CARBON SUPPLY INC.

Comparing Granular Activated Carbon (GAC) and Ion Exchange (IX) for PFAS Treatment in Water

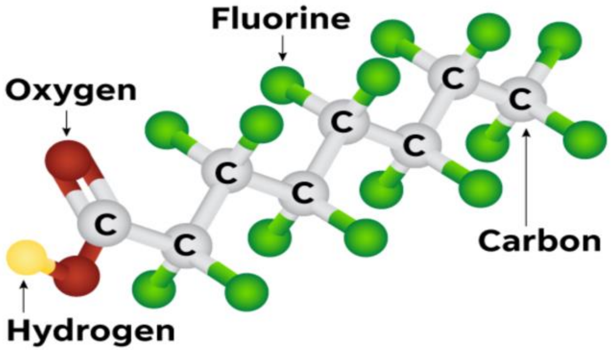
Agenda

1. It depends…
2. What are PFAS?
3. Long-chain vs. short chain
4. Technology Landscape
5. PFAS Behavior in Water
6. GAC Fundamentals
7. IX Fundamentals
8. Performance Comparison

1. Hawaii Specifics
2. Lifecycle Cost Profile
3. Environmental Considerations
4. Regulatory Fit
5. Decision Framework
6. It depends…

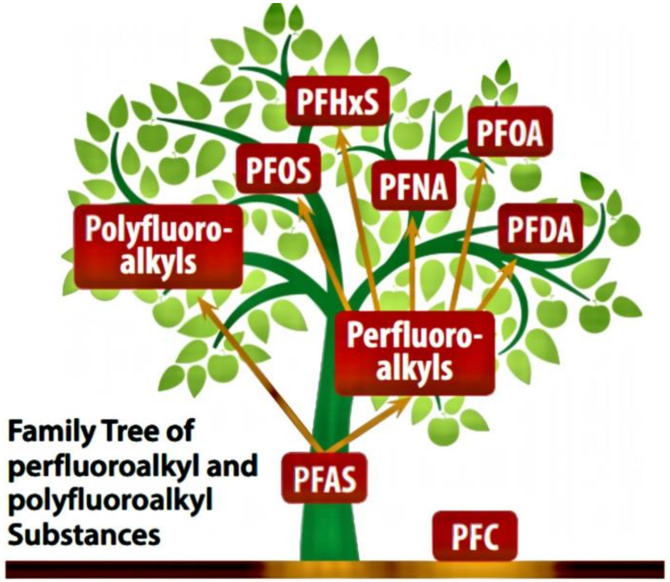
PFAS = Per- and Polyfluorinated Alkyl Substances

- Over ~10,000 unique compounds
- Synthetic (man-made), non-naturally occurring
- C-F bond is strongest in organic chemistry
- Used since the 1940's



THE GOOD

- Repels oil, water, grease, heat
- Chemically stable
- Non-stick surfaces, waterproofing, fire fighting, stain resistant carpet

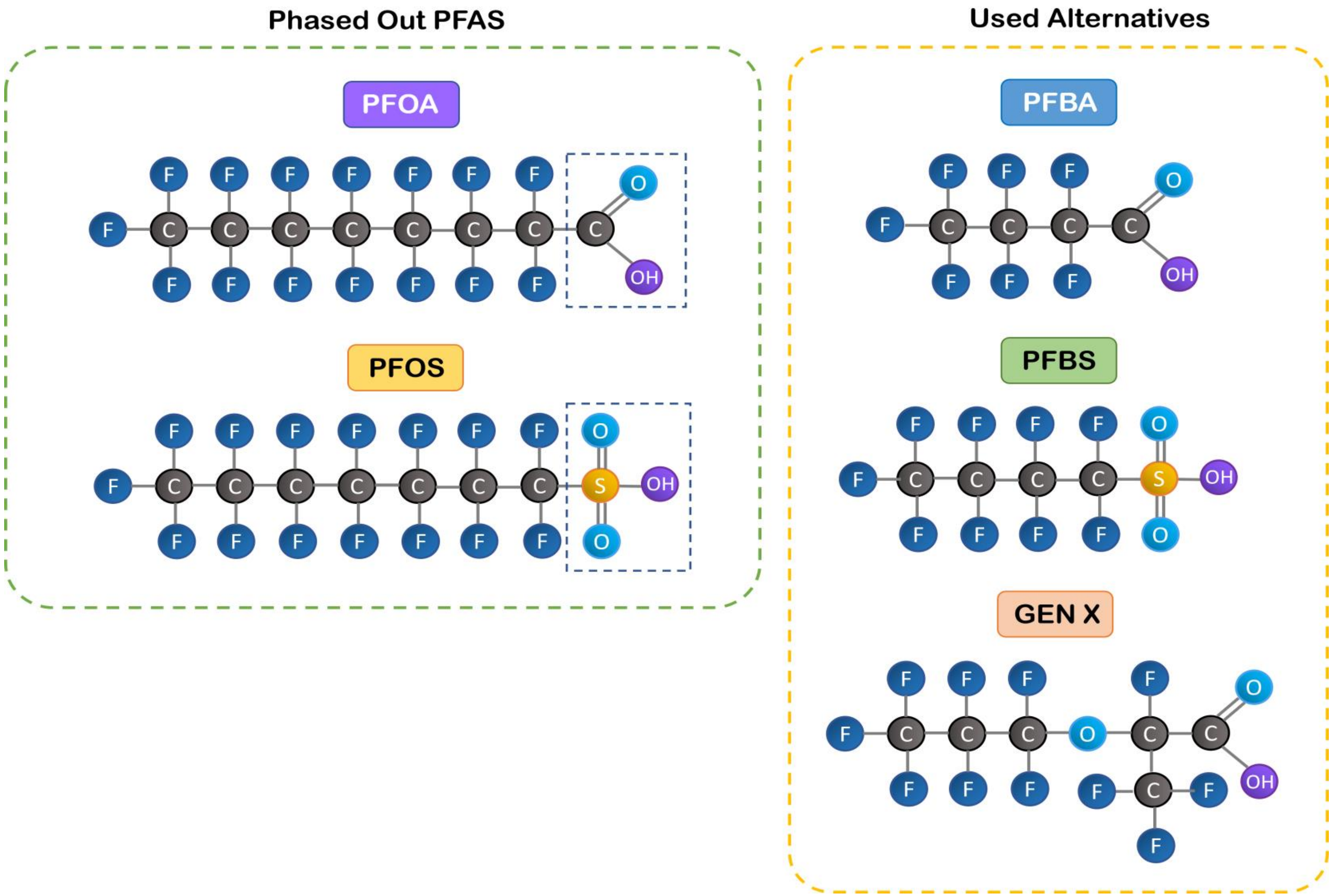


THE BAD

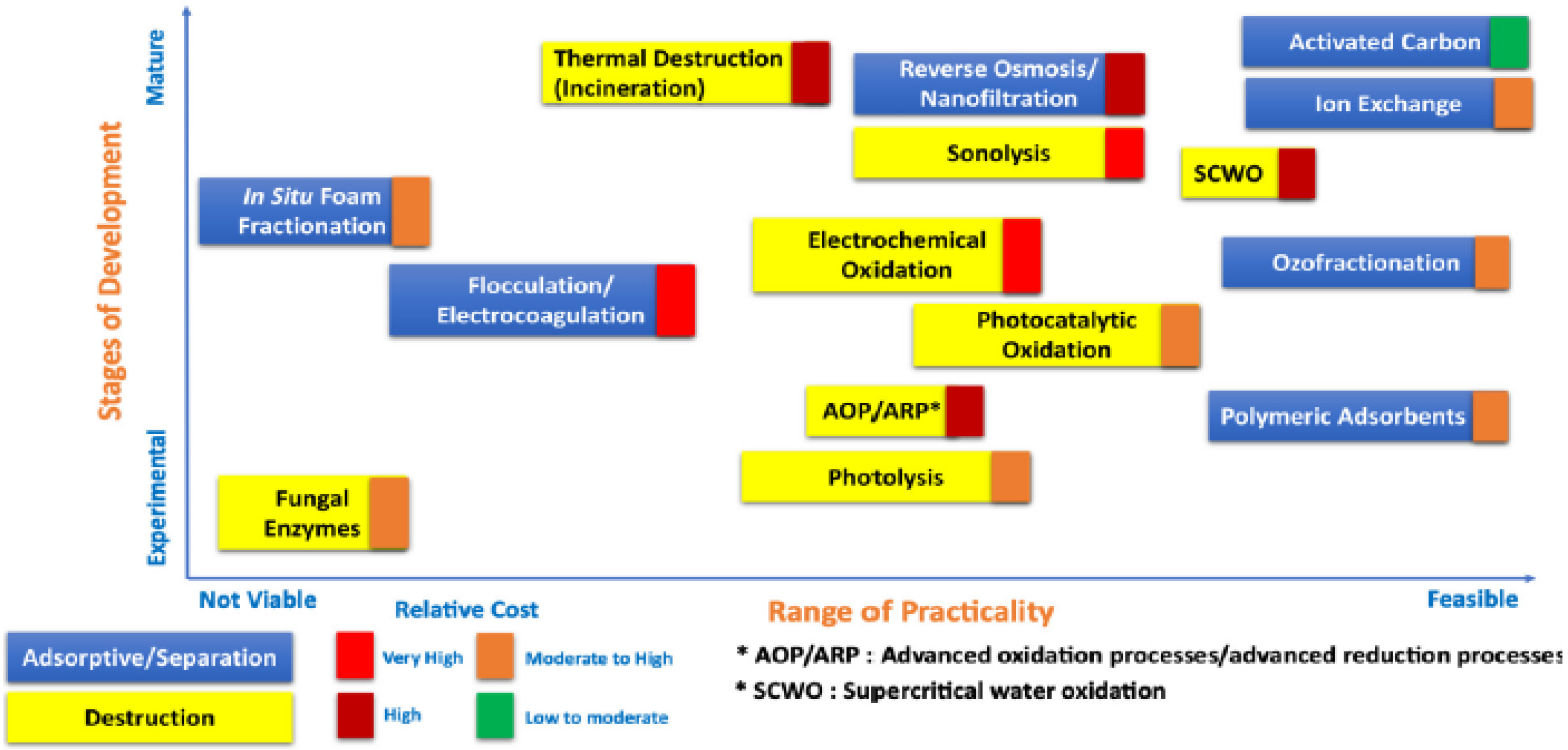
- Resistant to degradation
- Highly persistent, long half-life
- Bioaccumulative
- Toxic
- Suspected carcinogen

What are PFAS?

Long Chain vs. Short Chain



Definition depends on whether carboxylate (<8 carbon chain) or sulfonate (<6 carbon chain).



Technology Landscape

PFAS Behavior in Water

Highly stable

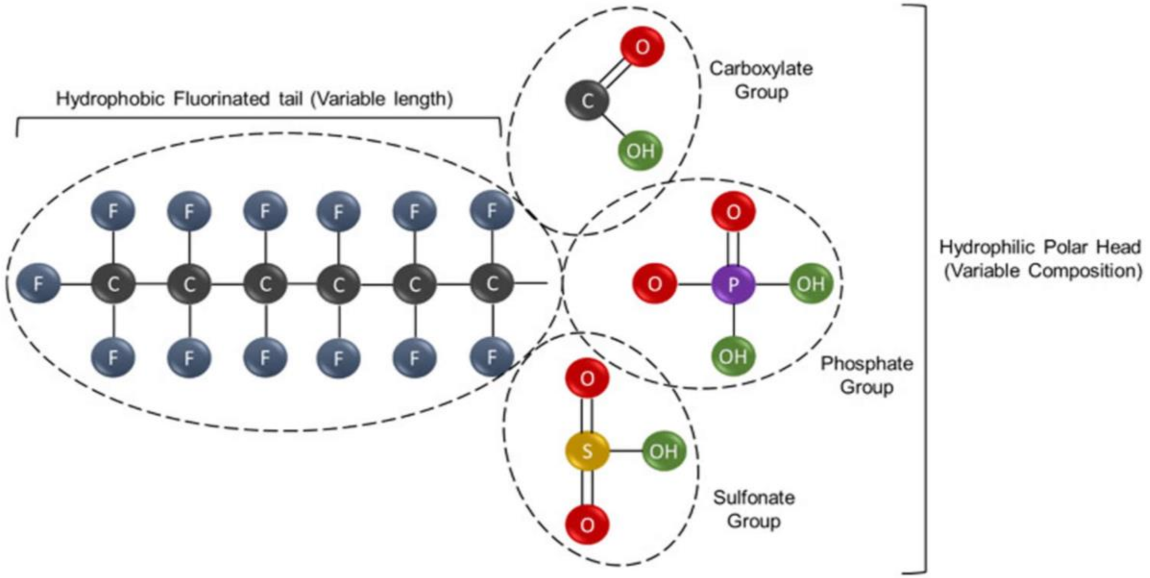
- strong C-F bonds
- resistant to hydrolysis, photolysis (UV) , and biodegradation
- earned them the “forever chemicals” nickname

Amphiphilic Structure

- Have **both** hydrophobic and hydrophilic parts
- Most have **hydrophobic fluorinated tail** and **hydrophilic head group** (carboxylate or sulfonate).
- Dual nature results in:
  - Tail resisting water (GAC)
  - Head interacts with water (IX)

Ionization

- At environmental pH (~6–8), PFAS are typically **anionic** and exist as:
  - Carboxylates (e.g., PFOA) as $–COO^{-}$
  - Sulfonates (e.g., PFOS) as $–SO_3^{-}$
- Ionic form enhances water solubility and affects interactions with adsorbents and biological systems



Hydrophobic Partitioning

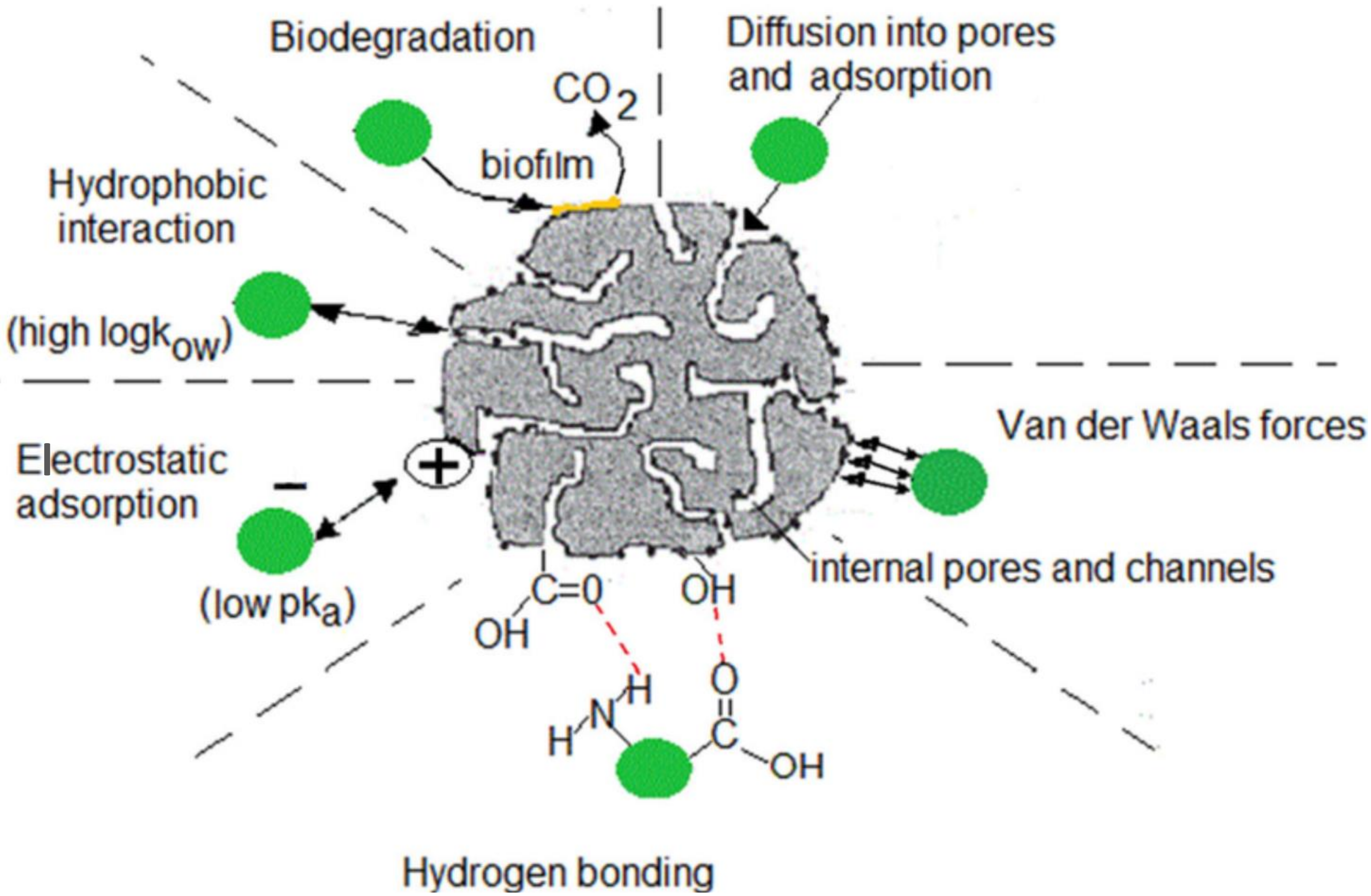
- Non-polar molecules preferentially migrate from polar environment (water) into non-polar phase (carbon surface)
- Best with long-chain hydrophobic fluorinated tails seeking out non-polar surface of GAC
- MAJOR influence

Van der Waals/Dispersion Forces

- High surface area enables weak intermolecular attractions stabilizing PFAS within pore structure
- MINOR influence

Electrostatic Interaction (minor)

- At low pH, positive localized surface charges can attract anionic head groups
- MINOR influence



How does GAC remove PFAS?

Electrostatic Interaction (IX)

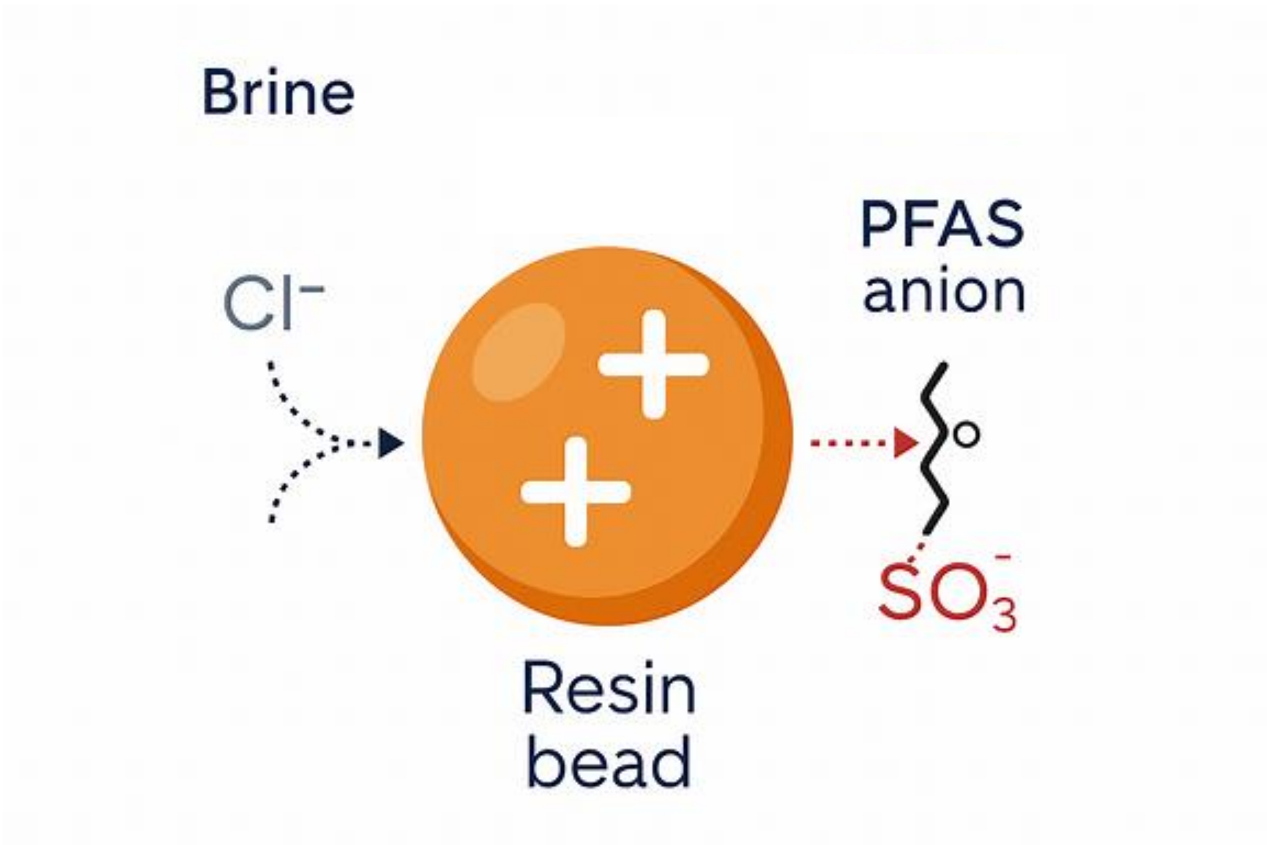
- PFAS exist as **anions** due to their carboxylate or sulfonate head groups
- Resins are typically strong base anion exchangers, made of crosslinked polymer beads with quaternary ammonium functional groups
- PFAS displaces a weaker anion (e.g., Cl^- or OH^-) on the resin surface
- MAJOR influence

Hydrophobic Partitioning

- MINOR influence

Van der Waals/Dispersion Forces

- MINOR influence/strength of bond



How does IX remove PFAS?

PARAMETER	GAC	IX
LONG-CHAIN	EXCELLENT	EXCELLENT
SHORT-CHAIN	POOR	GOOD
PFAS Affinity	Strong for long-chain (PFOA, PFOS)	Strong for short-chain (PFBS, GenX)
EBCT	10 - 15 min	2 – 5 min
Capacity Behavior	Smooth breakthrough Gradual saturation	Sudden breakthrough Sharp saturation
Co-contaminant Influence	Organics compete for adsorption sites	Competing anions compete for exchange sites (sulfates, nitrates)
Regeneration/Disposal	Thermal reactivation (PFAS destroyed)	Regeneration results in PFAS-laden brine (PFAS not destroyed)

Performance Comparison

1. Hawaii Department of Health (HDOH) Guidance (2024–2025)

HDOH aligns with EPA's 2024 Interim Guidance for PFAS destruction and disposal.

- Hawaii emphasizes **preventing PFAS migration into groundwater and marine ecosystems**, given the state's porous volcanic geology and reliance on aquifers.
- **Landfilling of PFAS media is discouraged** unless the landfill is engineered with leachate capture and monitoring. Even then, it is considered a last resort.
- **Thermal destruction is preferred**, but **Hawaii lacks in-state high-temperature incineration facilities** capable of meeting EPA's PFAS destruction thresholds.

2. Shipping Off-Island

Most spent GAC and IX media are **shipped to the mainland U.S.** for thermal destruction, reactivation or regeneration requiring:

- DOT-compliant hazardous waste manifesting
- Chain-of-custody documentation
- Coordination with permitted TSDFs (Treatment, Storage, and Disposal Facilities)

Hawai'i Specifics

EPA's updated guidance (March 2024) outlines three primary options for destruction and disposal:

Method	Description	Hawaii Consideration
Thermal Destruction	Incineration at >1000°C with emission controls	**Preferred** method, but must be done off-island
Landfilling	Engineered Subtitle C or D landfills with leachate control	**Discouraged** due to leachate risk and aquifer proximity
Underground Injection	Class I hazardous waste wells for liquid PFAS	**Not viable** in Hawaii due to geology and lack of infrastructure

Hawai'i Specifics

Disposal Differences

Granular Activated Carbon:

- Can be **thermally regenerated** if PFAS is fully destroyed and emissions are controlled
- Regeneration must occur at facilities with **documented PFAS destruction efficiency**
- GAC with high PFAS loading may be classified as hazardous waste depending on leachability

Ion Exchange Resins:

- Cannot be regenerated for PFAS; must be **destroyed or landfilled**
- Often treated as hazardous due to concentrated PFAS load
- Requires careful packaging and transport due to potential for PFAS leaching

Cost Component	Granular Activated Carbon (GAC)	Ion Exchange (IX)
Capital Cost	Moderate (larger footprint)	Moderate (compact system)
Media Cost	Lower per unit, higher use rate	Higher per unit, lower use rate
Changeout Frequency	Frequent (esp. in high TOC)	Less frequent
O&M Labor	Simpler, less specialized	More technical (resin handling)
Residuals Disposal	Spent carbon → incineration	Brine → offsite or advanced treatment
Energy Use	Low to moderate (thermal reactivation)	Low to moderate (regeneration)
Regeneration Cost	Not applicable (single-use or reactivation)	Applicable for regenerable resins
Environmental Impact	Lower if reactivated	Higher if brine disposal is complex
PFAS Profile Sensitivity	Poor for short-chain PFAS	Strong for short and long-chain PFAS
Footprint Requirement	Larger EBCT (10–20 min)	Smaller EBCT (2–5 min)

Cost Comparison Elements

500 GPM PFAS System (greenfield)

Cost Category	GAC	Ion Exchange
Capital Cost	$2.5M–$3.2M	$2.2M–$2.8M
Annual O&M Cost	$350K–$500K	$250K–$400K
Media Replacement	6–12 months (high TOC)	12–24 months (low TOC)
Residuals Disposal	Incineration	Offsite or advanced treatment
Footprint Requirement	Larger (EBCT 10 - 20 min)	Smaller (EBCT 2 - 5 min)
Labor & Complexity	Lower (simple operation)	Higher (brine handling, monitoring)
Energy Use	Low	Low to moderate
Environmental Impact	Lower if reactivated	Higher – complex brine disposal
Total 30-Year LCC	~$12M - $15M	~$10M - $13M

Life-Cycle Cost Comparison

SOURCE: EPA Cost Model

Decision Framework

Step 1: Define PFAS Profile
- Long chain vs. short chain vs. mixed
- Concentrated or trace levels

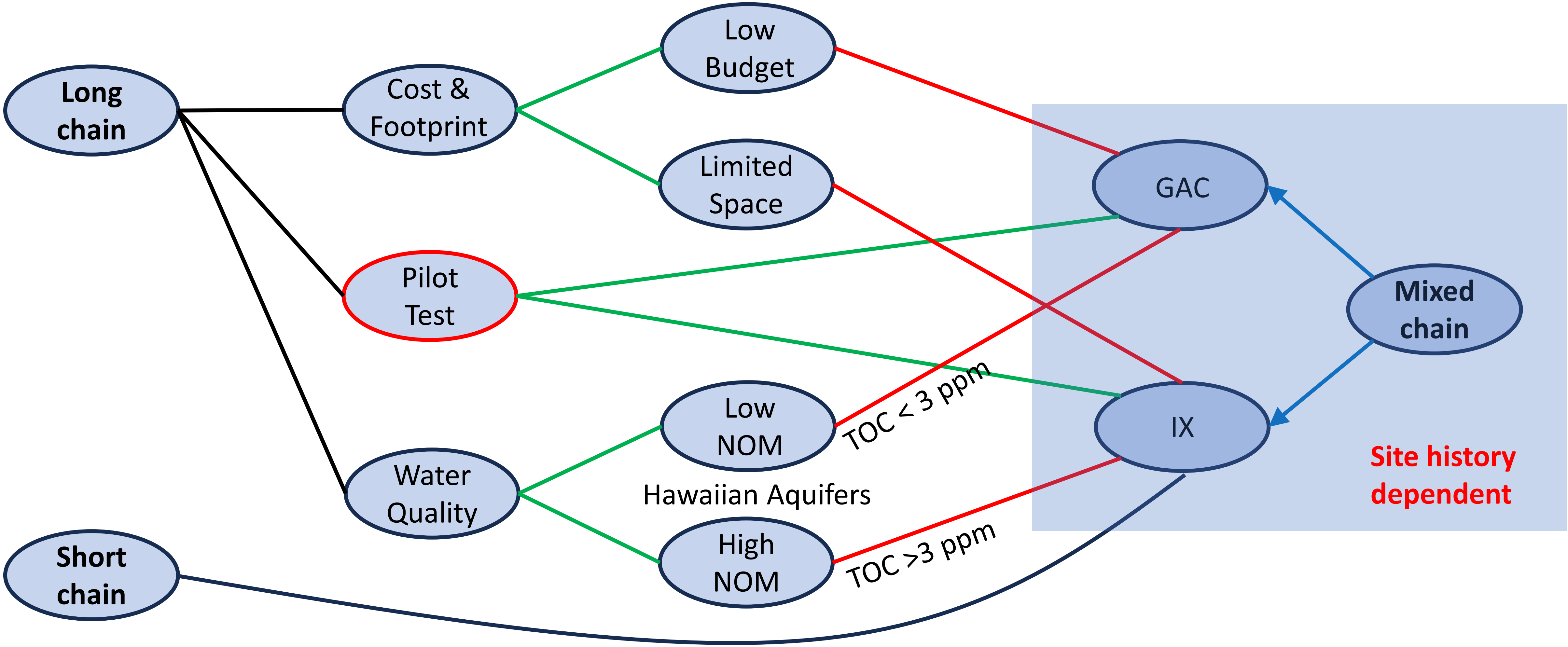
Step 2: Water Quality Characteristics
- Natural organic matter (NOM) & other organics reduce adsorption
- Inorganic salts compete for IX sites (sulfates, etc.)

Step 3: Performance Requirements
- Operational complexity
- Breakthrough time
- Media replacement frequency

Step 4: Cost Considerations
- Capital cost/operating cost
- Media replacement frequency
- Breakthrough time

Step 5: Regulatory & Site Specific Factors
- Footprint
- Local regulations
- Regen, react or disposal?

Step 6: Pilot Testing
- Bench or pilot testing to validate design assumptions



Decision Tree (in general)

CARBON SUPPLY INC.

Kevin Lavery

kevin@carbonsupplyinc.com

(408) 921-8478