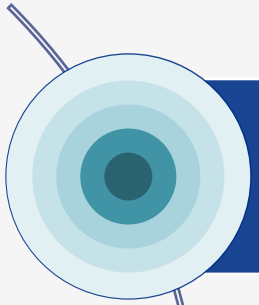
An Overview of PFAS-Relevant Treatment Technologies

Dec 10, 2024

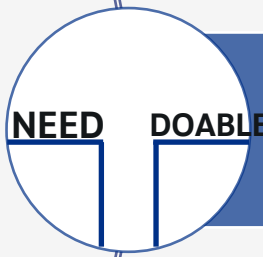
NeBC | northwest environmental business council

CDM Smith

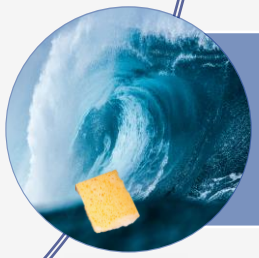
Three Take Home Messages



Concentration Factor represents current state of the practice

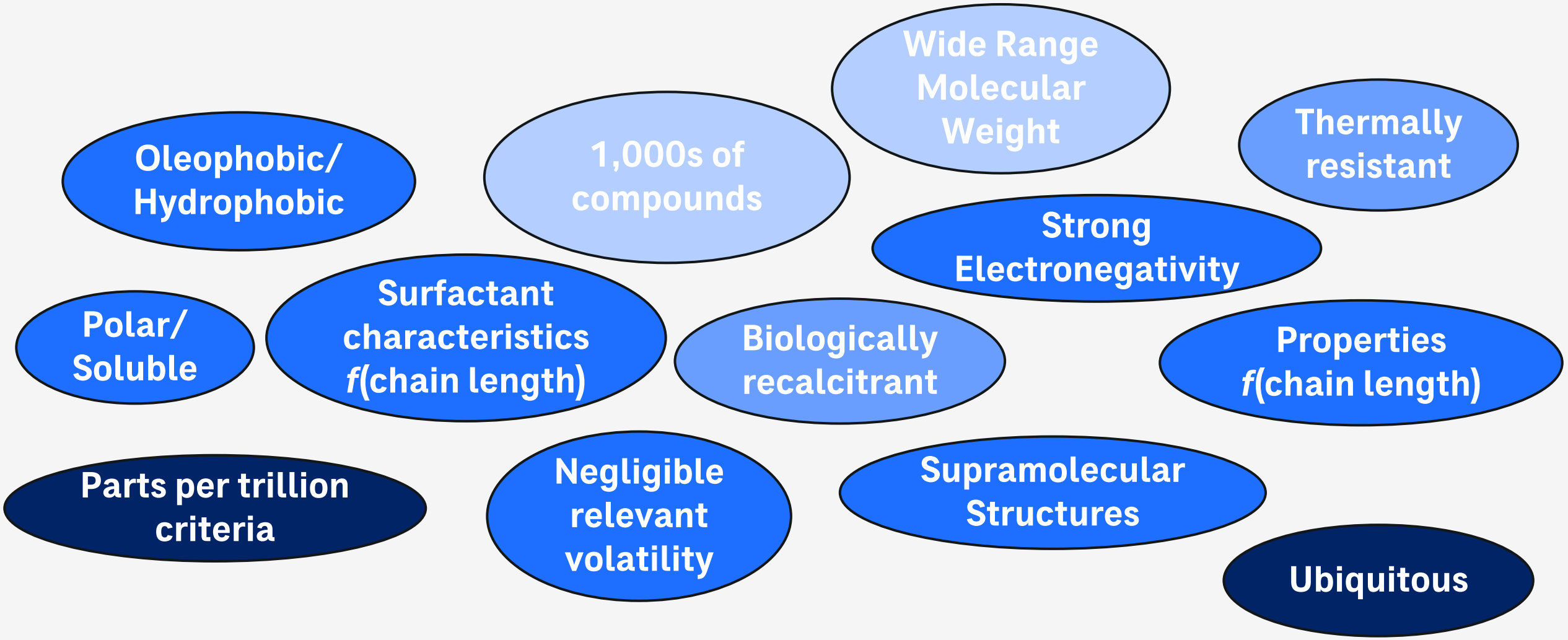


Pragmatic gap between what is needed and what is available



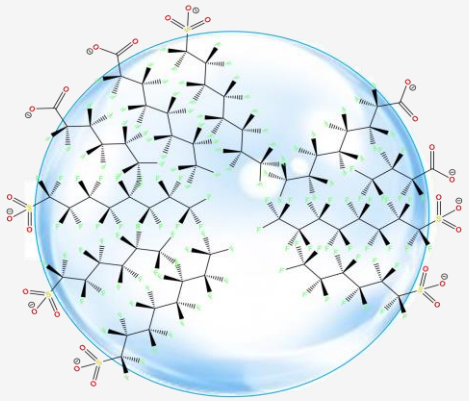
Destruction technology is commercially available, but scale limited

PFAS are different

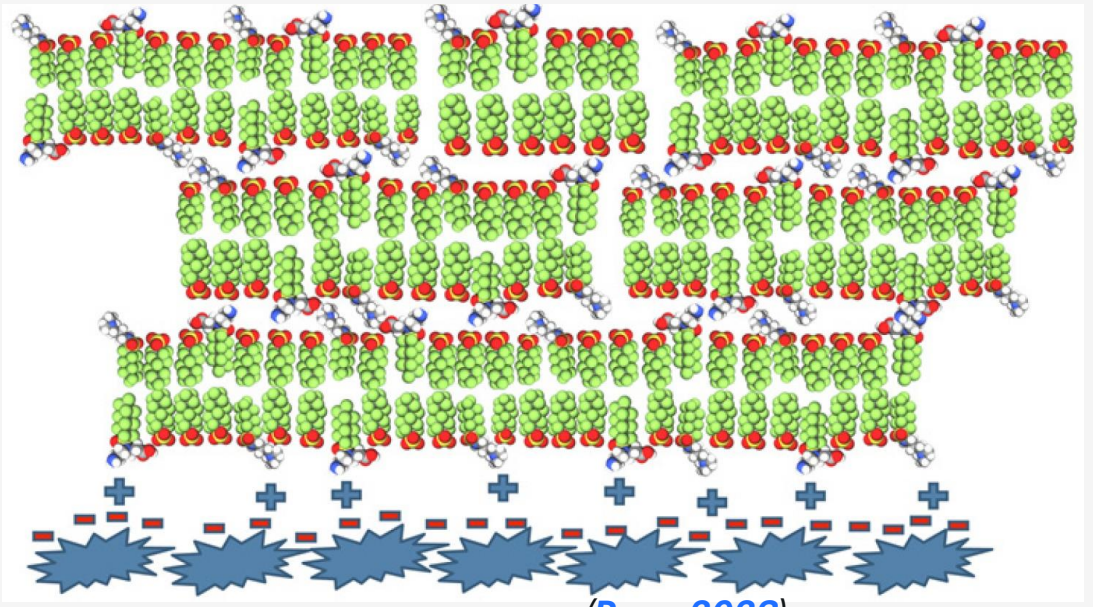


Persistent, Bioaccumulative, Toxic…and Mobile

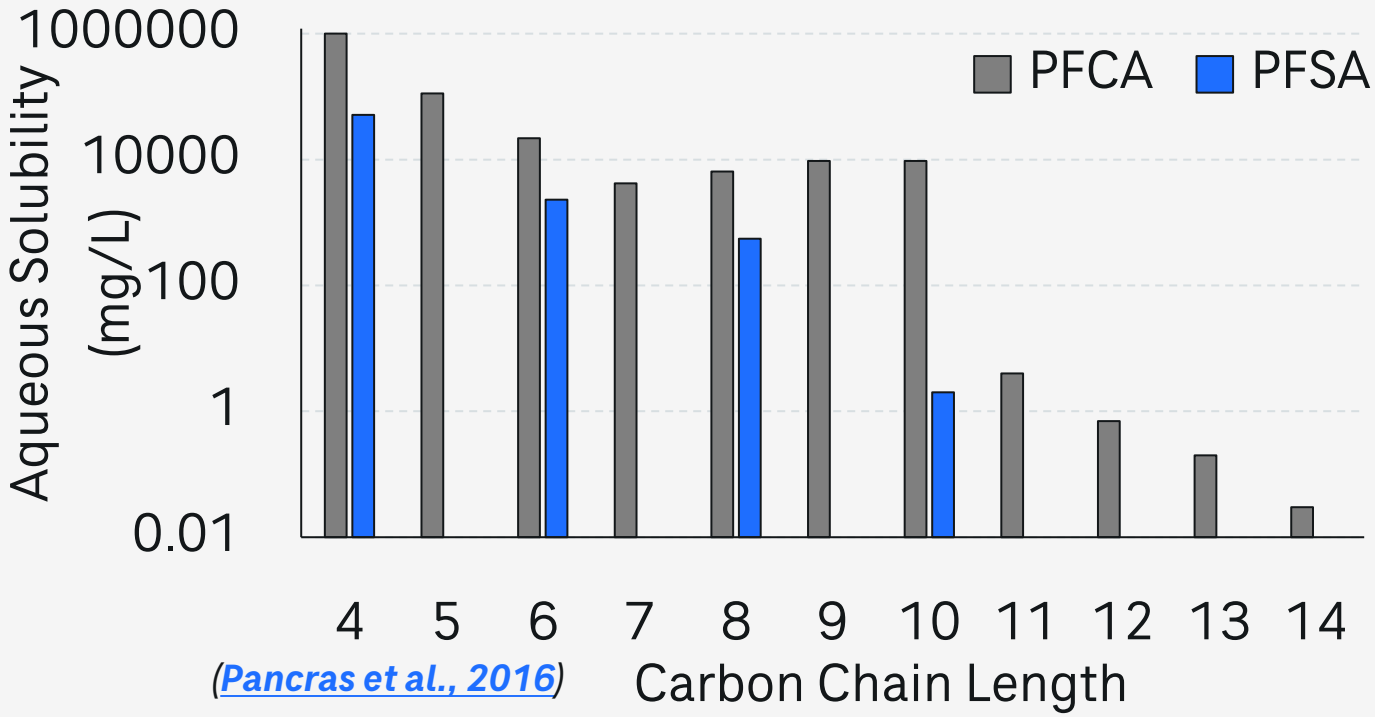
PFAS differences influence treatment



(McDonough and Ross et al., 2019)



(Ross, 2023)

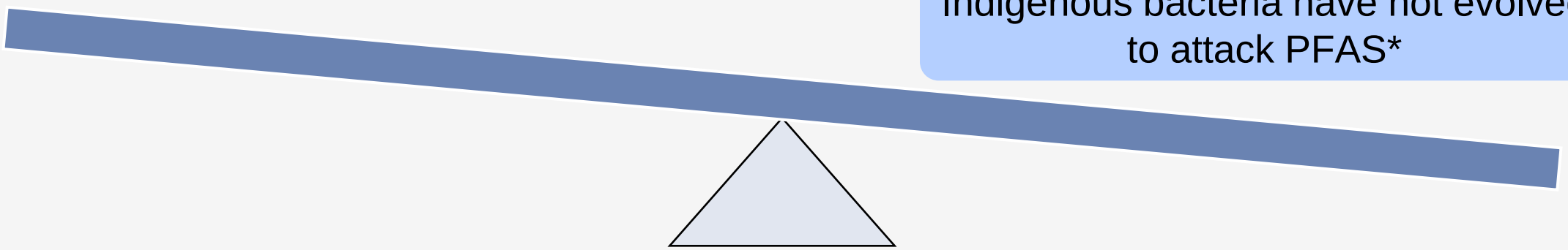


(Pancras et al., 2016)

PFAS differences influence bioremediation

- Unsaturated C-F bonds*
- Feammox*
- Fungal transformation*
- Partial defluorination*

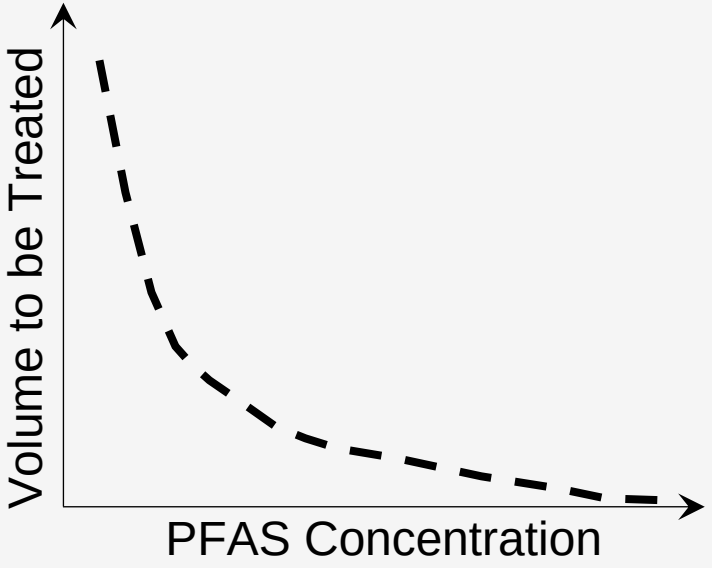
- Plausible alternative explanations*
- Impractical rate kinetics*
- Aerobic/anaerobic competition*
- Electronegativity, C-F density yields stability/recalcitrance*
- Indigenous bacteria have not evolved to attack PFAS*



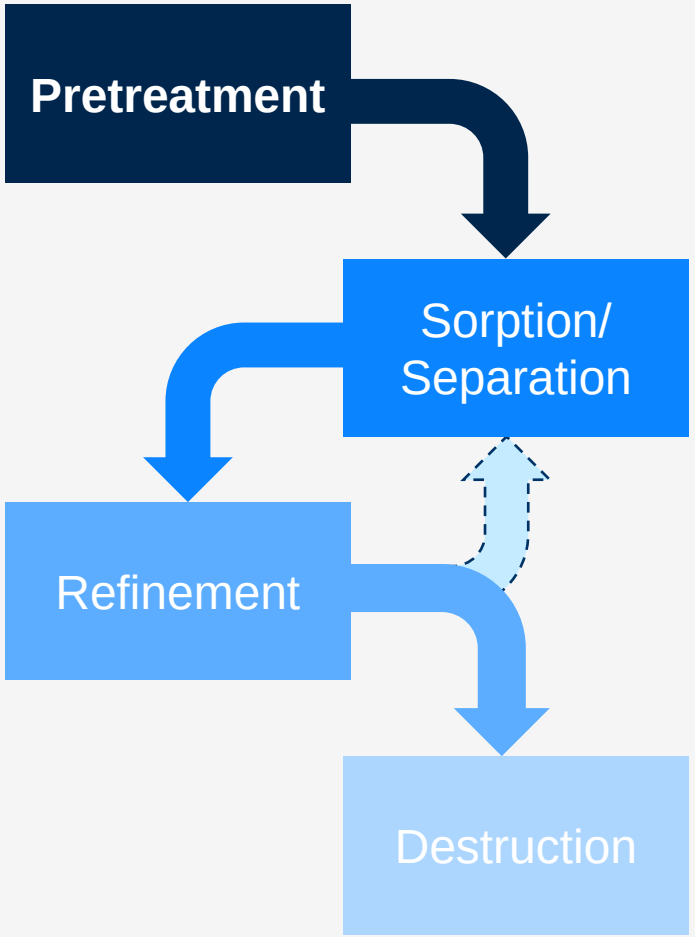
Biological defluorination is not currently a viable remedial strategy

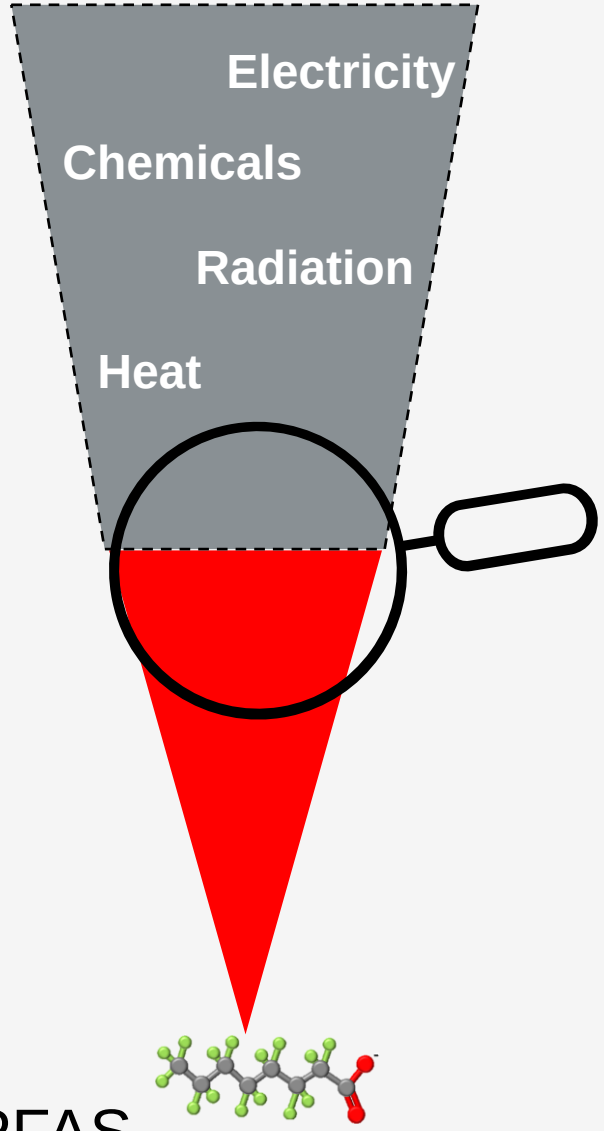
**Citations available upon request*

PFAS Remediation: State of the Practice



*(Modified after **Horst and McDonough et al., 2020**)*

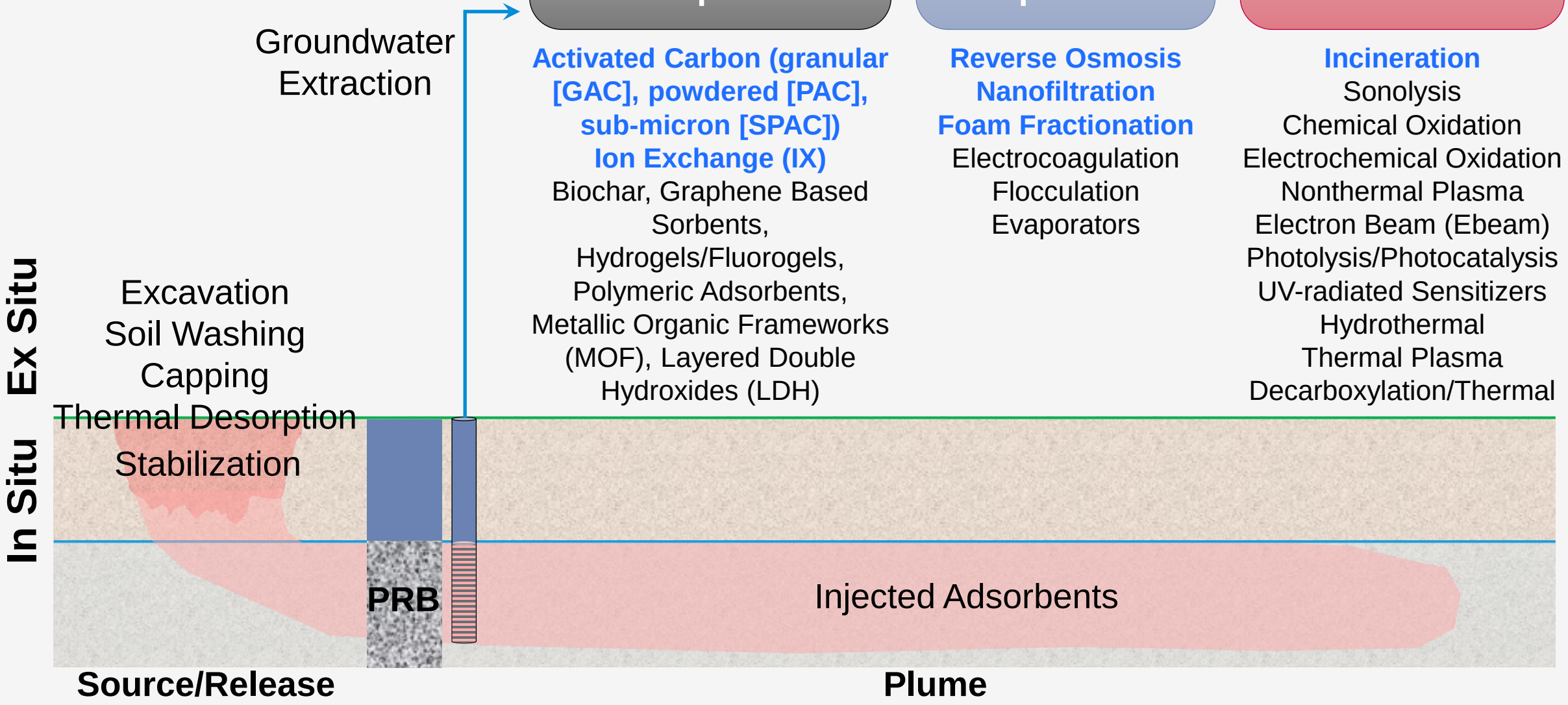




State of the Practice: Serial treatment to concentrate PFAS and reduce the volume requiring energy intensive destruction

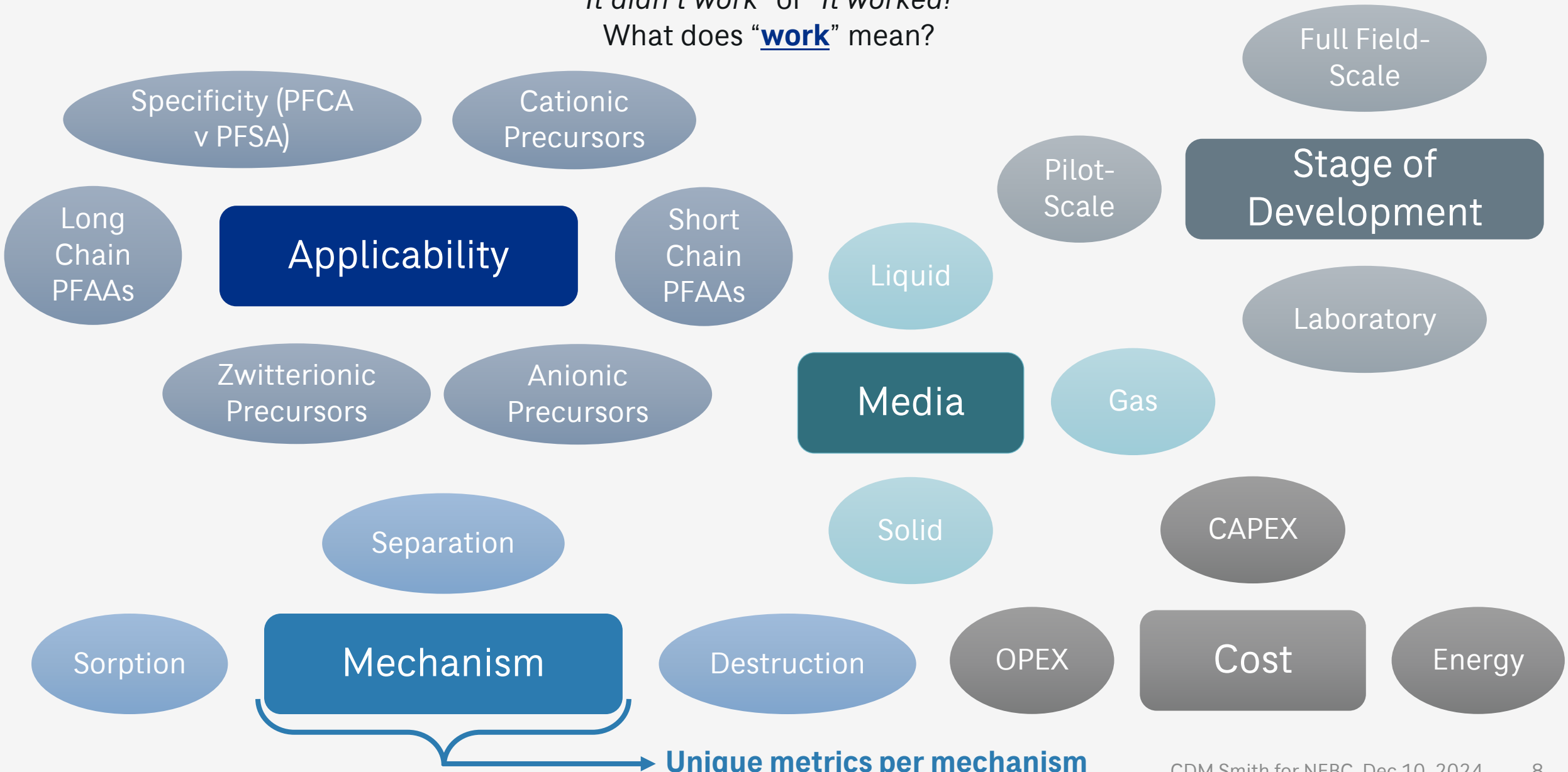
PFAS-Relevant Treatment Technologies

Sorption	Separation	Destruction
Activated Carbon (granular [GAC], powdered [PAC], sub-micron [SPAC])	**Reverse Osmosis**	**Incineration**
Ion Exchange (IX)	**Nanofiltration**	Sonolysis
Biochar, Graphene Based Sorbents, Hydrogels/Fluorogels, Polymeric Adsorbents, Metallic Organic Frameworks (MOF), Layered Double Hydroxides (LDH)	**Foam Fractionation**	Chemical Oxidation
	Electrocoagulation	Electrochemical Oxidation
	Flocculation	Nonthermal Plasma
	Evaporators	Electron Beam (Ebeam)
		Photolysis/Photocatalysis
		UV-radiated Sensitizers
		Hydrothermal
		Thermal Plasma
		Decarboxylation/Thermal



Did it “work?” Pragmatism in a red-hot market

“*It didn’t work*” or “*It worked!*”
What does “**work**” mean?



PFAS-Relevant Sorption: Its not just GAC and Resin!!!

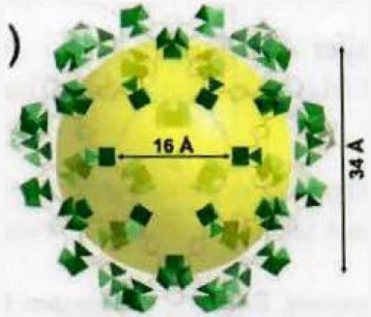
GAC/ Resins	• "Go to" sorbents • Economical, scalable, accepted
Modified clays, biochar	• Fluorosorb®; pyrolyzed cellulose • Available & competitive
Polymeric Sorbents	• CycloPure®; PQ-Osorb®; Puraffinity® • Promising, improving scalability
Experimental	• MOFs[1]; Hydro/Fluorogels; LDHs[2]; 2-phase composites • Esoteric, high sorption capacities

[1]Metallic Organic Frameworks; [2]Layered Double Hydroxides

DEXSORB (Cyclopure 2023)

FluoroSorb (CETCO, 2023)

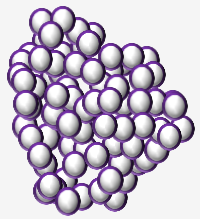
PQ-Osorb (ABS Materials 2018)



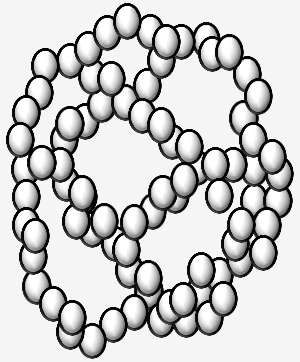
MOF Concept (Barpaga et al., 2019)

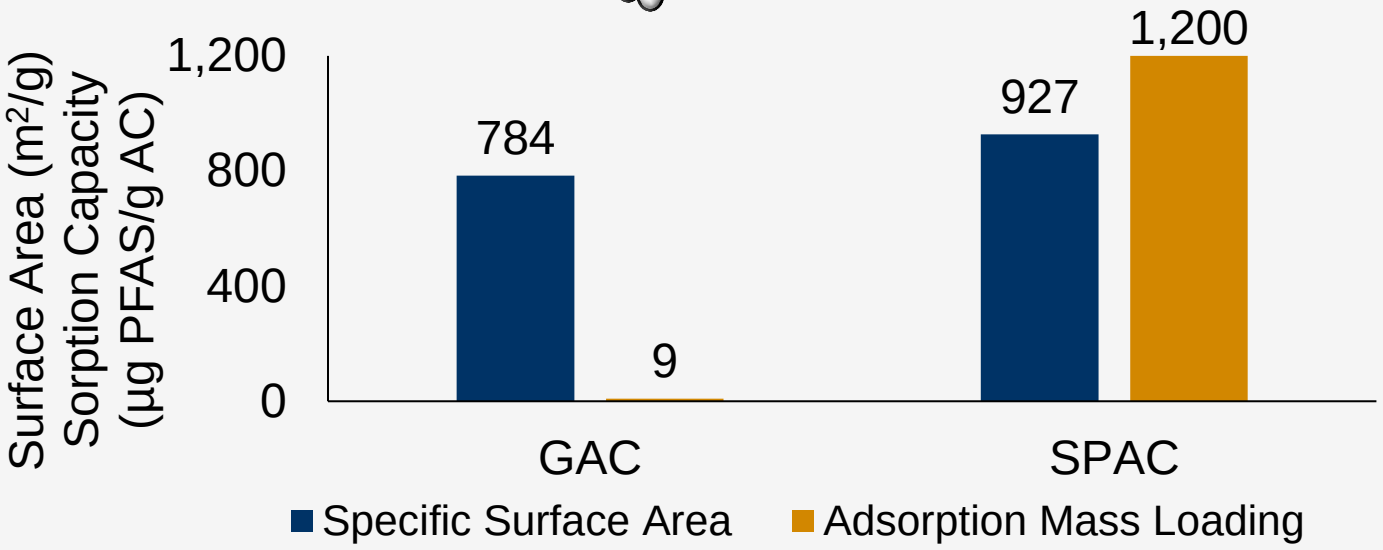
PFAS-Relevant Sorption: Optimization

Increased Access to Surface Area



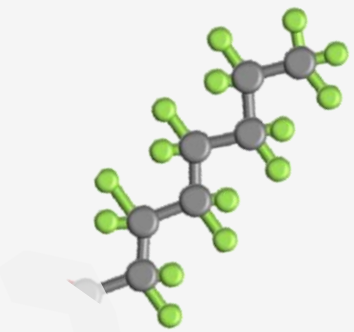
Edmiston 2020



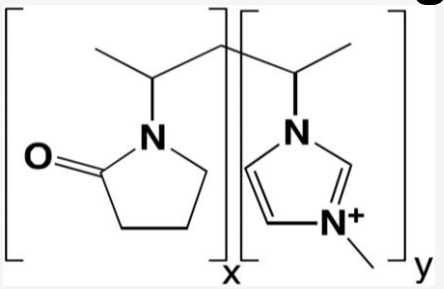


Adapted from [Murry et al., 2019]

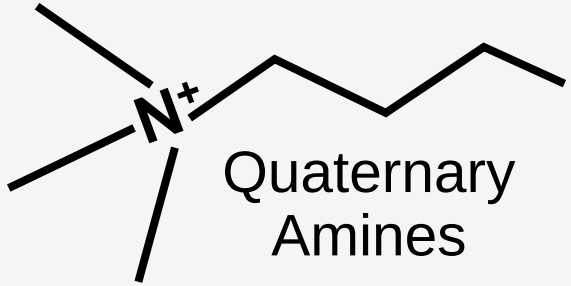
Functionalizing



Perfluoroalkyl moiety



Polymers of Quaternary Amines



Quaternary Amines

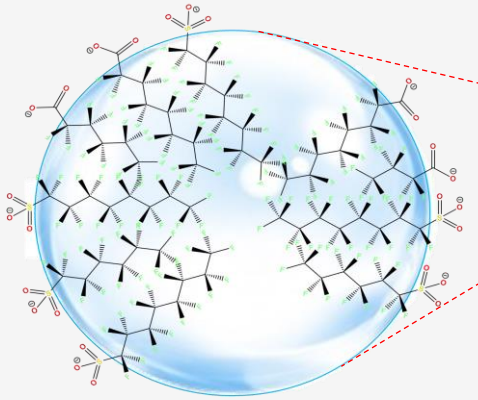
Reactivation (GAC) and Regeneration (other sorbents)

Various solvents

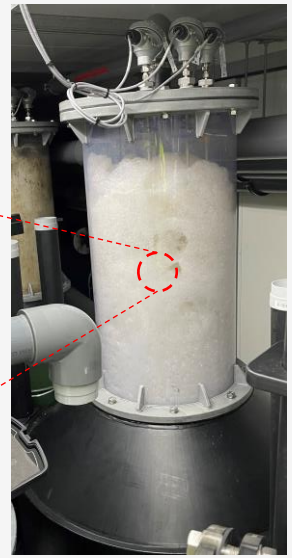
Electro-Sorption/Desorption

Separation Developments

Foam Fractionation

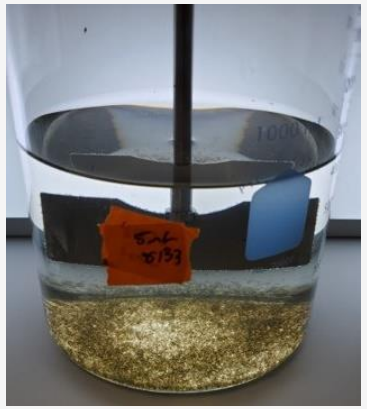


[McDonough and Ross et al., 2019]



Foam fractionate (EPOC, 2023)

Flocculation



Cationic Coagulants (Menkhaus 2020)

[Tan et al., 2023]

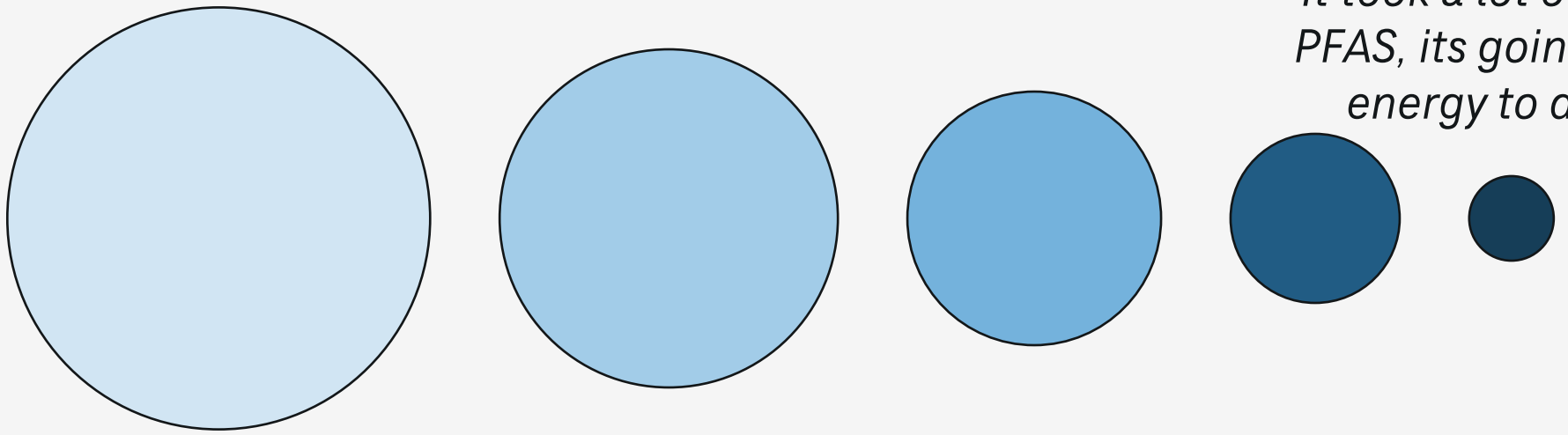
Membrane Separation

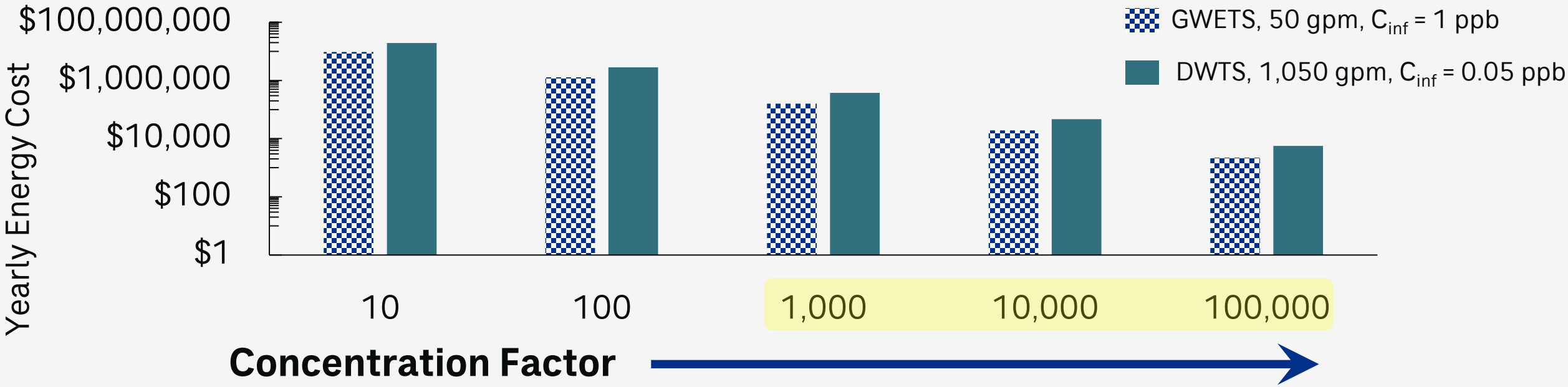
Field-Scale RO (Storch, 2018)

Municipal-Scale RO (Bellona, 2023)

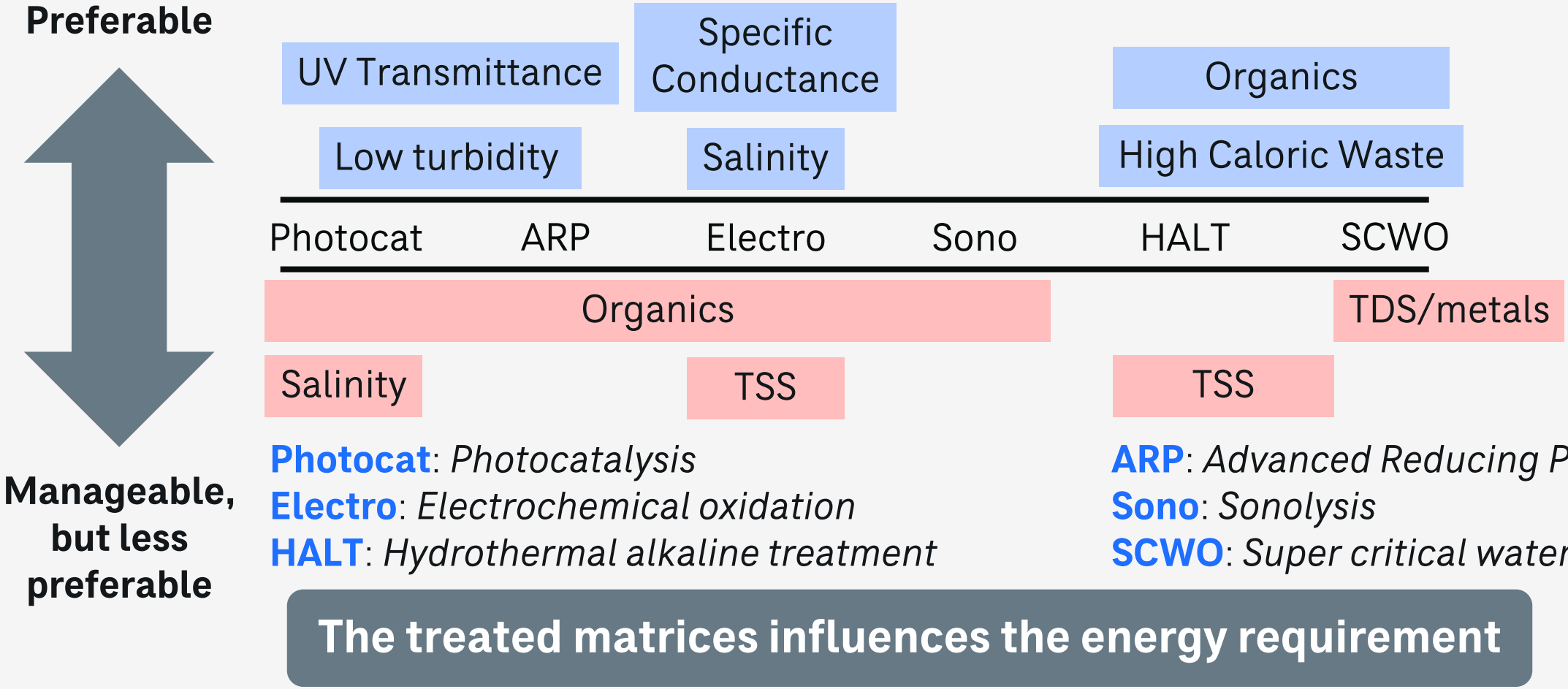
PFAS Destruction is Energy Intensive

"It took a lot of energy to make PFAS, its going to take a lot of energy to destroy PFAS."





The “Best” Technology Will Vary



Photocat: *Photocatalysis*
Electro: *Electrochemical oxidation*
HALT: *Hydrothermal alkaline treatment*

ARP: *Advanced Reducing Processes*
Sono: *Sonolysis*
SCWO: *Super critical water oxidation*

The treated matrices influences the energy requirement

TDS = total dissolved solids
TSS = total suspended solids

Defining Destruction

- Carbon in PFAS is eventually fully oxidized (mineralized) to carbon dioxide (CO_2)
- Fluorine in PFAS converted to fluoride (F^-; hydrogen fluoride [HF])
- Mineralized species will not reform carbon fluorine bonds unlike perfluoroalkyl radicals

Objective is mineralization (not partial defluorination)

Electrochemical Oxidation

(*Aclarity, 2023*)

Hydrothermal

(*Aquagga, 2023*)

Non-Thermal Plasma

(*DMAX Plasma, 2022*)

UV-Radiated Sensitizers

(*Claros, 2023*)

Summary on Thermal Treatment for PFAS

Critical need for PFAS mineralization

Thermal treatment may present a near-term & practical solution

Developing sampling & analytical methods give insight into reactive mechanisms

Hydrothermal options present good alternatives while improving scalability

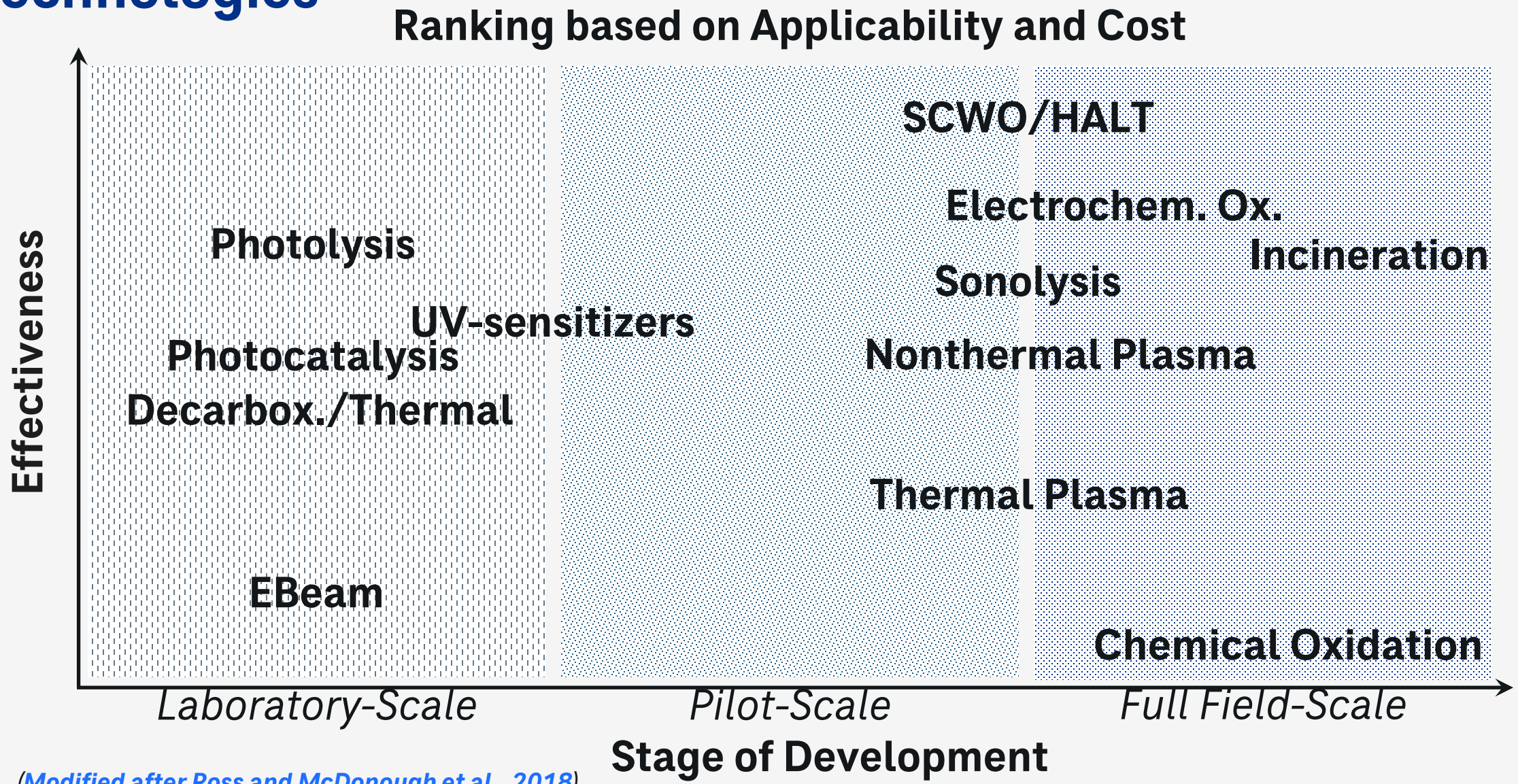
Approaching an industry consensus: >1,000°C for >2 s with adequate $H_2O_{(g)}$ & $O_{2(g)}$

Thermal desorption, GAC reactivation, & pyrolysis proven for solids – questions remain on PIDs

MSW/sludge combustors likely a source of PIDs

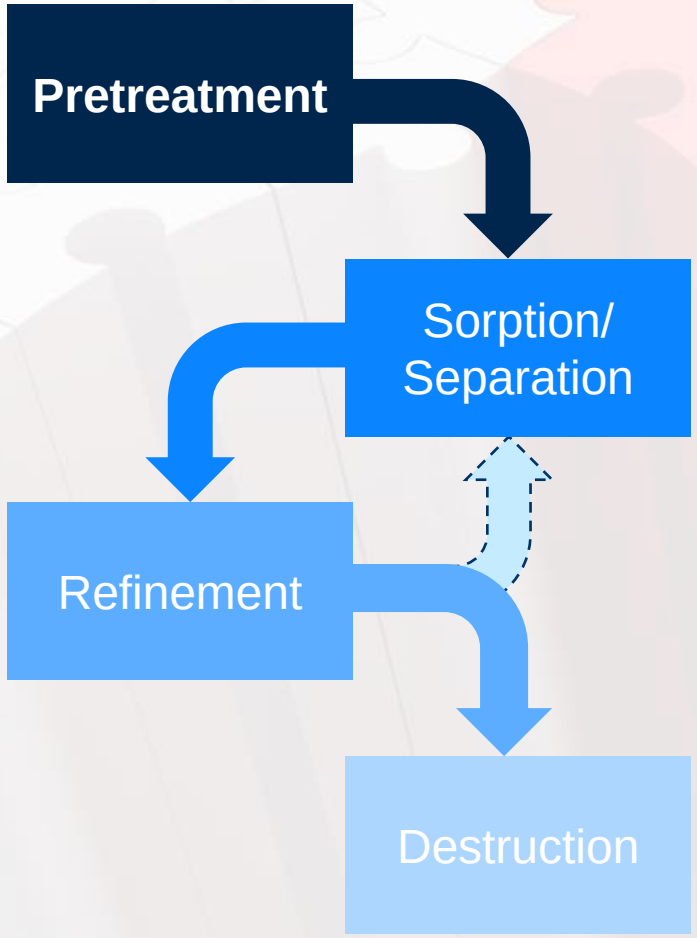
HWIs at PFAS-relevant conditions may approach "adequate destruction"

PFAS-Relevant Liquid Phase Destruction Technologies



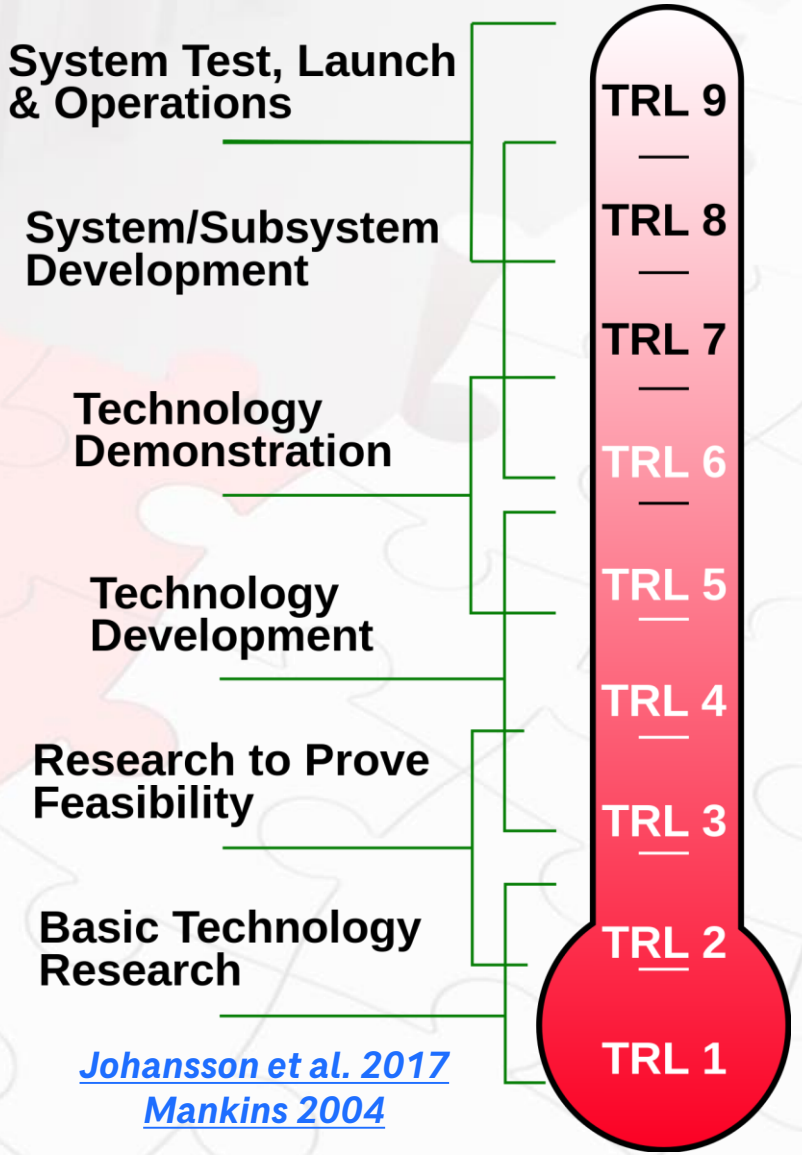
(*Modified after Ross and McDonough et al., 2018*)

Summary



Concentration Factor

Pragmatism



Johansson et al. 2017
Mankins 2004

Reality

Summary

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Hicks et al., 2019