LEACHATE AND LANDFILL LIQUIDS COMMITTEE
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Operation and Cost Considerations PFAS Treatment in Landfill Leachate

Florida SWANA Winter Conference

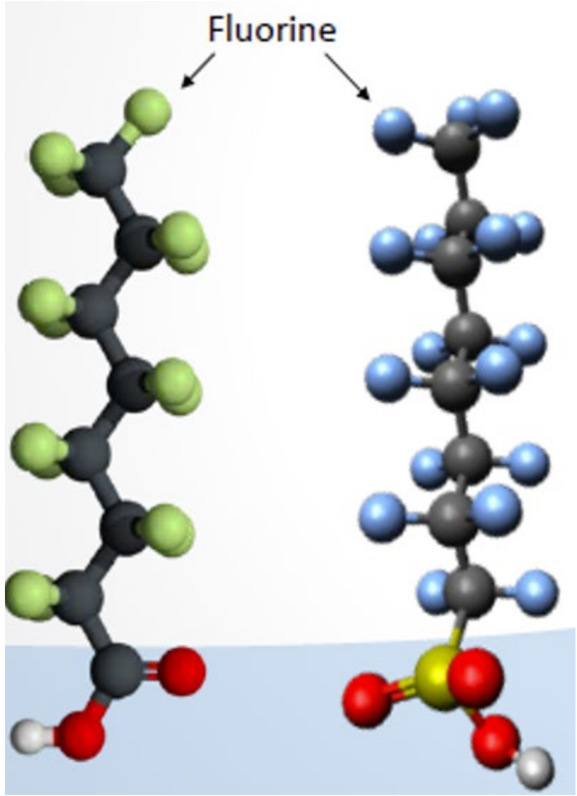
Orlando, FL

- Ivan A. Cooper, PE, BCEE
- Civil & Environmental Consultants, Inc.

- February 20, 2024

Agenda

- Timing
- Operational Considerations
  - Construction
  - Operations
  - Utilities
- Costs
- Summary



Perfluorooctanoic acid (PFOA) Perfluorooctanesulfonic acid (PFOS)

Ref: EPA

Federal Regulatory Timing

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- 2023 activities
  - EPA's national primary drinking water regulation for (PFOA), (PFOS), (PFNA), (PFHxS), (PFBS), and GenX)
  - EPA's rule designating PFOA and PFOS as CERCLA hazardous substances
  - EPA's proposed listing of PFOA, PFOS, PFBS, and GenX as RCRA hazardous constituents
  - DoD's proposal to prohibit procuring products containing PFOA or PFOS
  - Recommending Sampling/reporting
- Jan 31 2024 EPA Proposed Rule
  - *Definition of Hazardous Waste Applicable to Corrective Action for Releases from Solid Waste Management Units*
  - *Listing of Specific PFAS as Hazardous Constituents*
- Plan 15 Schedule
- EPA Landfill Study ~ 4 years
- Implementation to put systems on-line ~ 3 years
- Bottom Line – system operational 2030

Regulatory Timing

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- Florida Proposed
  - Possibly more aggressive than Feds!
  - Local Permits/Actions –Limiting or banning acceptance
  - FL HB 1665 - As of Jan 13 -in Water Quality, Supply & Treatment Subcommittee
  - FL SB 1692 –As of Feb 8 - Favorable by Appropriations Committee on Agriculture, Environment, and General Government; YEAS 9 NAYS 0, Now in Fiscal Policy

- Start Planning Now!

FL HB 1665 /SB 1692 - PFAS and 1,4- Dioxane Pretreatment Initiative

- Preventing contaminants of emerging concern from discharging into wastewater facilities and waters of the state.
- Requires wastewater facilities to conduct inventory of industrial users that are probable sources of specified contaminants
- Authorizes wastewater facilities to develop and propose local limits for PFOS, PFOA, or 1,4-dioxane
- **If adopted,**

  Starting July 2025, Interim specific discharge limits for industrial users:

  PFOS, 10 nanograms per liter (10 ppt)
  PFOA, 170 nanograms per liter (170 ppt)
  1,4-dioxane, 200,000 nanograms per liter (0.2 ppm)

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Leachate Considerations

- Complex mixture
  - Organics VOC and SVOC
  - Ammonia/TKN
  - Metals
  - Others
    - PCB
    - 1,4 dioxane
    - Pesticides
    - PFAS
  - Variability
    - Between LFs
    - Daily Variability – concentrations/flows
  - Disposal
    - Pretreated or not
    - POTW or direct discharge
  - PFAS Treatment is a Train of Technologies
    - Pretreatment – Removal/Concentration - Management/Destruction – Effluent Polishing

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- Few Process are single unit operations
- Commercial Status – **Full Scale** / Limited / Developing or Laboratory

Segregation – Adsorptive	Segregation- Physical Chemical	Destructive
Activated Carbon Granular Colloidal Ion Exchange Polymers Modified bentonite Mixed Media	Reverse Osmosis/Nano/Ultra Foam Fractionation Deep Well Injection Cementitious encapsulation	Plasma Thermal Supercritical Oxidation Electrochemical Photochemical Oxidation/Reduction Persulfate Sonolysis UV Permutations Pyrolysis Mechanochemical Degradation Hydrothermal Alkaline - HALT

Operational Concerns

- Flexibility
  - Changing regulations means new equipment – how to adjust?
- System Costs
  - Replacement media, backwash or other waste, residuals disposal
- Training
  - Can staff work with equipment – finding new staff?
  - Operator certification
- Operator Friendliness
  - Monitoring/Flow volumes
  - SCADA or Phone Apps
  - Media accessibility/changeouts – storage onsite and delivery issues
  - Tools needed
  - Testing
- Ease of Installation
  - Tanks or inside a building
  - Piping changes – welding or plastic
- Adaptability
  - How flexible is each process to continual changes in treatment requirements/New permit limits?

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Current Liquids Treatment Technologies
(Usually Treatment Trains)

- Separation Technologies
- Most Amenable to Leachate Treatment
  - Activated Carbon
  - Resin
  - FluoroSorb/Mixed Media
  - RO
  - Deep Well
  - Foam Fractionation

Source: NH Business Review 2018v

Source: Australian DOD 2018

GAC

Operational Issues

Technology	Pros	Cons
Granular Activated Carbon 	• Effective for Long Chain PFAS • Simple to Operate • Simple to Change Media (Service) • Can be reactivated and reused • Many vendors/suppliers • Relatively temperature insensitive • Treated flow for dust control	• Needs RSSCT Test to evaluate breakthrough • Large Quantities of spend media • Needs good pretreatment - Ultrafiltration, biological treatment (Pretreatment requires treatment waste disposal) • Short chains PFAS breaks through quicker • After saturation, needs changeout - can be frequent • Washout of media, especially after changeout, contains PFAS. Therefore, need backwashing after changeout • Flow sensitive to prevent channeling/rat-holing • Activated carbon may become fouled biologically reducing effectiveness. May need to bleed bleach • Specialized equipment to prevent dust generation and uniform distribution in tanks • Can be resource intensive over long times for testing and replacements

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Operational Issues

Technology	Pros	Cons
Ion Exchange Ion Exchange Resin 	• Can remove most compounds, GenX • Not flow sensitive • Short detention time compared to other adsorbents • Lasts longer than Activated Carbon, so less frequent changeout or regeneration • Relatively temperature insensitive	• Needs Pretreatment and often Post treatment • Other constituents interfere – iron, chlorides, TSS, etc. • When will breakthrough occur? • Regeneration at site of offsite, or disposal. • If regenerated, results in concentrated PFAS stream • Biological fouling • Add bleach – may cause some IX to foul or become "blocky" – Gel types • Replacement media very costly

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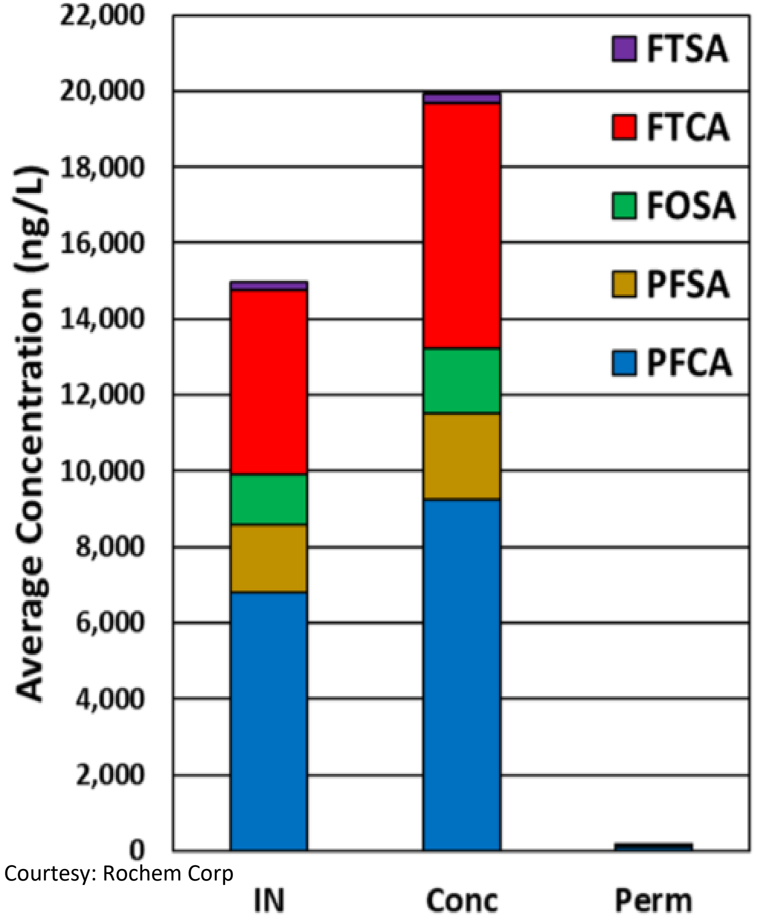
Reverse Osmosis Leachate Process Flow

- Membrane Based Separation Process- 99.9% removal +/-
- Separates Water from Organic and Inorganic Compounds.
- Effluent for reuse or disposal.
- What to do with Reject???
  - Recirculation returns the contaminants to the landfill.
  - Solidification
  - Evaporation – Crystallization
    - Heat needed
    - Air Emissions
  - Other –
    - Electrochemical Oxidation
    - Plasma



Courtesy: Rochem Corp

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Operational Issues

Technology	Pros	Cons
Reverse Osmosis, NF	• 2 or 3 stage very effective • Robust monitoring available • Some Mfg. do not require pretreatment (filters on skid) • Membranes last years • Permeate reuse on site for dust control	• Requires high pressures – big amp draw • Problems with high TDS – permeate percentage reduced • Generates large amounts of reject to manage • Fouling - Cleaning frequency/chemicals • Requires housing in a building • Depends on membranes, may not remove all PFAS • May need to be chained with other technologies

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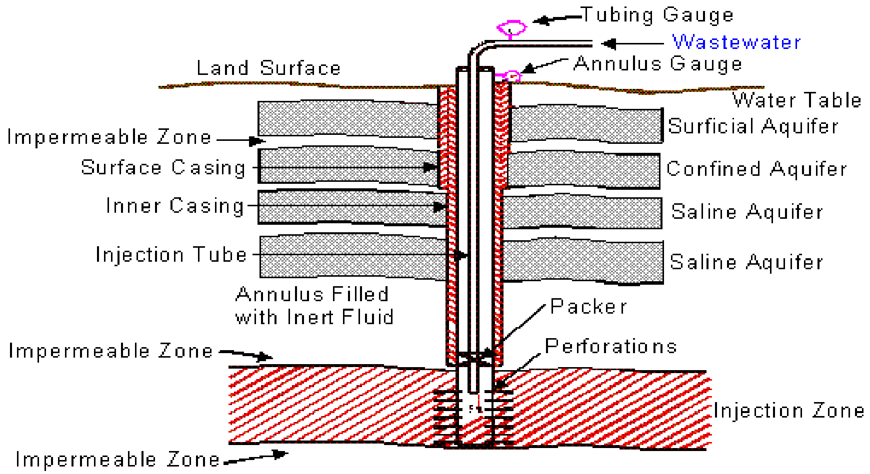
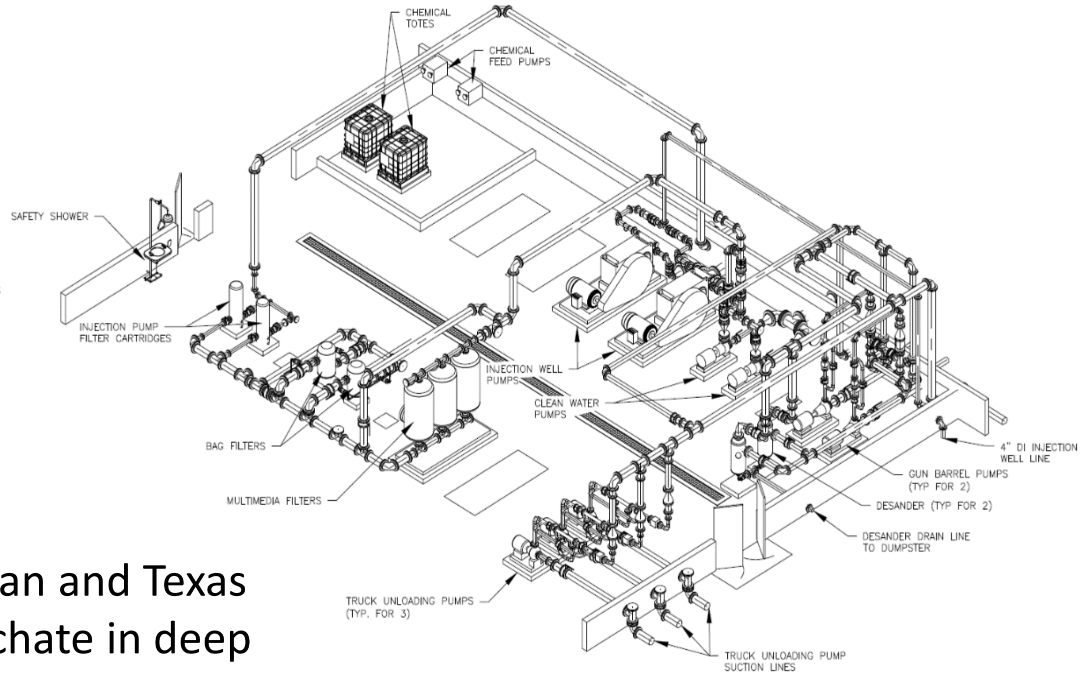
Deep Well Injection

- Depends on Geology, Receptors, Seismicity
- Long, Expensive Permit Time
- Pretreatment/Filtration, Ion Removal
- High Pressure Pumps



Sites in Michigan and Texas dispose of leachate in deep wells



Operational Issues

Technology	Pros	Cons
Deep Well Injection	• Others manage disposal • O&M may be low	• Pretreatment to prevent clogging formation • Manage pretreatment residuals • CAPEX Can be costly • Needs nearby disposal well • Manage hauling trucks

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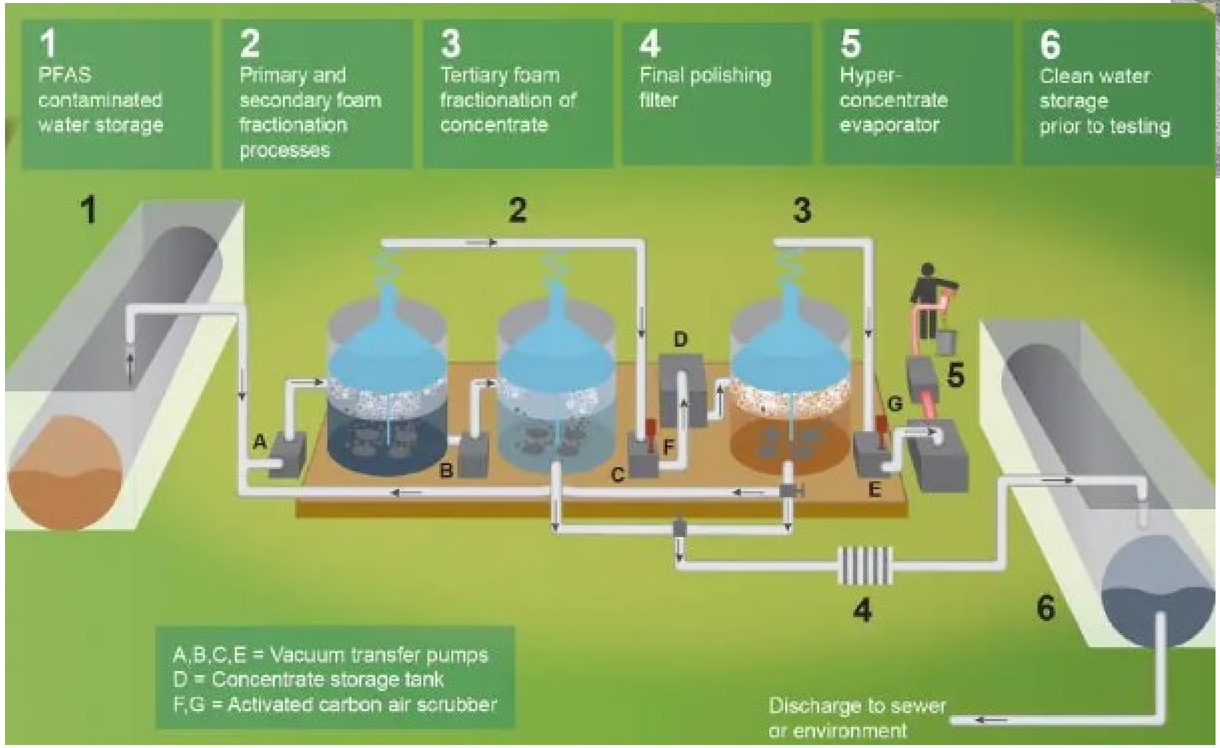
Foam Fractionation

- Removal of six Massachusetts PFAS to below drinking water standards



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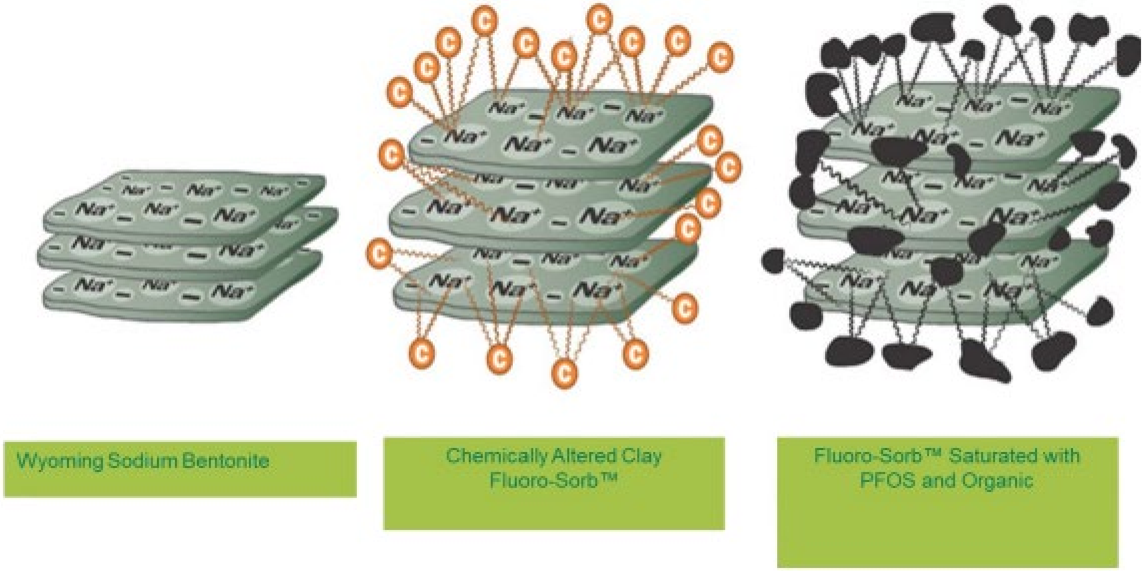
Operational Issues

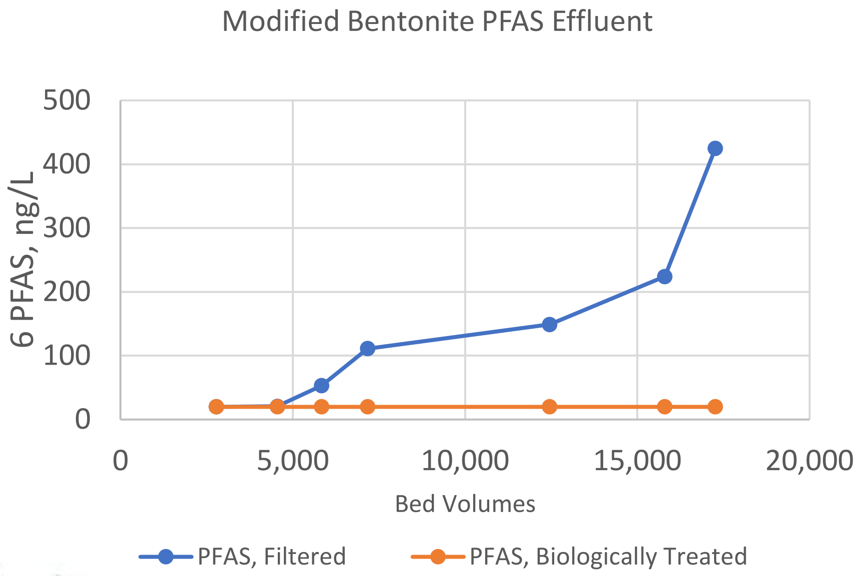
Technology	Pros	Cons
Foam Fractionation	• Commercially available • Internet support for process monitoring and changes • Comes in 40-foot containers • Can be located outdoors • Low operating costs • Low volume concentrate –needs solidification/destruction	• Pretreatment recommended • Incomplete removal of all PFAS • Skimming and disposal of foam • Residual concentrated PFAS disposal/destruction • Possible additional treatment of FF leachate/combined treatment • Reactor plugging by fluoride salts • Vary operational parameters by aeration rate, pH, temp. salinity, surfactants, stability, quality foam

Surface Modified Bentonite (Adsorbent)

- 3 minute EBCT

FLURO-SORB® 200 adsorbent





Courtesy: Cetco

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Operational Issues

Technology	Pros	Cons
Surface Modified Bentonite (FluoroSorb)	• Commercially available • Monitor flow and pressures • Clay plates separate and give longer life • Longer bed life than activated carbon • Research active – improvements coming!	• Pretreatment recommended • Focus on PFAS, no removal other constituents • Better at removal of long chain than short chain • PFHxS, others often bleeds through • Static bed versus fluidized bed installation • Replacement of media • Treatment of expended media • May bleed PFAS if not stabilized • Possible post-treatment of leachate

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Evaporation

Courtesy: Heartl;and

Courtesy Encon Evaporators

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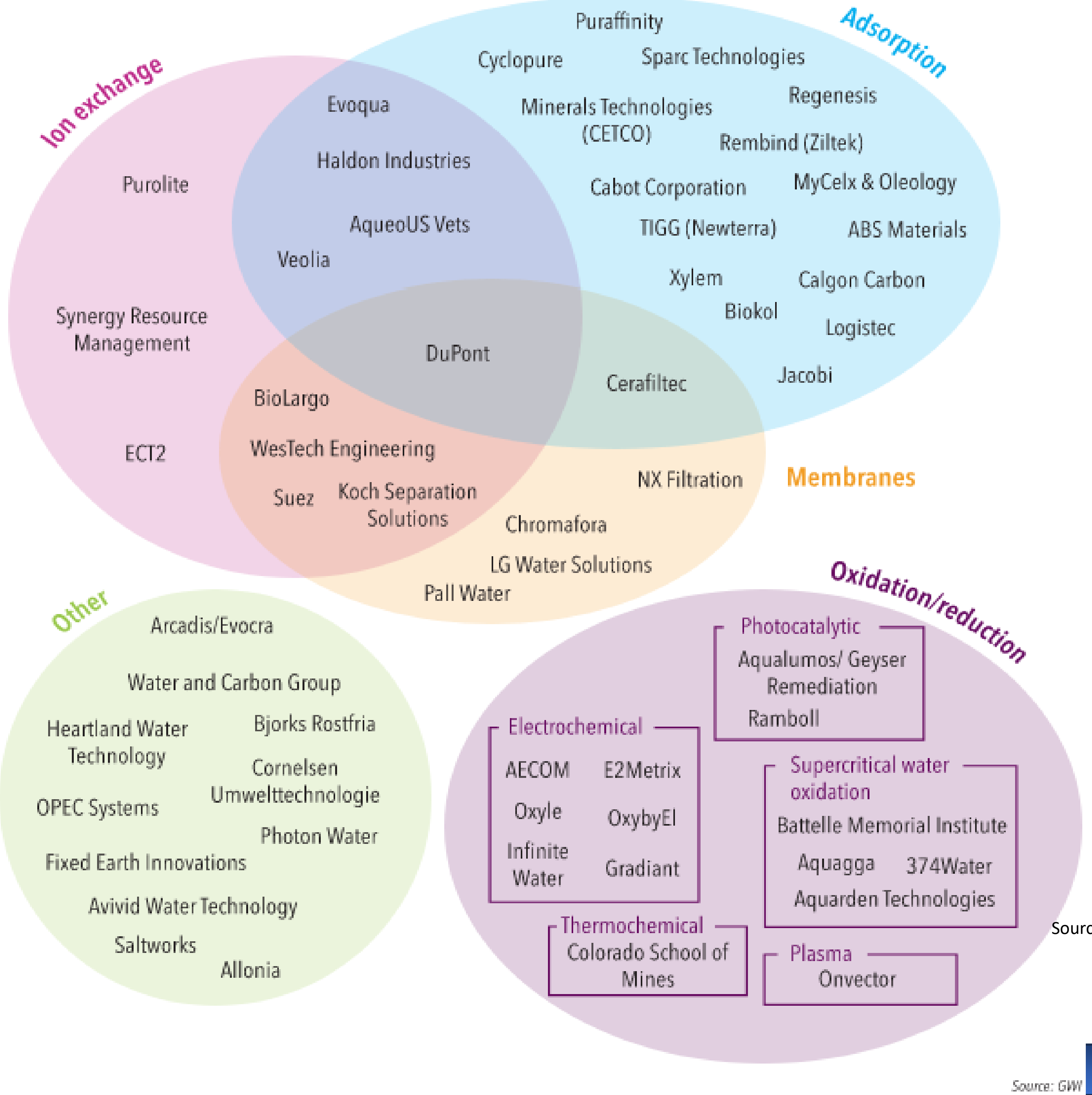
Operational Issues

Technology	Pros	Cons
Leachate Evaporators	• Mature designs • Significantly reduces volumes • May be candidate for residuals or entire leachate flow	• Costly • Significant design/construction time • Large energy consumption • Needs concentrate management • May not remove all PFAS • Some may be emitted in exhaust • Visual plume maybe objectionable • Public perception

Residuals Technologies

- Destruction
  - Incineration
  - Plasma
  - Supercritical Water Oxidation
  - ElectroChemical Oxidation
  - Deep Well Injection
- Stabilization/Solidification
  - Cementitious S/S
    - Encapsulation (In totes or vessels)
    - Holcim/ADC
  - Return to the landfill
  - Hazardous Waste Landfill Haul and Dispose

Current PFAS Market Players



Source: PFAS treatment market concentrates on waste reduction and total destruction, GWI, May 2021

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Cost Opinion of Various Leachate Pretreatment Alternatives

Major Process Description	Flow Rate	Low CAPEX Less 20%	Mid - Opinion	High CAPEX Plus 100%	Annual OPEX	Treatment System Life Cycle Cost - Present Worth	Mid opinion annual Capital Recovery Factor (CRF) = 0.087186	Combined Annualized Cost, CRF + OPEX	Treatment Cost/Gal
Leachate Ultrafiltration Filtration + GAC	10,000 gpd	$3,714,000	$4,642,000	$9,284,000	$524,000	$10,700,000	$405,000	$929,000	$0.25
Leachate MBR + FluoroSorb	10,000 gpd	$4,252,000	$5,315,000	$10,630,000	$635,000	$12,600,000	$463,000	$1,098,000	$0.30
Leachate RO with Concentrator	10,000 gpd	$8,875,000	$11,094,000	$22,188,000	$697,000	$19,100,000	$967,000	$1,664,000	$0.46
Leachate Foam Fractionation	10,000 gpd	$5,341,000	$6,676,000	$13,352,000	$286,000	$10,000,000	$582,000	$868,000	$0.24
Leachate Zero Liquid Discharge Evaporator	10,000 gpd	$6,266,000	$7,833,000	$15,666,000	$1,199,479	$21,600,000	$683,000	$1,882,479	$0.52

CAPEX Leachate Treatment @ 10,000 GPD

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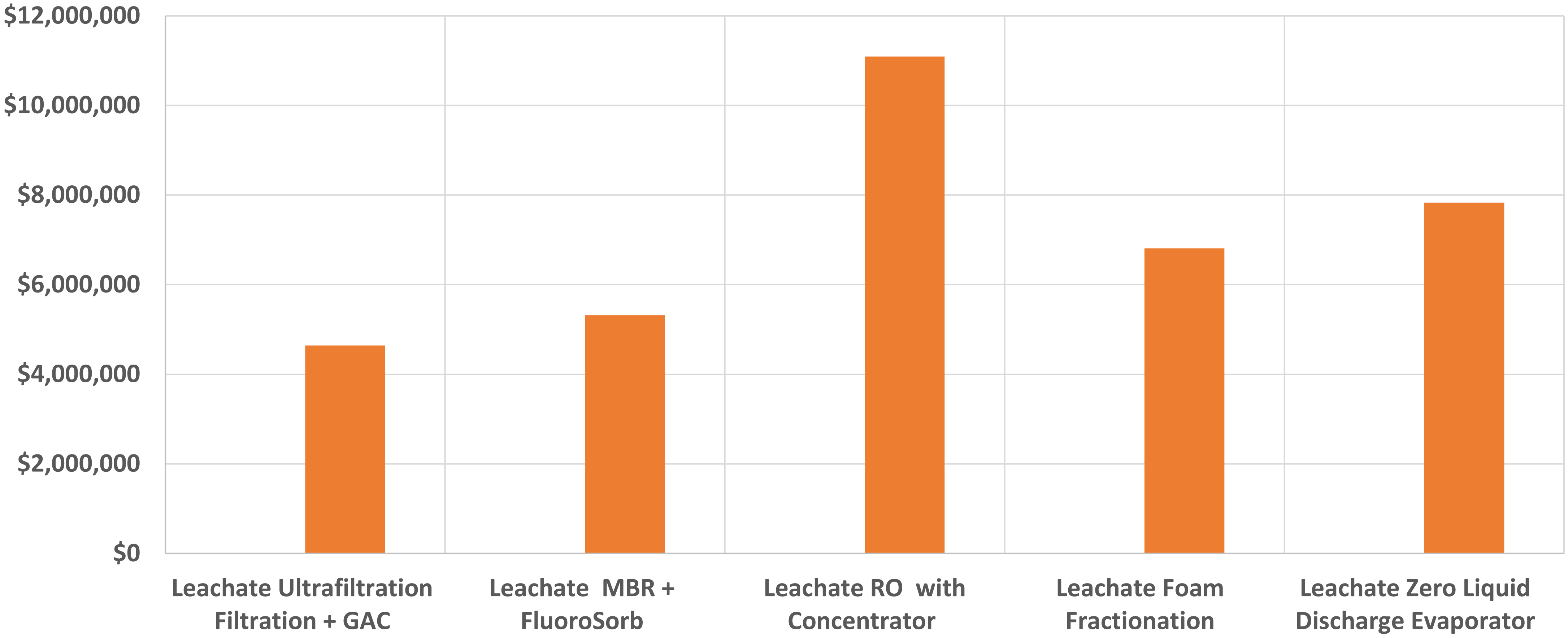

CAPEX Impact of Size on Costs Based on Foam Fractionation

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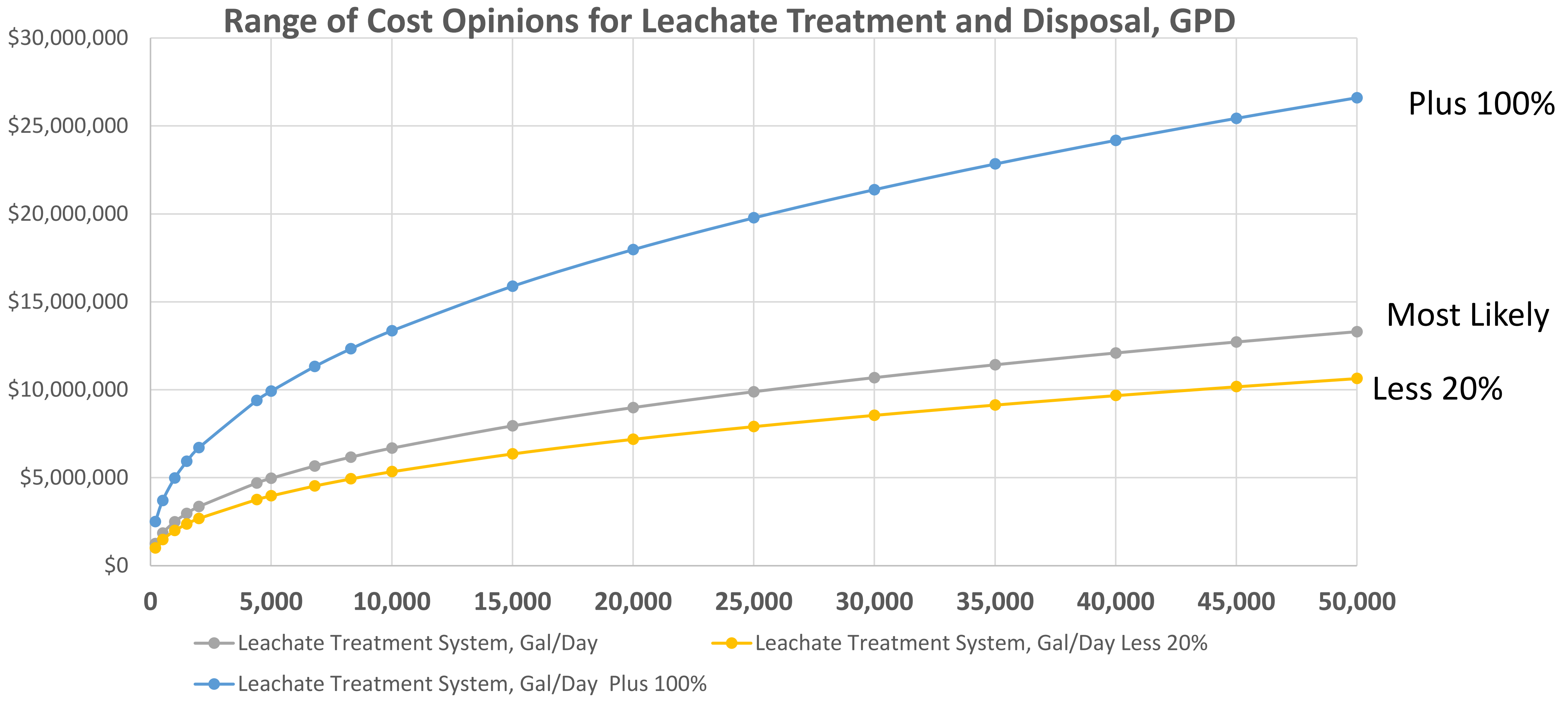
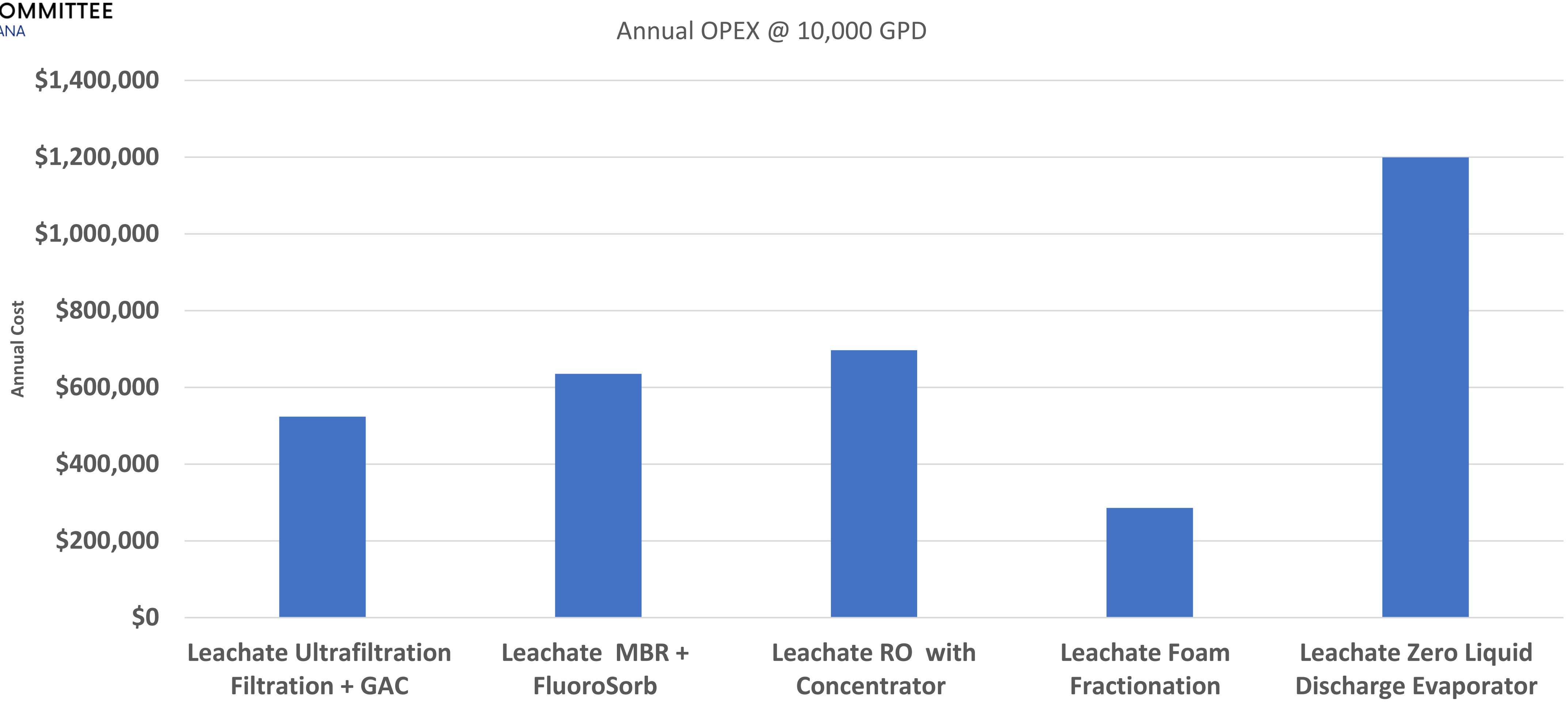


Annual OPEX @ 10,000 GPD



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Landfill Leachate PFAS Treatment and Disposal Cost/Gal (CAPEX and OPEX) @ 10,000 GPD

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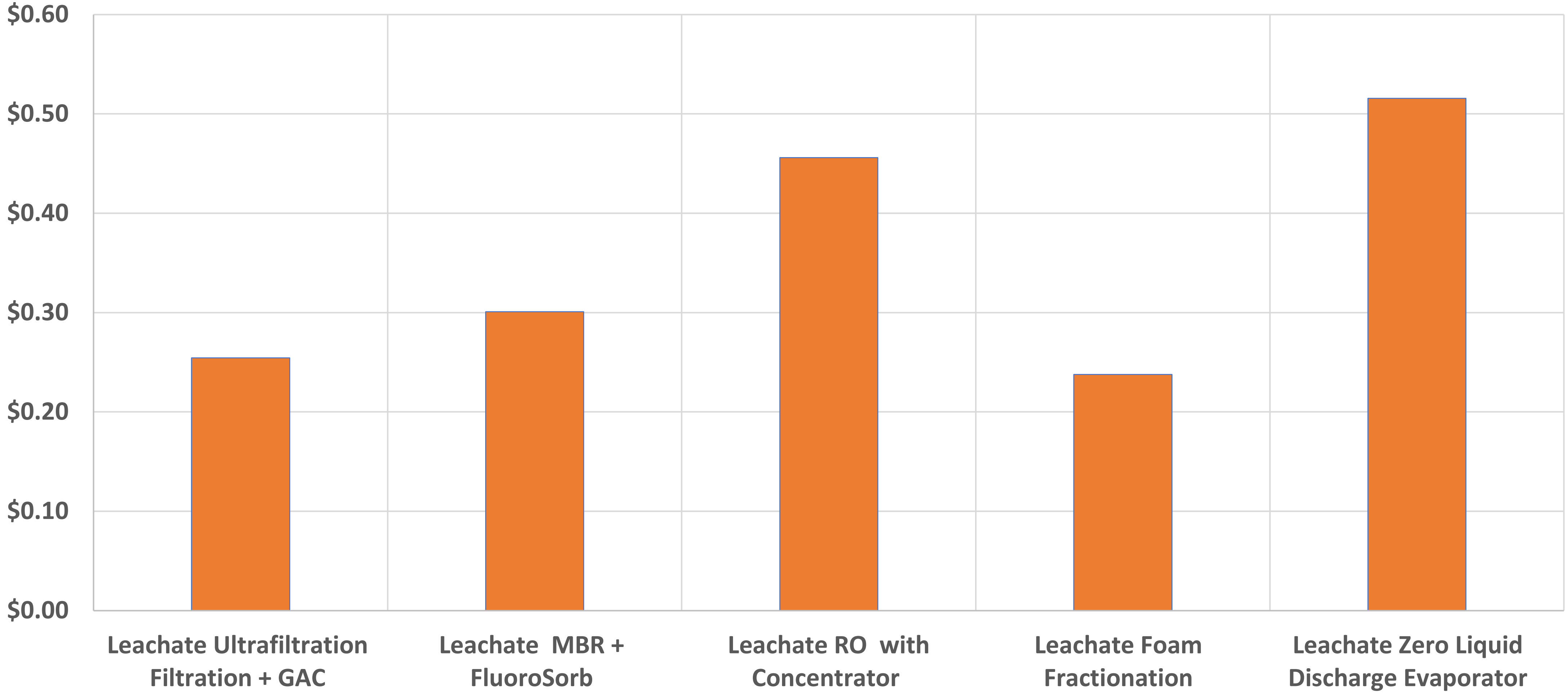

Treatment Challenges

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- Carboxylates (ex. PFOA) harder to remove than Sulfonates (ex. PFOS)
- Longer chain easier to remove/destroy than shorter chain
- Many technologies focus on longer chain, shorter chain problematic
- Many technologies require multi step processes , time to permit & construct!!!
- Mixtures, precursors, co-contaminants means more testing
- Energy intensity means more costs
- Limited field-scale examples
- Life cycle costs?
- More testing and operations time

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Questions?

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Residuals Technologies

- Destruction
  - Incineration
  - Plasma
  - Supercritical Water Oxidation
  - ElectroChemical Oxidation
  - Deep Well Injection
- Stabilization/Solidification
  - Cementitious S/S
    - Encapsulation (In totes or vessels)
    - Holcim/ADC
  - Return to the landfill
  - Hazardous Waste Landfill Haul and Dispose

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Incineration

- EPA – 99.99% destruction at 1,400 deg C at 1 second detention time
- DOD banned for a time

Courtesy Heartland Heliostorm

Operational Issues

Technology	Pros	Cons
Incineration	• Monitor flow, turbulence, temperature • Possible complete PFAS destruction • Ship to offsite incineration • Mobile vendors can make periodic visits to manage stored concentrate to avoid costly construction • Heartland's Heliostorm operates at 3,000 deg C – more complete destruction?	• Startup/shutdown procedures • Long time to permit/construct • Fuel usage • Visual emissions/public concerns • Possible recombining to other larger molecules • Public concerns • Expensive to install, operate, maintain

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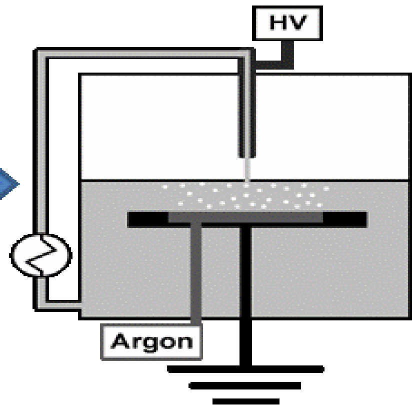
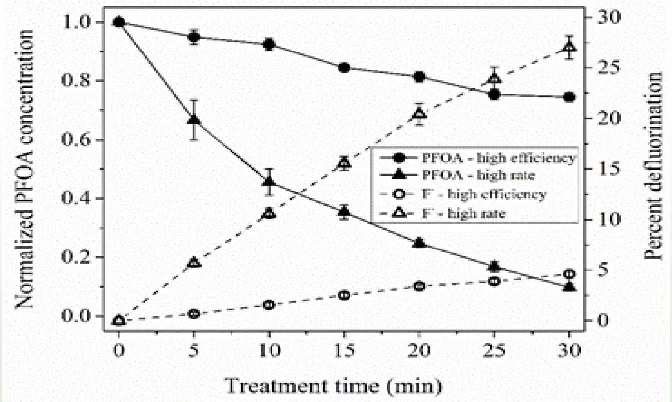
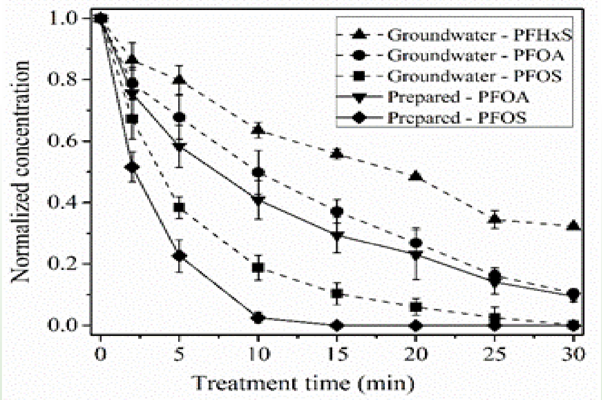
Plasma Destruction

Bench-scale enhanced contact plasma reactor



Plasma produces aqueous electrons and H radicals which are capable of chemically degrading PFASs



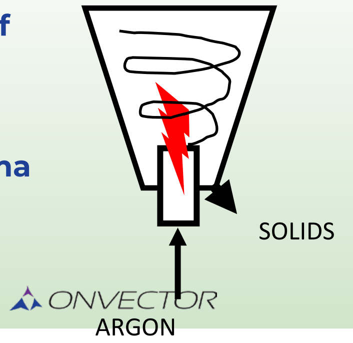


Major byproducts: fluoride ions, fluorinated gases and shorter-chain PFAAs

Plasma hydrocyclone
Water enters tangentially at the top, spins down, then exits at the center top forming a reverse vortex tornado flow.

Cyclonic separation of solids

Recirculation of plasma carrier gas (argon)



Operational Issues

Technology	Pros	Cons
Plasma Destruction	• Monitor flow and pressures • Daily operations may be minimal • Best used for small volumes of concentrated PFAS removed by other processes (i.e., Foam Fractionation) • Possible complete PFAS destruction	• Under development • May not remove or destroy all PFAS • Long term operation requirements unknown • Treat off-gas (Caustic or Carbon?) • Power - Free and hydrated electrons in plasma (reductive reactants) break C-F bonds due to their very high energy (50 to 100 eV)

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Supercritical Water Oxidation (SCWO)

- Water above 705ºF and 3,200 lbs/in^2 - Rapidly destroys PFAS
- >99.99% removal under 10 seconds or less
- If organics, no additional fuel needed
- Creates HF – needs neutralization

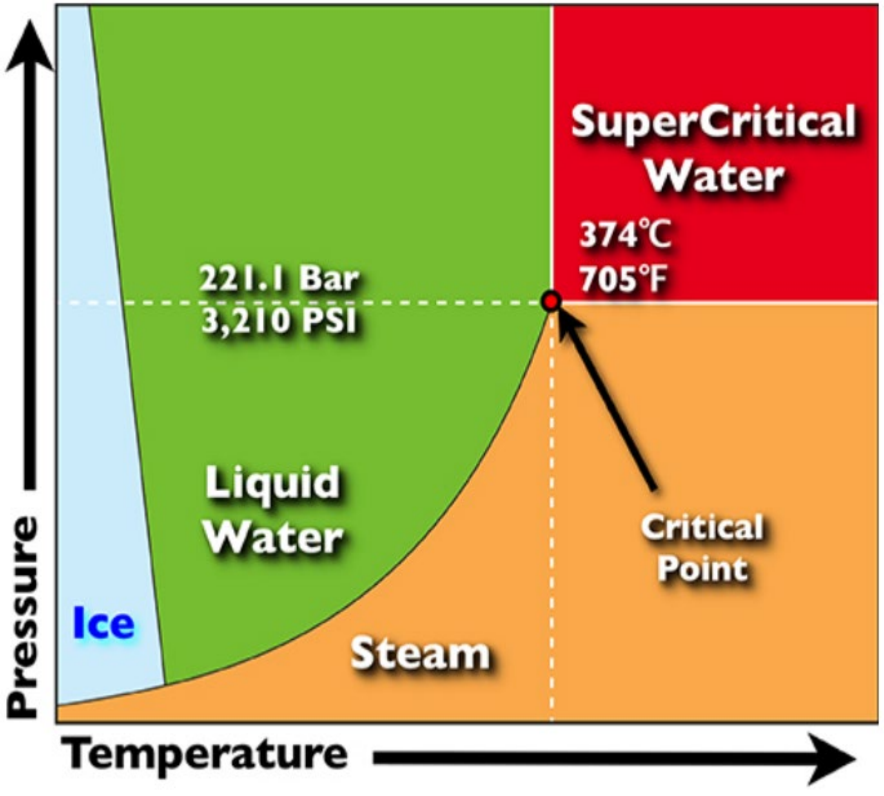

Figure 1. *SCWO reactions occur above the critical point of water. Image credit: Jonathan Kamler.*

EPA, Jan 2021

Operational Issues

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Technology	Pros	Cons
Supercritical Water Oxidation (SCWO)	• Monitor flow and pressures, gas emissions • Daily operations may be minimal • After initial Temp/pressure, may not require more energy • Best used for small volumes of concentrated PFAS removed by other processes (i.e., Foam Fractionation) • Possible complete PFAS destruction – results in inert ash • Several vendors available	• Limited Suppliers • Costly to run – depends on waste stream • Corrosive gases - HF -Treat off-gas (Activated Carbon?), sequestering with calcium • Long term operation requirements unknown • May not removal all PFAS • Materials of construction • High Pressure/temperature • High energy - Free and hydrated electrons in plasma (reductive reactants) break C-F bonds due to their very high energy (50 to 100 eV)

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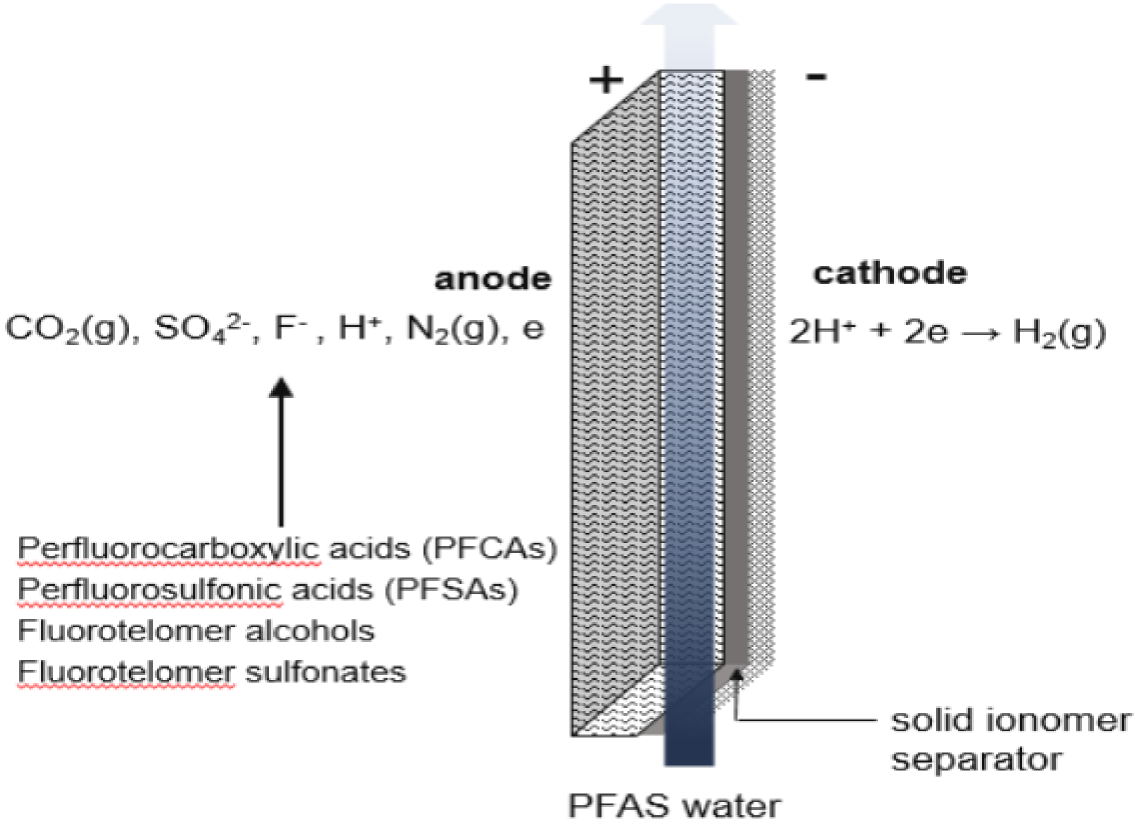
Electrochemical Oxidation

Various Equipment designs



- Several Vendors
  - ECT2; Aclarity; Sanexen; Siemens; OXbyEL; others
- Power Requirements:
  - 0.125 - 0.5 kwh/gallon
  - 6 volts produces free electrons
- Electrode materials
  - Titanium; boron doped diamond
- Single pass v. multiple pass
- Destroys ammonia too!

Operational Issues

Technology	Pros	Cons
Electrochemical Oxidation	• Monitor flow and power feeds, gas emissions • Daily operations may be minimal • Operates at ambient temperature • Small footprint • Several vendors available	• May need pre and post treatment may be required • Long term operation requirements unknown • Replacement materials – Expensive electrodes • Generates toxic products, HF, Perchlorates formed ?– removal control • Long processing time for PFAS destruction • Power requirements

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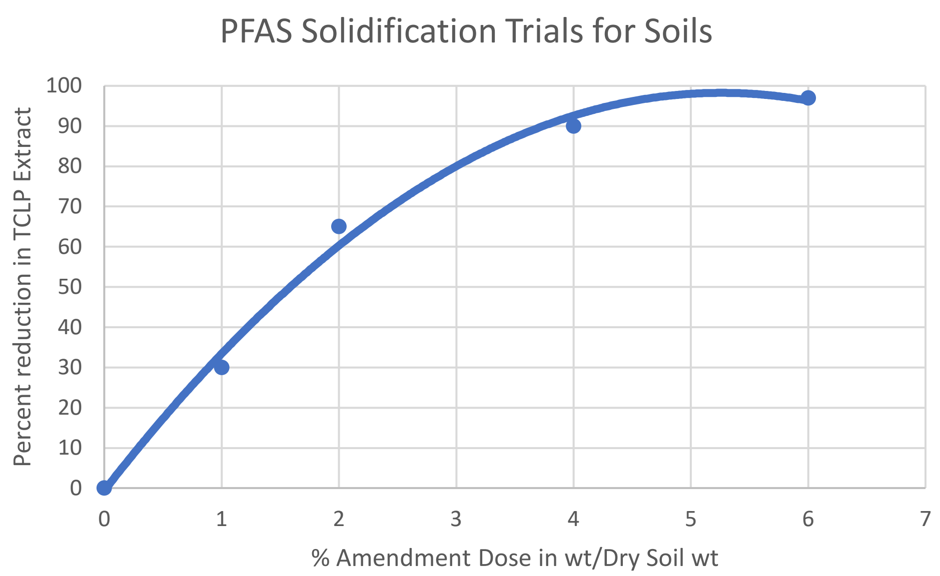
Leachate Residuals PFAS Stabilization

- CEC Solidification of SAFF
- 0.6:1 TCLP 99.9% retention all PFAS



Tests by Dan Cassidy, Western Michigan University - 6% dose Fluoro Sorb achieved < 70 ppt [PFOA+PFOS] in leachate in all soils using TCLP Test.

Techniques:
Mixture of generic S/S amendments known to sorb PFAS*:
Powdered activated carbon (PAC),
Iron oxide (Fe2O3) powder,
Montmorillonite clay,
Ground-granulated blast-furnace slag (GGBFS), and
Portland cement (PC)
Fluoro Sorb

Disposal:
Landfill
Alternate Daily Cover

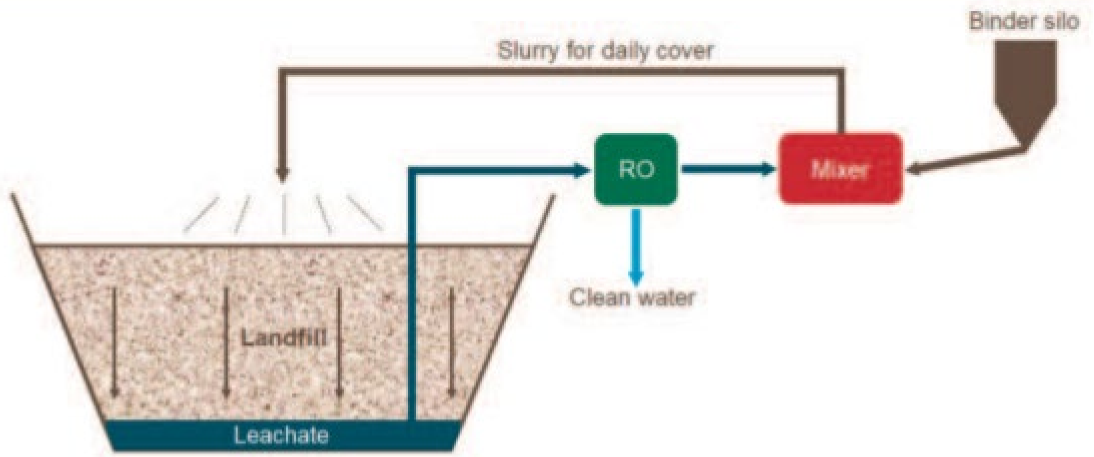
[PFOS] = **14,000 -** 100,000 ng/Kg
[PFAS] = 2,500 – 17,000 ng/Kg

Tested with Fluoro Sorb from Cetco

Fixation of Residuals (Holcim/Lafarge)

- Proprietary cement binder
- No free liquid (Paint Filter Test)
- Friable for use as Alt Daily Cover

MAR- Enviroset	As Received	SPLP
	Results	Results
Sand	ppt (ng/L)	ppt (ng/L)
PFNA	800	11
PFOS	4,900	63
PFOA	1,500,000	390
NY State-Enviroset		
Sand		
PFNA	500	ND
PFOS	5,900	ND
PFOA	2,400	ND



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Technology	Pros	Cons
Solidification	• Possible disposal back to Landfill • ADF or in blocks • Simple, everyday type operation	• Does not destroy PFAS, but reduces mobility and leachability • Tests to confirm no release • May not be effective on all PFAS • Volume and weight - Mass takes up airspace • Time to cure before disposal • ADC proposed – not commercially used • Possibly costly based on volume of solidification materials