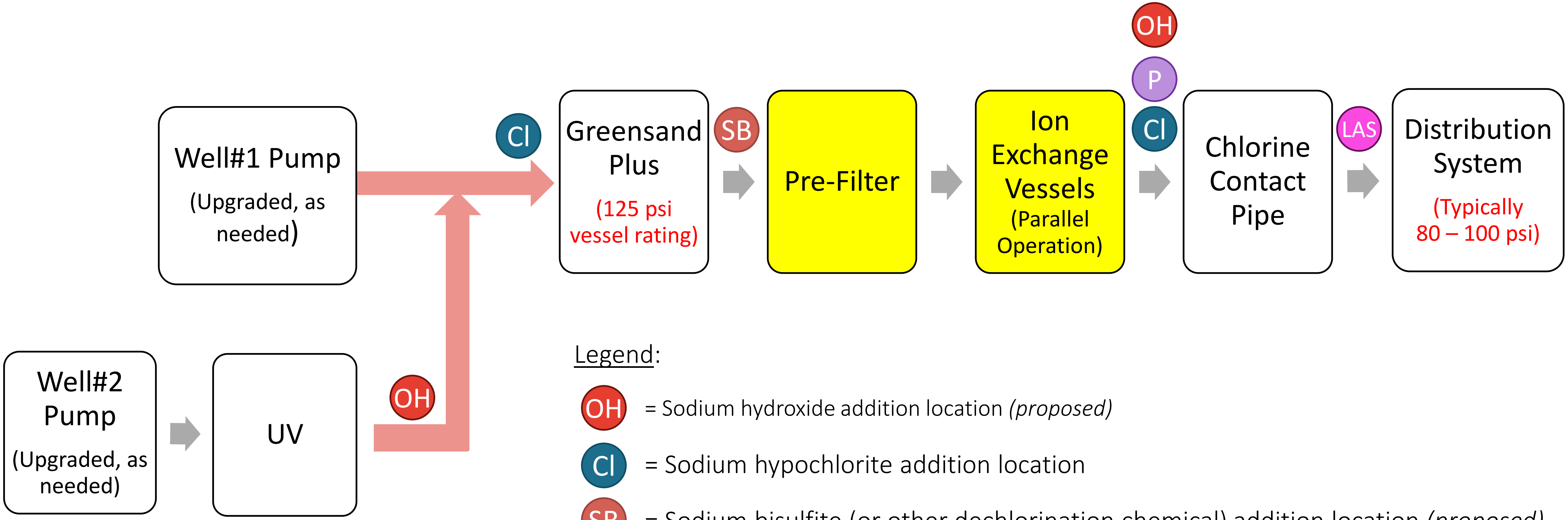
- Ion-Exchange Resin (IX)
  - Effective
  - Smaller footprint
  - Minimizes operational effort - longer life and less frequent media replacement
  - Bench scale testing on several resins
  - Selected 2 resins, with 3rd resin being considered

Ion exchange (PFAS selective resin)

Ion exchange and adsorption

Resin Bench Scale Testing Set-up

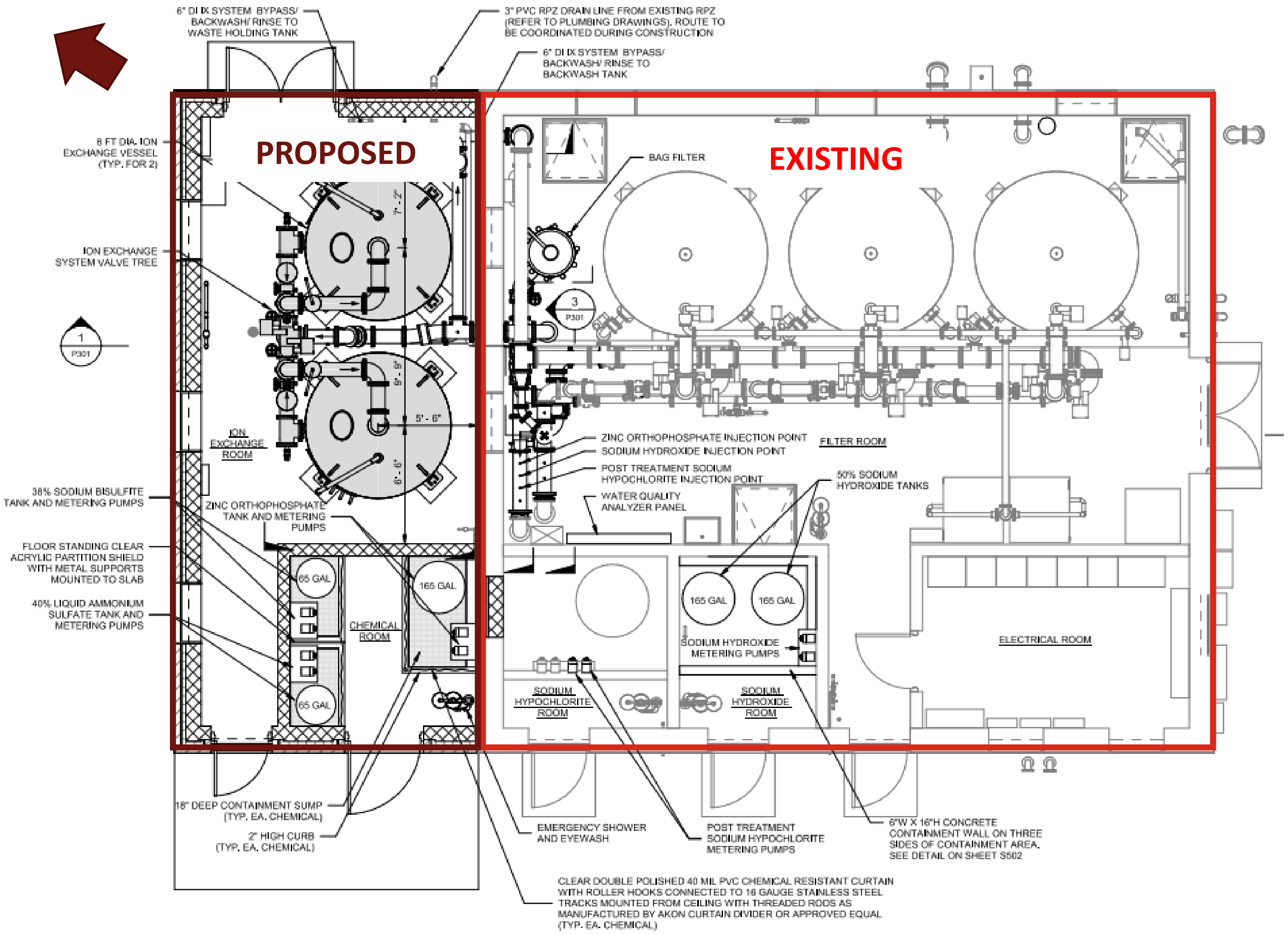
Project 1: Proposed Process Flow Diagram



Legend:

- OH = Sodium hydroxide addition location *(proposed)*
- Cl = Sodium hypochlorite addition location
- SB = Sodium bisulfite (or other dechlorination chemical) addition location *(proposed)*
- P = Zinc orthophosphate addition location *(proposed – replaces Seaquest)*
- LAS = Liquid ammonium sulfate addition location *(proposed)*

Project 1: Proposed Facility Floor Plan



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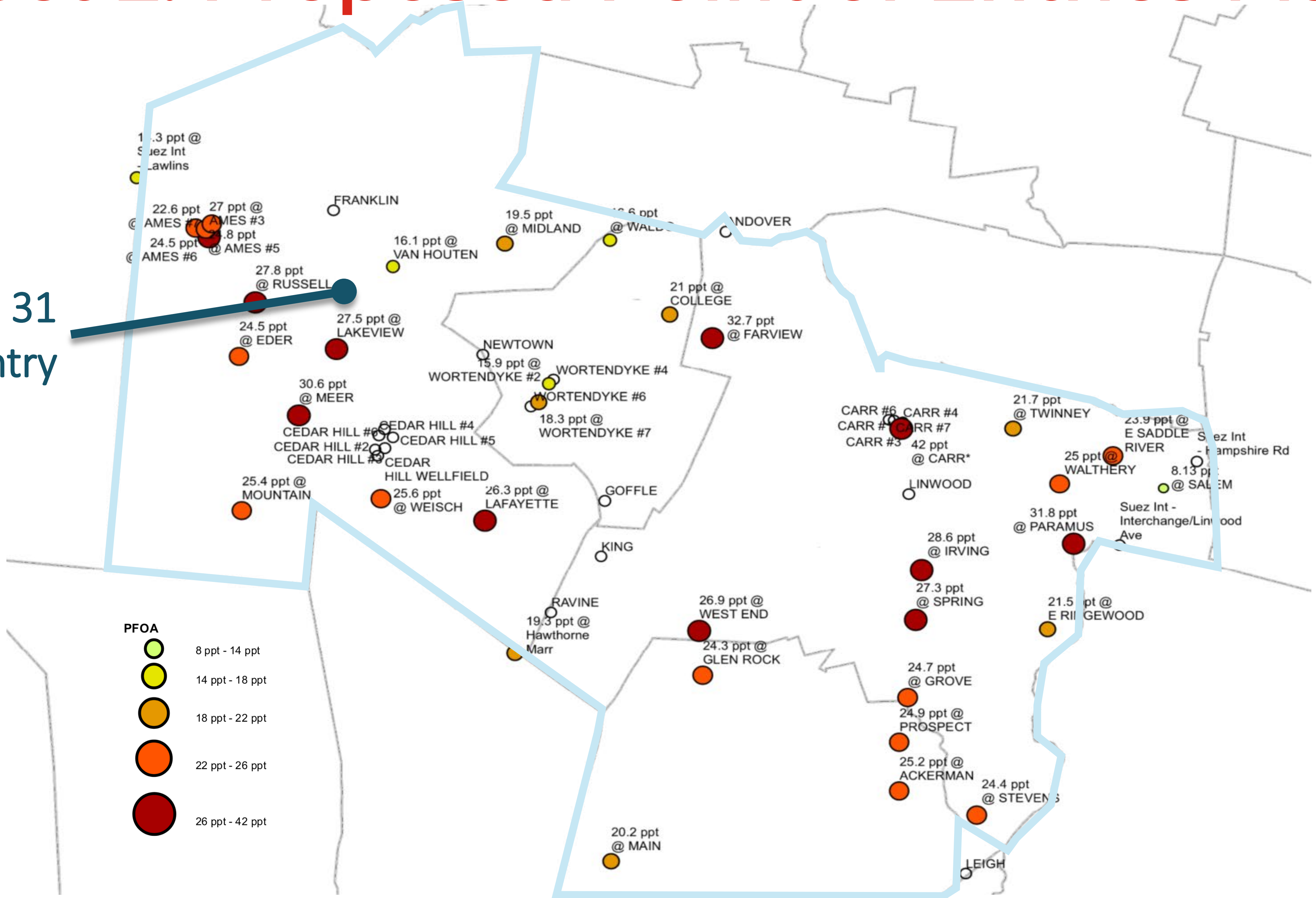
Project 2:
Solution for Water System with PFAS in 52 Wells

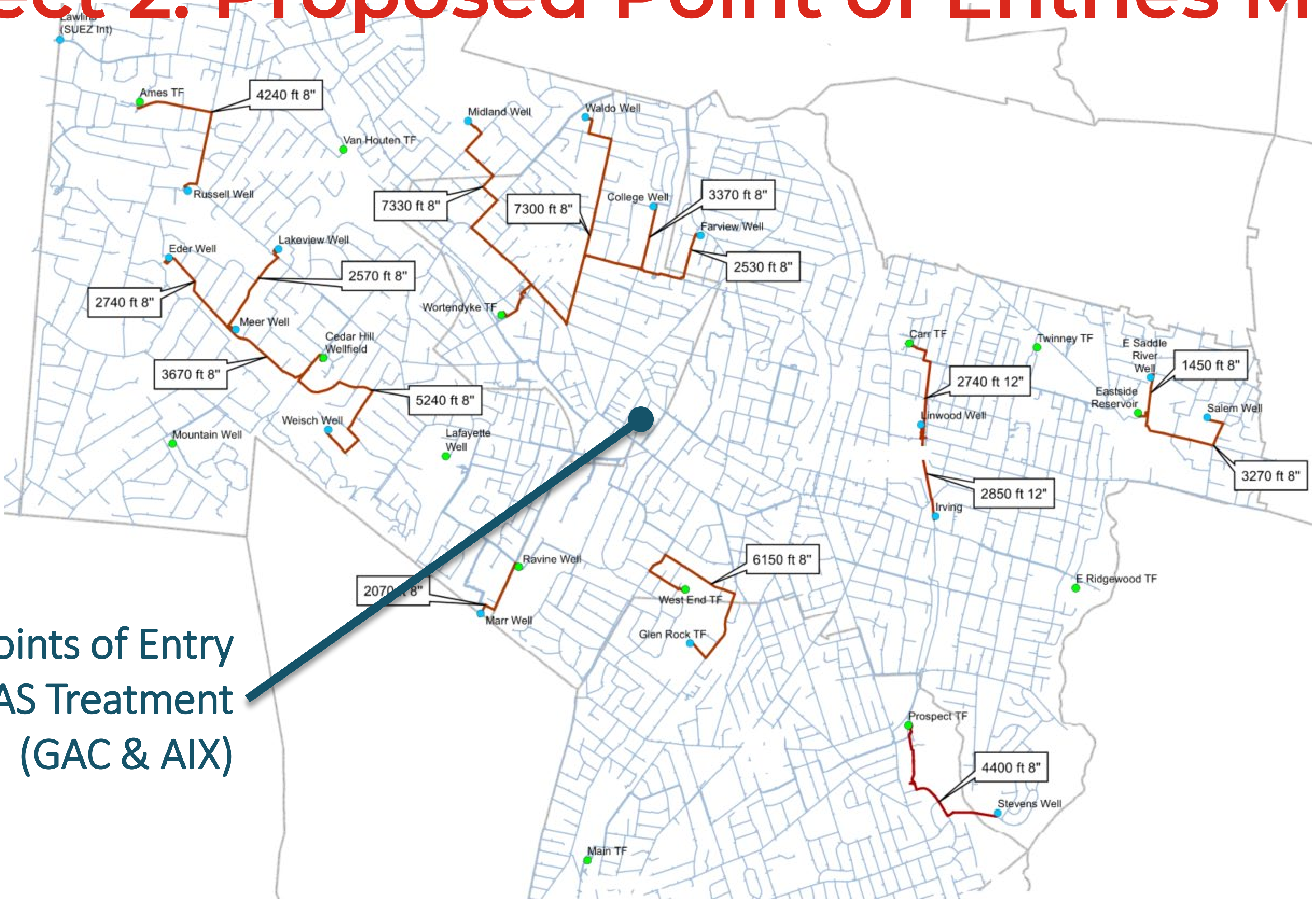
Study Phase Started in 2019

Project 2: Proposed Point of Entries Map

52 Wells & 31 Points of Entry



Project 2: Proposed Point of Entries Map



31 to 13 Points of Entry with PFAS Treatment (GAC & AIX)

Questions?

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Thank you!

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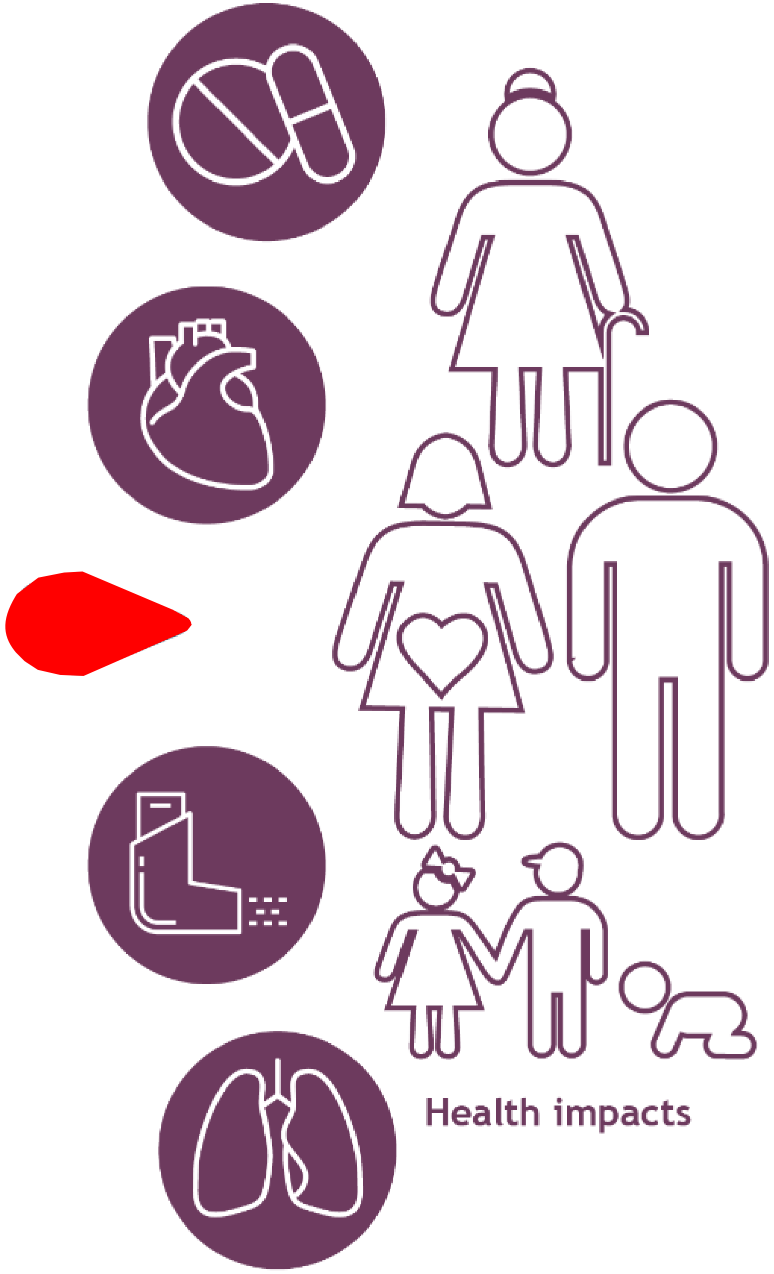
PFAS Health Impacts

- Thyroid
- Cholesterol
- Blood pressure
- Kidney and testicular cancers
- Fertility
- Birth weight
- Vaccine effectiveness



Source: Agency for Toxic Substances and Disease Registry