Prepared for: Holbrook Board of Health

DEXSORB®: New Technology for PFAS

CYCLOPURE

Environmental Engineering Group
January 20, 2022

CYCLOPURE.COM

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Cyclopure Develops Adsorbents for Water Purification

Founded
2016

Technology Center
Skokie, IL

Leadership

Frank Cassou
CEO
(Tech Executive)

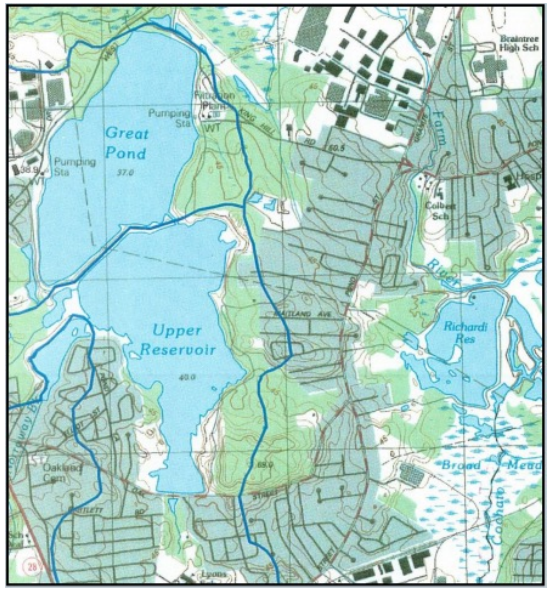
Dr. Irwin Jacobs
Lead Investor
(CEO Emeritus, QUALCOMM)

Dr. Gerhard Schmid
Vice Chairman
(CEO Emeritus, Wacker Chem)

Prior Work With Holbrook Water

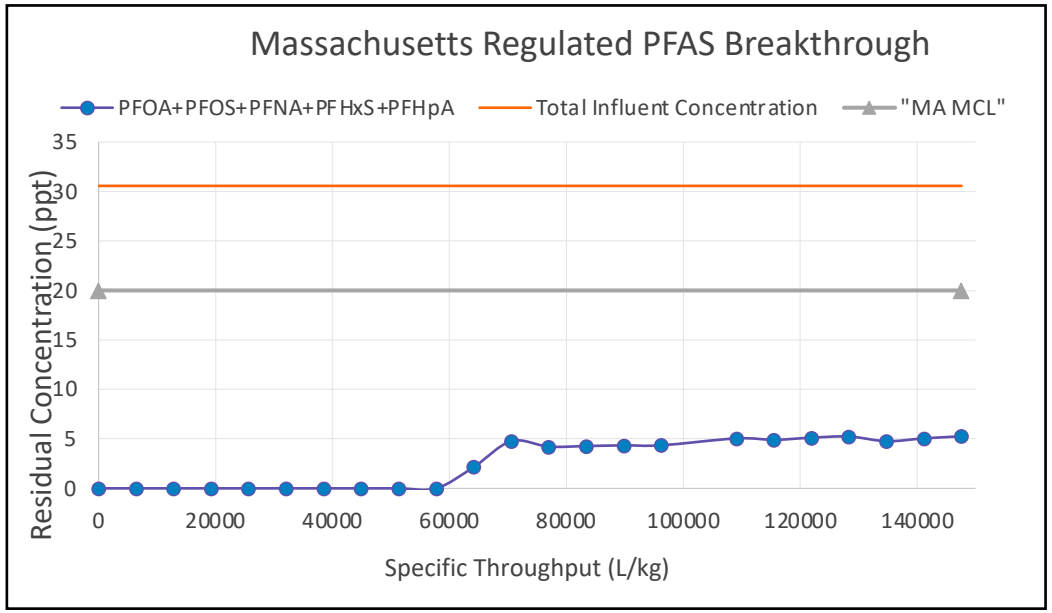
Tri-Town Drinking Water Project - AECOM RSSCT

Tri-Town (Braintree Holbrook, and Randolph), MA



PFAS Characterization

Compound	Concentration (ppt)
Perfluorohexanesulfonic acid (PFHxS)[a]	2.65
Perfluoroheptanoic acid (PFHpA)[a]	2.39
Perfluorooctanoic acid (PFOA)[a]	5.49
Perfluorooctanesulfonic acid (PFOS)[a]	2.17
Perfluorononanoic acid (PFNA)[a]	0.71
Perfluorobutanoicacid (PFBA)	3.94
Perfluoropropane sulfonate (PFPrS)	0.25
Perfluoropentanoic Acid (PFPeA)	4.93
Perfluorobutanesulfonic acid (PFBS)	2.47
Perfluorohexanoic acid (PFHxA)	4.12
Perfluoropolyethers (PFPeS)	0.48
Perfluorobutane sulfonamide (FBSA)	0.62
Total PFAS	**30.22**



PFAS6 Results for Randolph/Holbrook Joint Water Plant

Quarterly Compliance Period	Monitoring Period	Sample Collection Date	PFAS6 Result (ng/L)	Quarterly Average (ng/L)	PFAS6 MCL (ng/L)
Quarter 2, 2021	Month 1	4/19/2021	18.8	19	20
	Month 2	5/10/2021	18.5		
	Month 3	6/07/2021	20.1		
Quarter 1, 2021	Month 1	7/7/2021	23.4	25*	20
	Month 2	8/3/2021	27.0		
	Month 3	9/8/2021	25.5		

* A quarterly average exceeding 20 is a violation of the PFAS6 Maximum Contaminant Level (MCL).

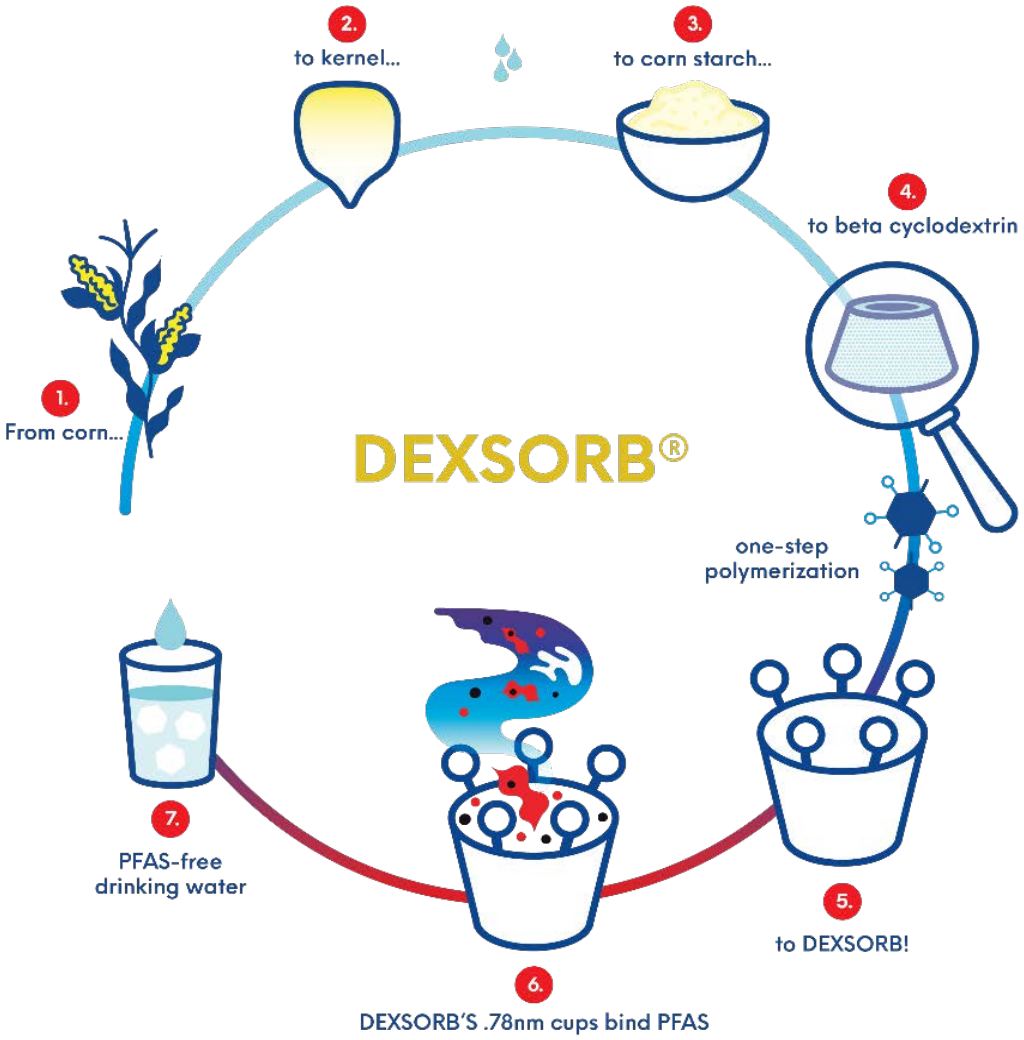
Background Water Characterization

Parameter	Concentration (mg/L)	RL
Calcium [Ca^{2+}]	14.3	0.5
Magnesium [Mg^{2+}]	3.3	0.5
Potassium [K^{+}]	2.1	1.0
Sodium [Na^{+}]	73.5	2.0
Chloride [Cl^{-}]	150.0	10.0
Sulfate [SO_4^{2-}]	7.8	5.0
Nitrate/Nitrite [NO_3^{-}/ NO_2^{-}]	0.027	0.050
Total Organic Carbon (TOC)	2.3	1.0

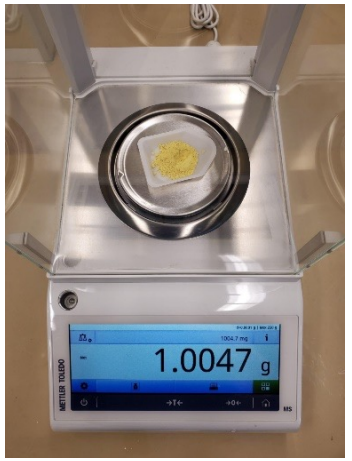
DEXSORB Adsorbents

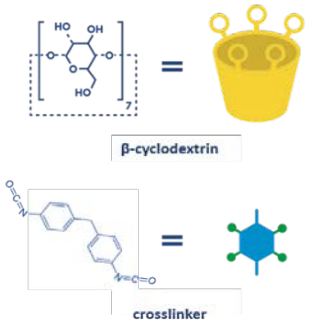
Proprietary Technology: Corn-based DEXSORB®

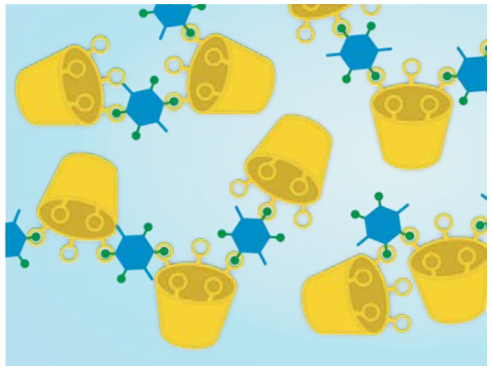
Renewable Cyclodextrin Polymers

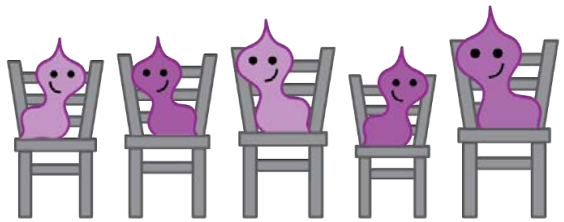


One-Step Synthesis: 1 g of DEXSORB = $3x10^{20}$ CD cups



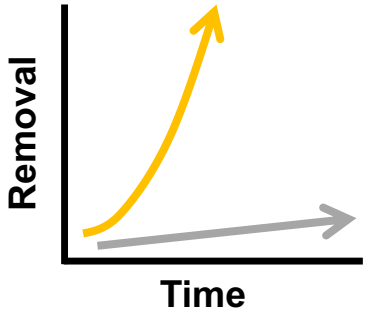






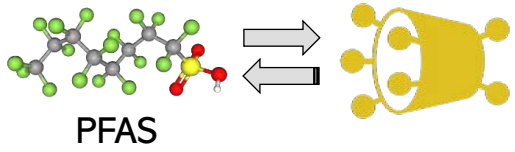
Adsorption Mechanism: Host-guest Complexation

Rapid Kinetics



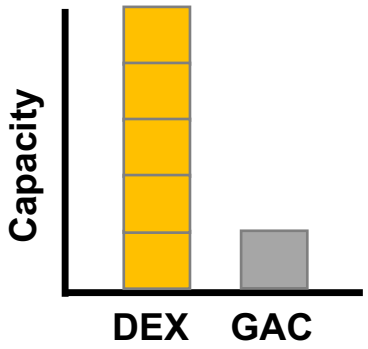
- **Well defined** porous structures across high surface area
- **Uniform hydrophobic 0.78-nm cyclodextrin** cavities
- **Cationic surface charge** for enhanced PFAS interactions

Easy Regeneration



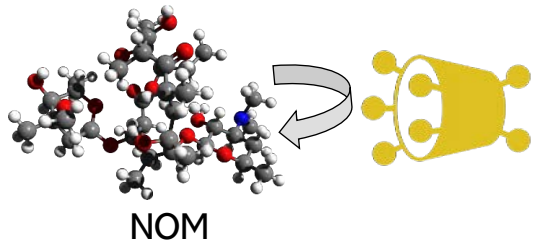
- **Reversible** host-guest (desorption)
- **Green and safe** regeneration under ambient conditions
- **Multiple-cycle reuse**

High Capacity



- **1 g = $3x10^{20}$** cyclodextrin cups
- **1 kg = 5 kg** of bituminous GAC in GW and DW in single use
- **1 kg > 25 kg** of bituminous GAC in complex matrices

Resistance to Fouling



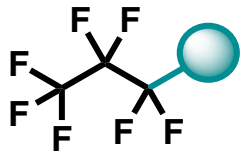
- No impact from **inorganic ions** (too small to fit in cavities)
- No impact from **natural organic matter** (too large to fit)
- Equal PFAS removal in all matrices (molecular selectivity)

Adsorption Mechanism: Host-guest Complexation

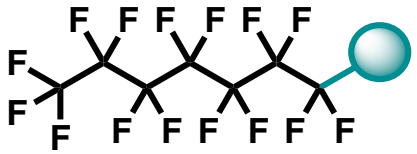
Size Inclusion Selectivity for PFAS

Effective for all forms of PFAS:

Chain-Length

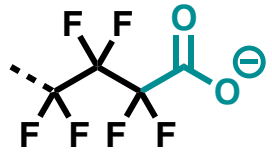


Short-Chain

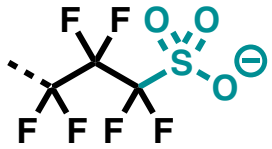


Long-Chain

Functional Group

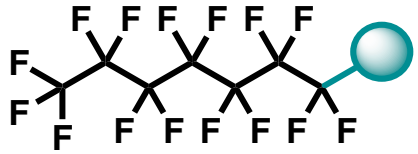


Carboxylates

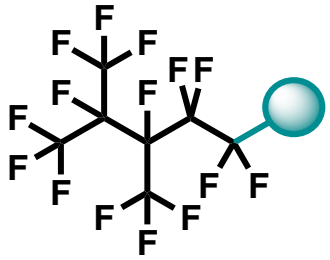


Sulfonates

Branching



Linear



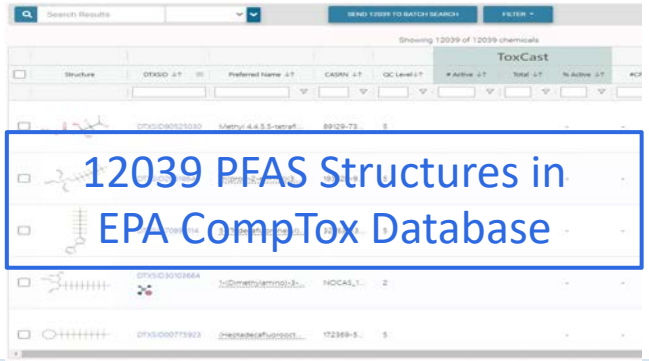
Branched

Future Proof Solution for growing list of regulated PFAS:

Fluorotelomer alcohol
4:2 FTOH, 6:2 FTOH
8:2 FTOH, 10:2 FTOH

Fluorotelomer sulfonate
4:2 FTS, 6:2 FTS
8:2 FTS, 10:2 FTS

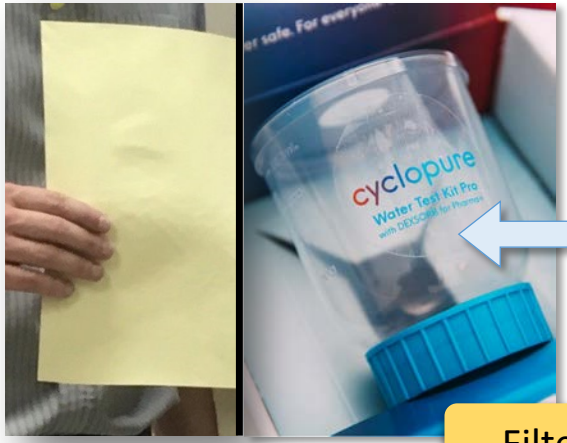
Sulfonamides
PFBSA, PFHxSA,
PFOSA, 6:2 FTAB



DEXSORB Sorbent Processing

Powder

- High surface area
- Easy access to cavities
- High kinetics and capacity



Filter Paper

Extruded Block

Granules

- Flow through hydraulics
- Resist Fouling
- Preserve kinetics and capacity

Gravity Filter

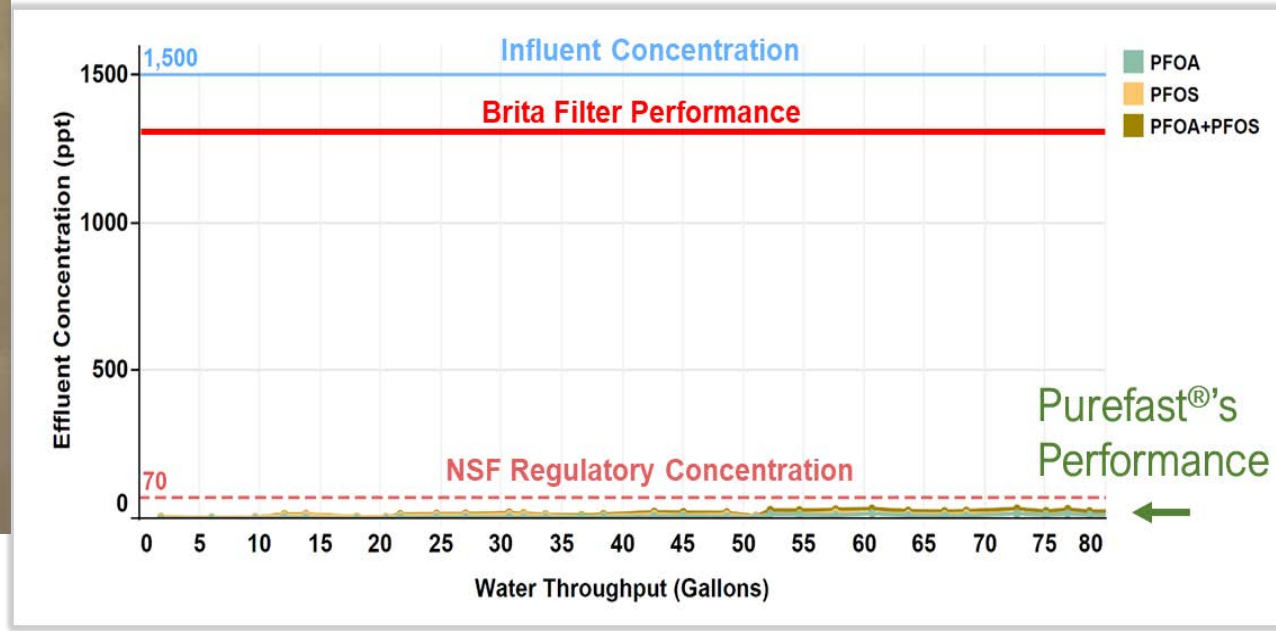
Lead-lag Vessels

DEXSORB® Purefast Filter for Brita Pitcher

Highlights:

- **$40** for **80 gallons** treatment capacity
- DEXSORB for PFAS removal
- Equivalent to over **850 bottled water** (12 oz)

Purefast Performance at NSF Challenging Levels



Engineering Development

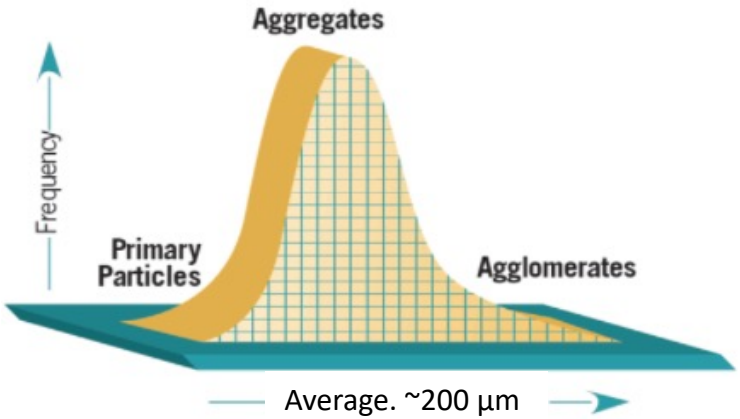
BRIDGING DEXSORB® Technology to Engineered Solutions

As-synthesized DEXSORB

Engineering Design

Packed Bed Filtration

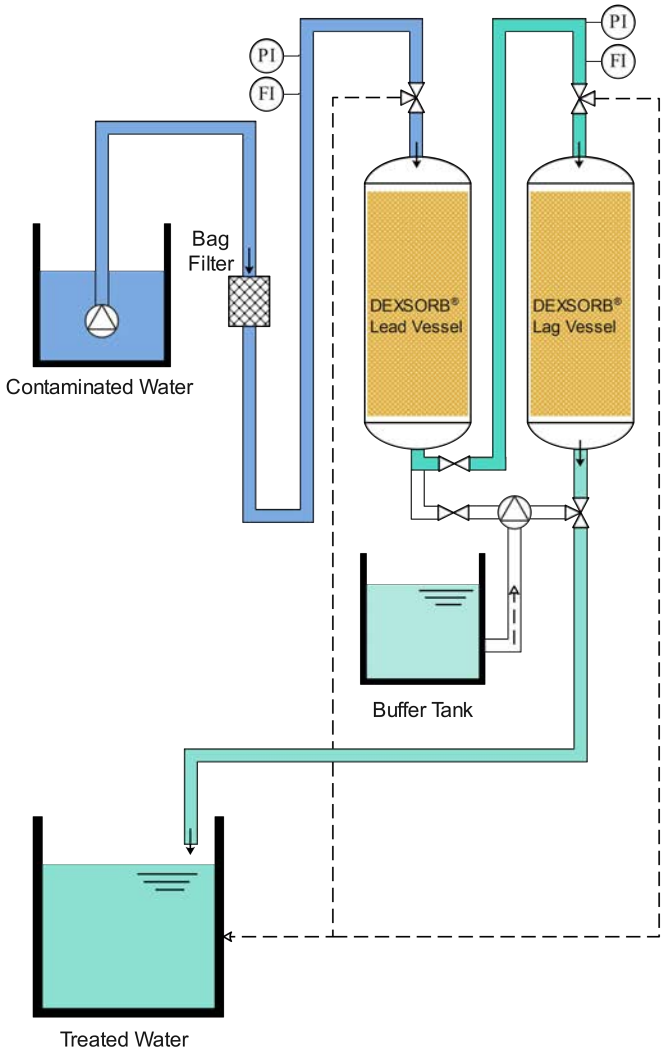
Powder Media

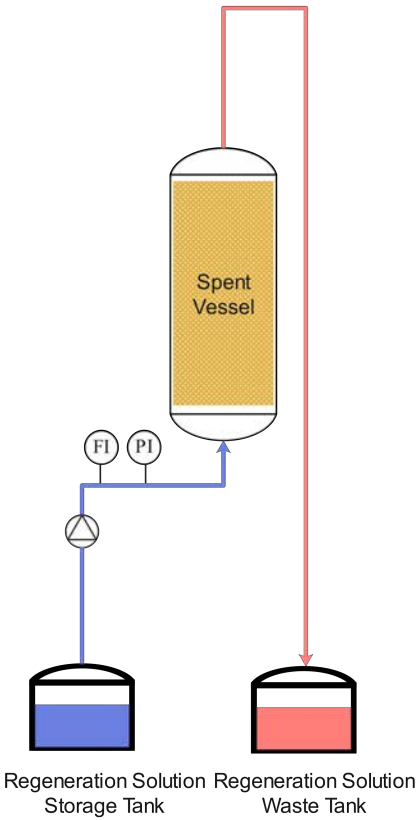


- **Particle Size Distribution**
- **Shape, Density, and Stability**
- **Empty Bed Contact Time**
- **Treatment Capacity**

- **Influent Flow Rate**
- **PFAS Contamination Level**
- **General Water Quality**
- **Target PFAS Removal**

Cyclopure Packed Bed Filtration System





System Advantages:

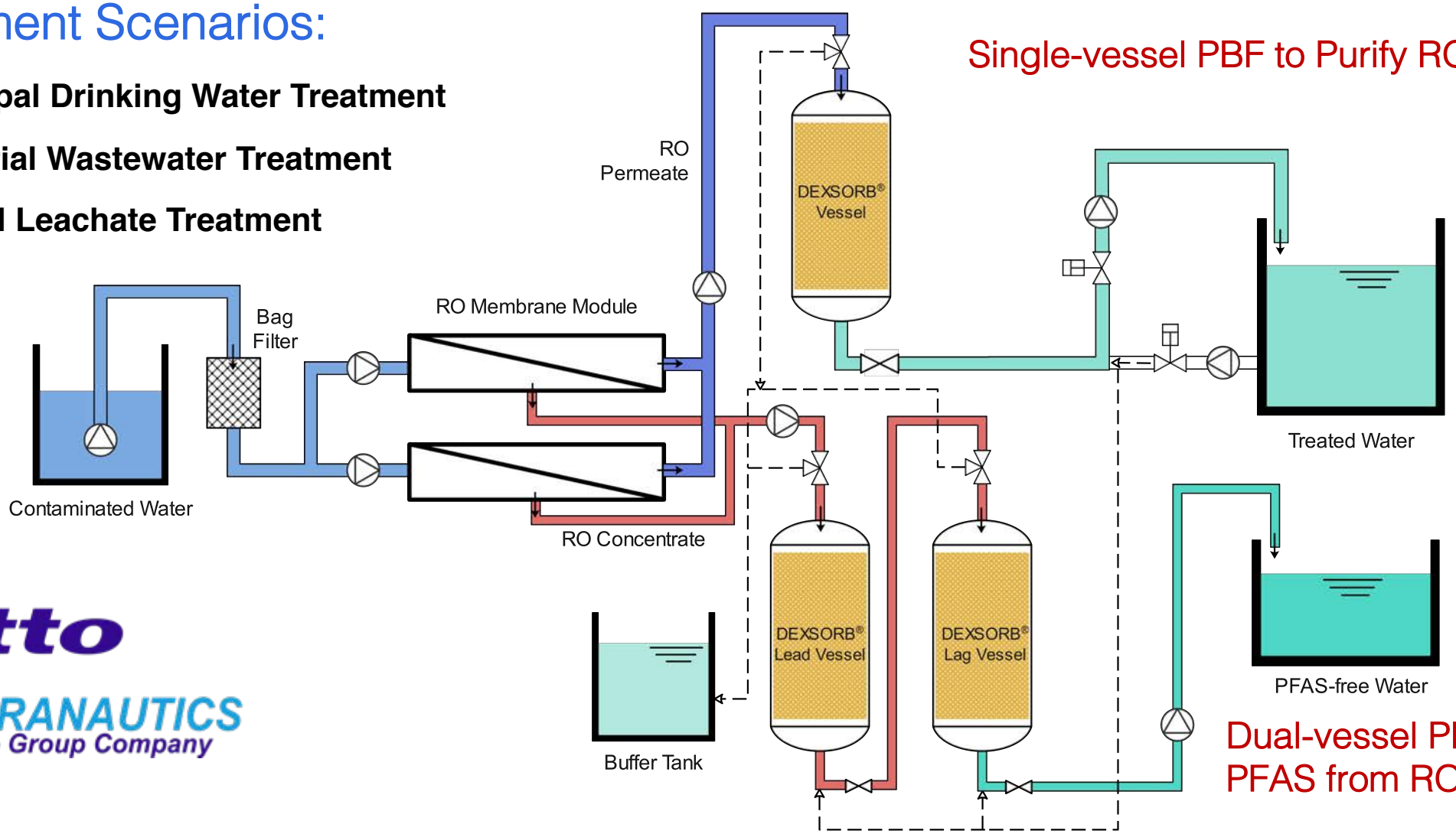
- **Flexible:** Easy Deployment
- **Scalable:** Low to high MGD
- **High Capacity:** Long Use Cycle
- **Sustainable:** Regeneration
- **PFAS Destruction:** Isolate waste streams

Parameters	Per Vessel
Vessel Internal Diameter (ID)	7″ to 10″
Vessel Height (L)	60″
Empty Bed Contact Time (EBCT)	5 minutes
Flow Rate	0.25 to 2.5 GPM
DEXSORB Loading	10 to 40 lbs
Treatment Capacity	Up to 1.5 M gal
Operation Time	12 to 18 months
Regeneration Cycles	5+

DEXSORB PBF Coupled with RO Permeate and Concentrate

Treatment Scenarios:

- **Municipal Drinking Water Treatment**
- **Industrial Wastewater Treatment**
- **Landfill Leachate Treatment**



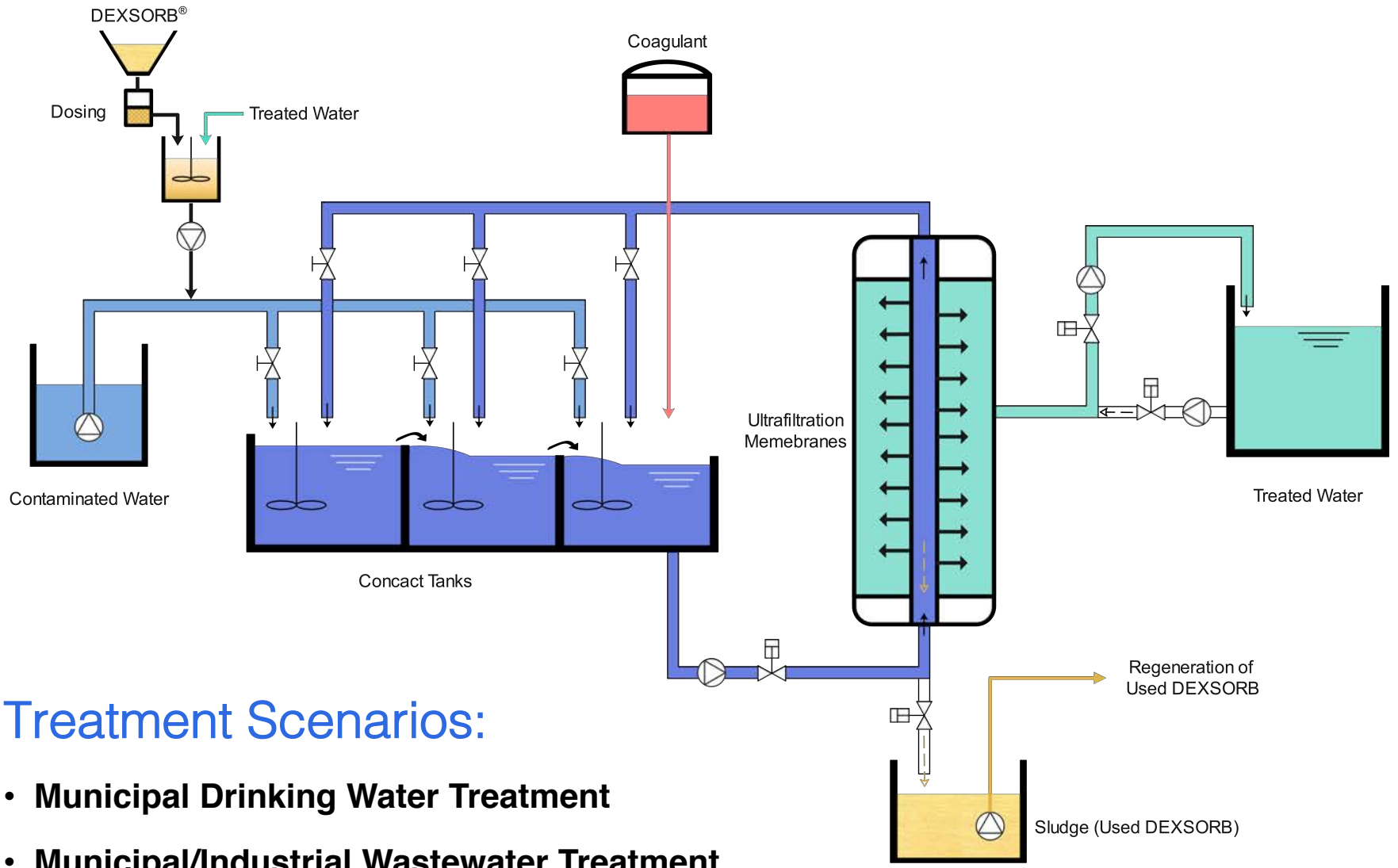
Single-vessel PBF to Purify RO Permeate

Dual-vessel PBF to remove PFAS from RO Concentrate

Nitto

HYDRANAUTICS
Nitto Group Company

Powder DEXSORB for Batch Contact Adsorption



System Advantages:

- **Short Contact time:** Minimal contact time to equilibrium
- **Simple Application:** In-line dosing
- **Efficient:** Kinetics and capacity minimize material use rate
- **Easy Separation:** Easy separation from water by coagulation or ultrafiltration

Treatment Scenarios:

- **Municipal Drinking Water Treatment**
- **Municipal/Industrial Wastewater Treatment**

dunea DUIN & WATER

Industrial + Municipal

Municipal

Drinking Water

Wastewater & Leachate

Industrial

Wastewater

Food & Beverage

Environmental

Surface Water

Groundwater

DEXSORB Environmental: First-Ever End-to-End Solution

NSF ANSI 61 Certified as Safe for Drinking Water Treatment

OFFICIAL LISTING

NSF certifies that the products appearing on this Listing conform to the requirements of NSF/ANSI/CAN 61 - Drinking Water System Components - Health Effects

This is the Official Listing recorded on February 3, 2021.

Facility: Skokie, IL

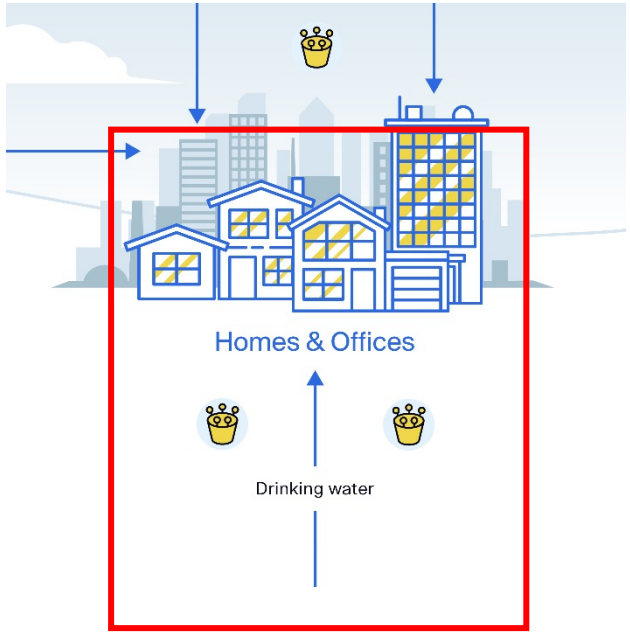
Trade Designation	Process Media Size	Water Contact Temp	Water Contact Material
Adsorption Media			
DEXSORB+ [1]	12 x 40 mesh	CLD 23	SYN

[1] This product is Certified for a maximum use level of 150 g/L.

Chemical and Physical Characteristics

Polymer Structure	crosslinked cyclodextrin
Appearance	yellow powder or granule
Adsorption Mechanism	hydrophobic & electrostatic
Bulk Density (wet)	0.40 g/mL; 0.40 kg/L
Specific Gravity	1.1
Effective Size (powder)	20 to 150 µm
Effective Size (granule)	200 to 2000 µm
Thermal Stability	300 °C (572 °F)

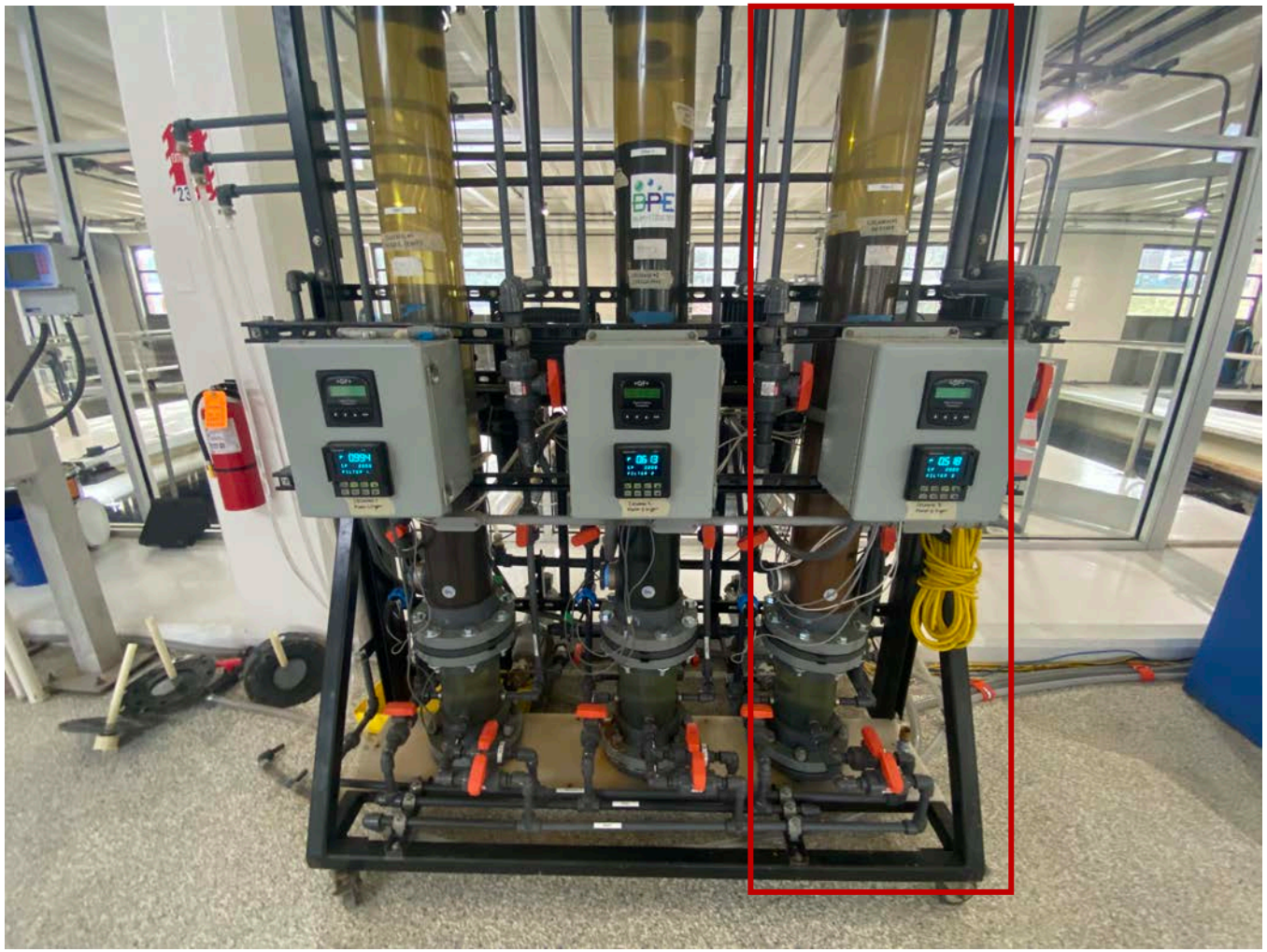
DWTP RO Concentrate Treatment in North Carolina



HDR

GREENSBORO
NORTH CAROLINA

Gravity Filtration System at Greensboro DWTP

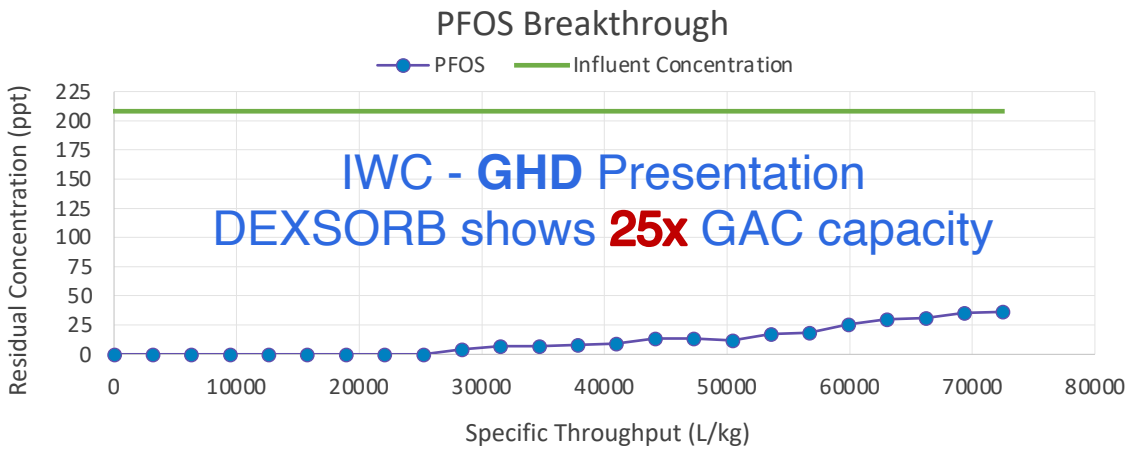


Pilot Operating Conditions:

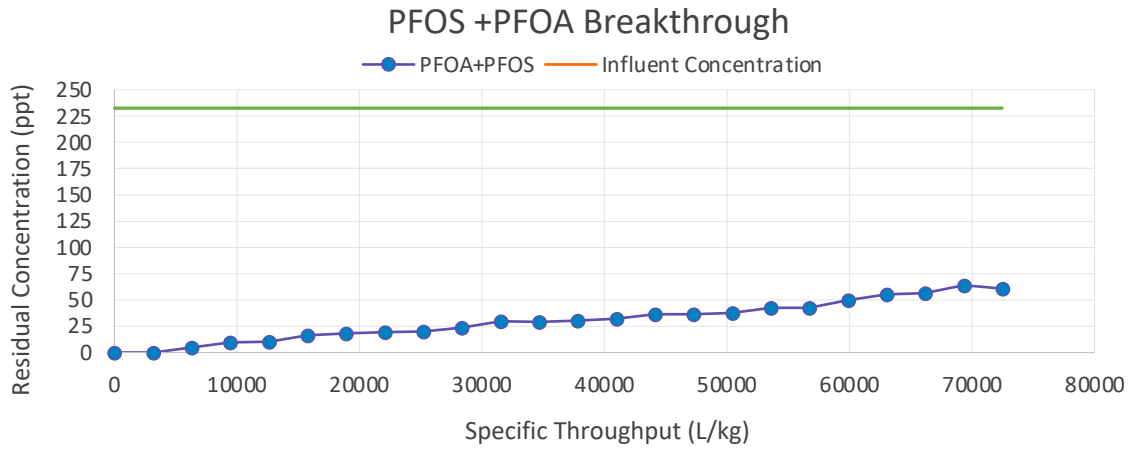
- Gravity filtration to remove PFAS from RO concentrate
- EBCT: 10 minutes
- Media Loading: 5 gallons; 17 lbs
- Operation: 9 months, > 200,000-gal

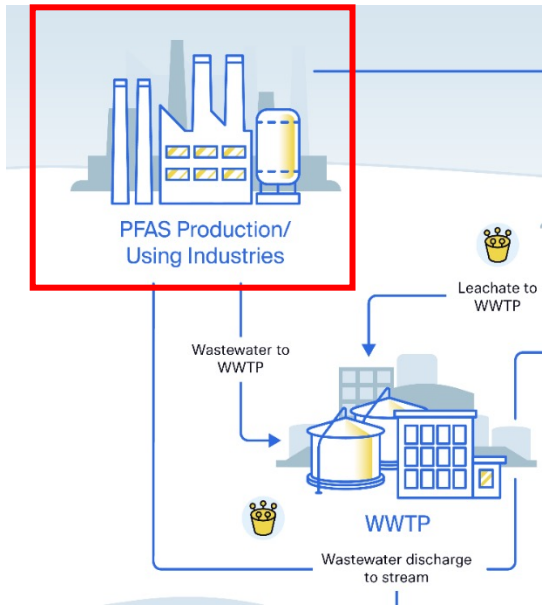
Groundwater Remediation at Former GM Site in Michigan

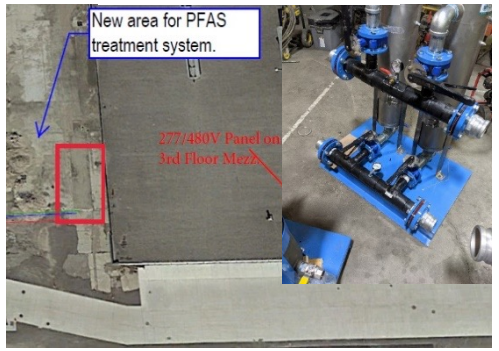
RSSCT: Excellent PFAS Removal + Capacity



IWC - **GHD** Presentation
DEXSORB shows **25x** GAC capacity







Pilot Operating Conditions:

- EBCT: 5 + 5 minutes (Lead-Lag configuration)
- TOC – 14.8 mg/L; High oil-and-grease content
- PFAS target: PFOS – from 208 ppt to < 11 ppt

MI WQS Discharge Limits: PFOS 11 ppt; PFOA 420ppt

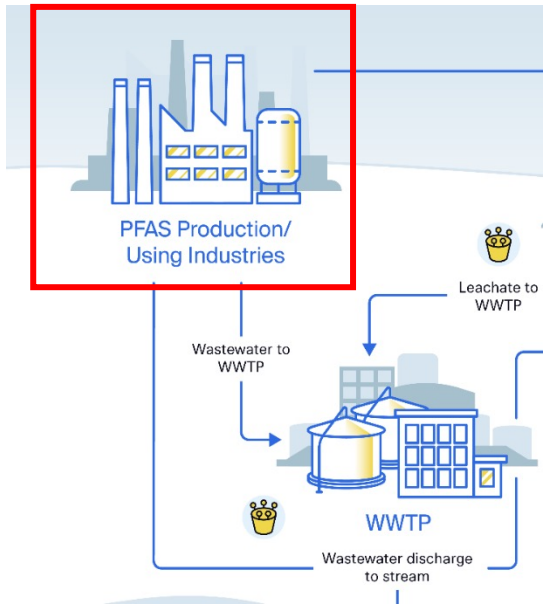
Pilot System Scheduled for Q2 2022

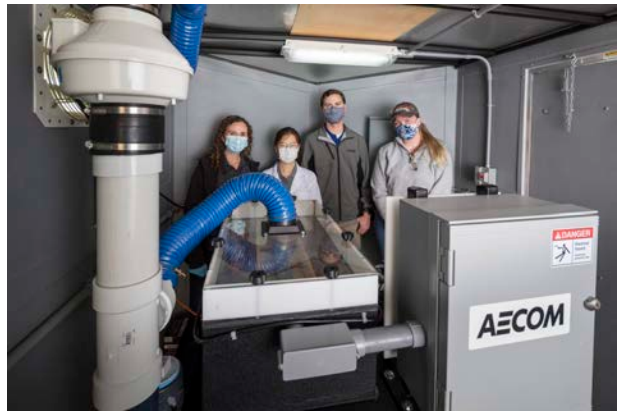
Military Base PFAS Remediation in California

Joint Project with AECOM Sponsored by AFCEC BAA

AECOM

AIR FORCE CIVIL ENGINEER CENTER



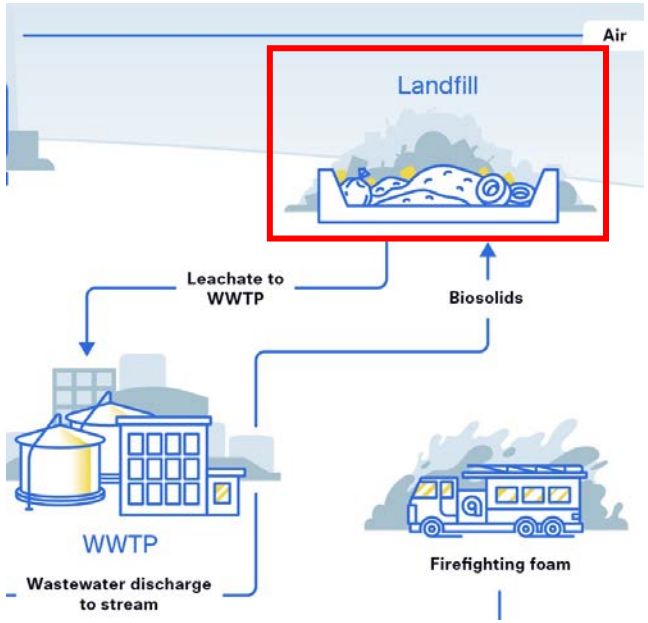


Test Site and Operating Conditions:

- **Travis Air Base in CA**
- EBCT: 5 + 5 minutes (Lead-Lag configuration)
- Regeneration after 8-month operation

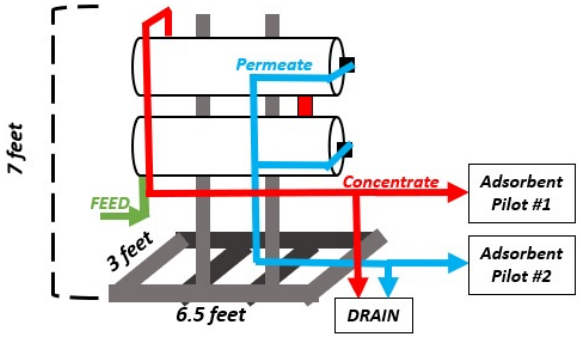
Field Installation Scheduled for Q2 2022

Landfill Leachate RO Concentrate Pennsylvania



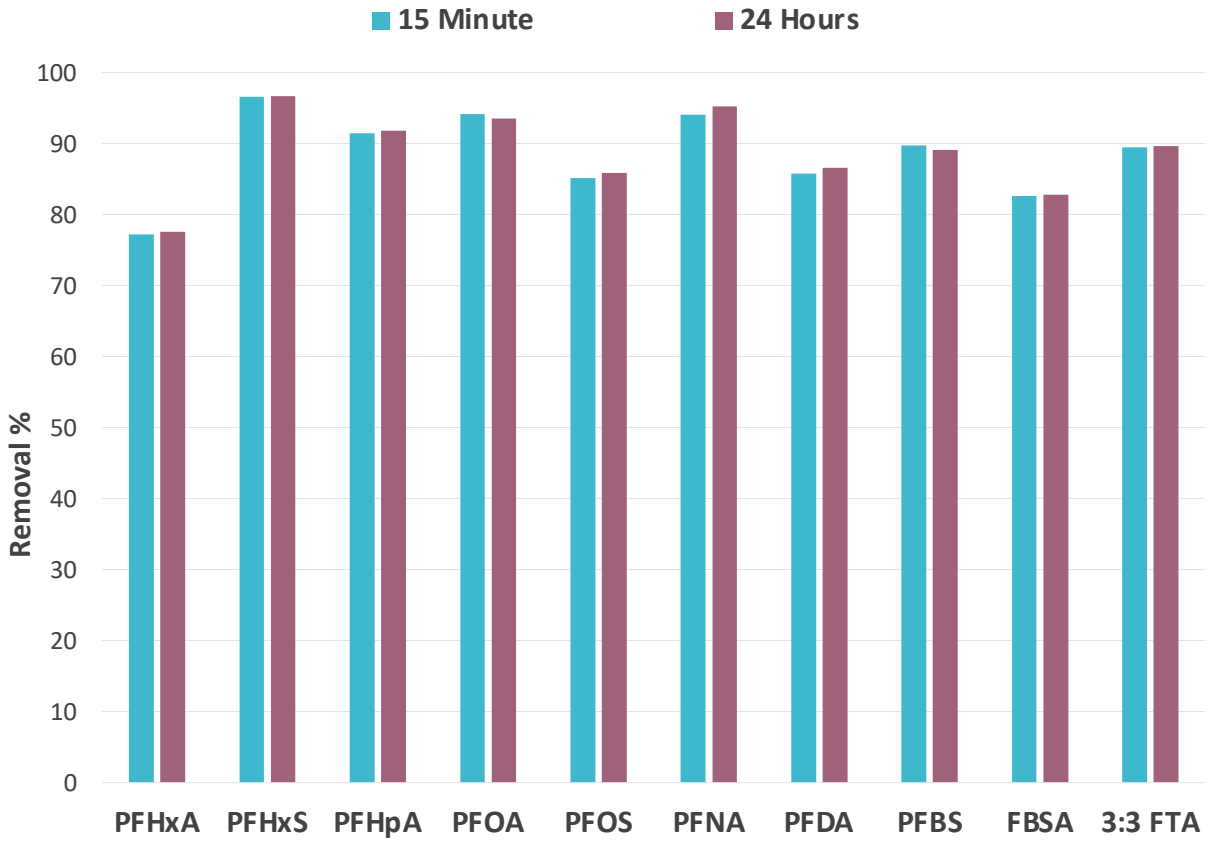
Nitto

HYDRANAUTICS
Nitto Group Company



Leachate RO Concentrate Treatment with Hydranautics

PFAS Level: 76,248 ppt **TOC: > 2000 mg/L** **TDS: > 5000 mg/L**



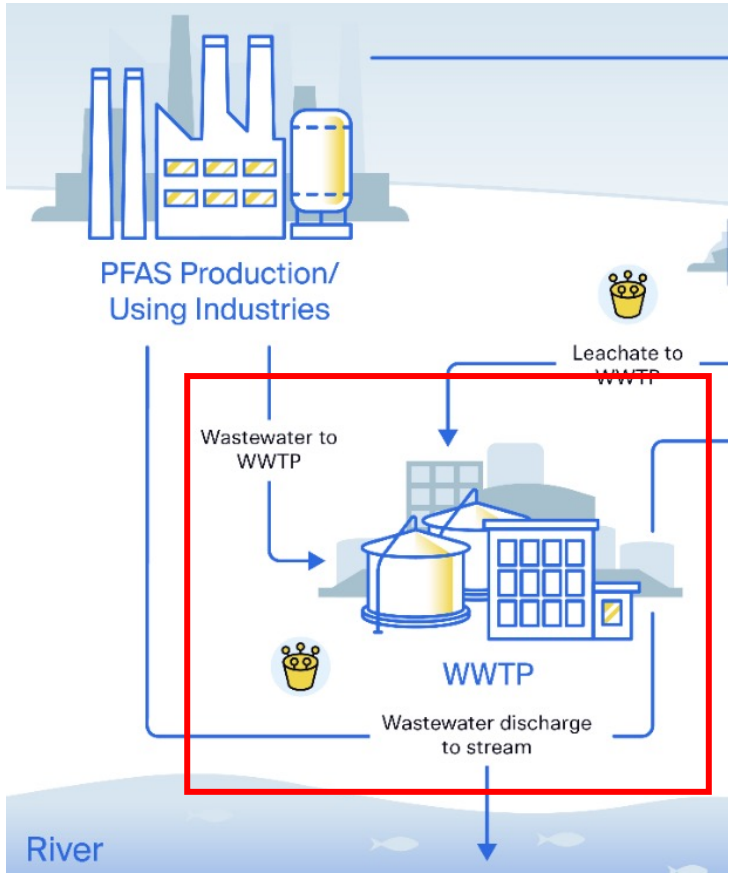
Wastewater Treatment Pilots

NASA WWTP

Operating since August 2021

PFAS Removal

TETRA TECH



Waternet WWTP

Q2 2022

19 OMPs Removal

Witteveen Bos

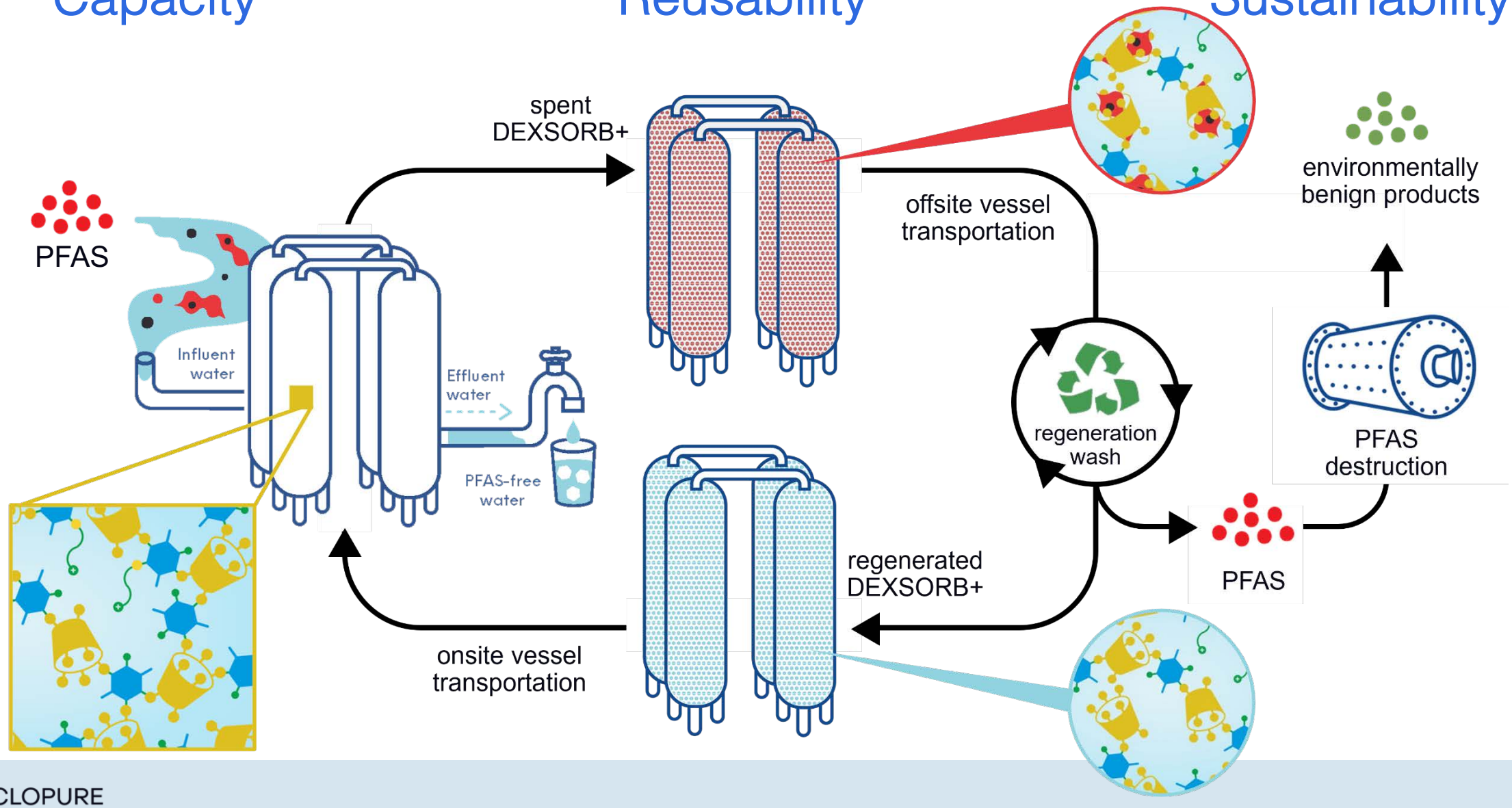
Sustainable Disposal

DEXSORB+ Treatment Train

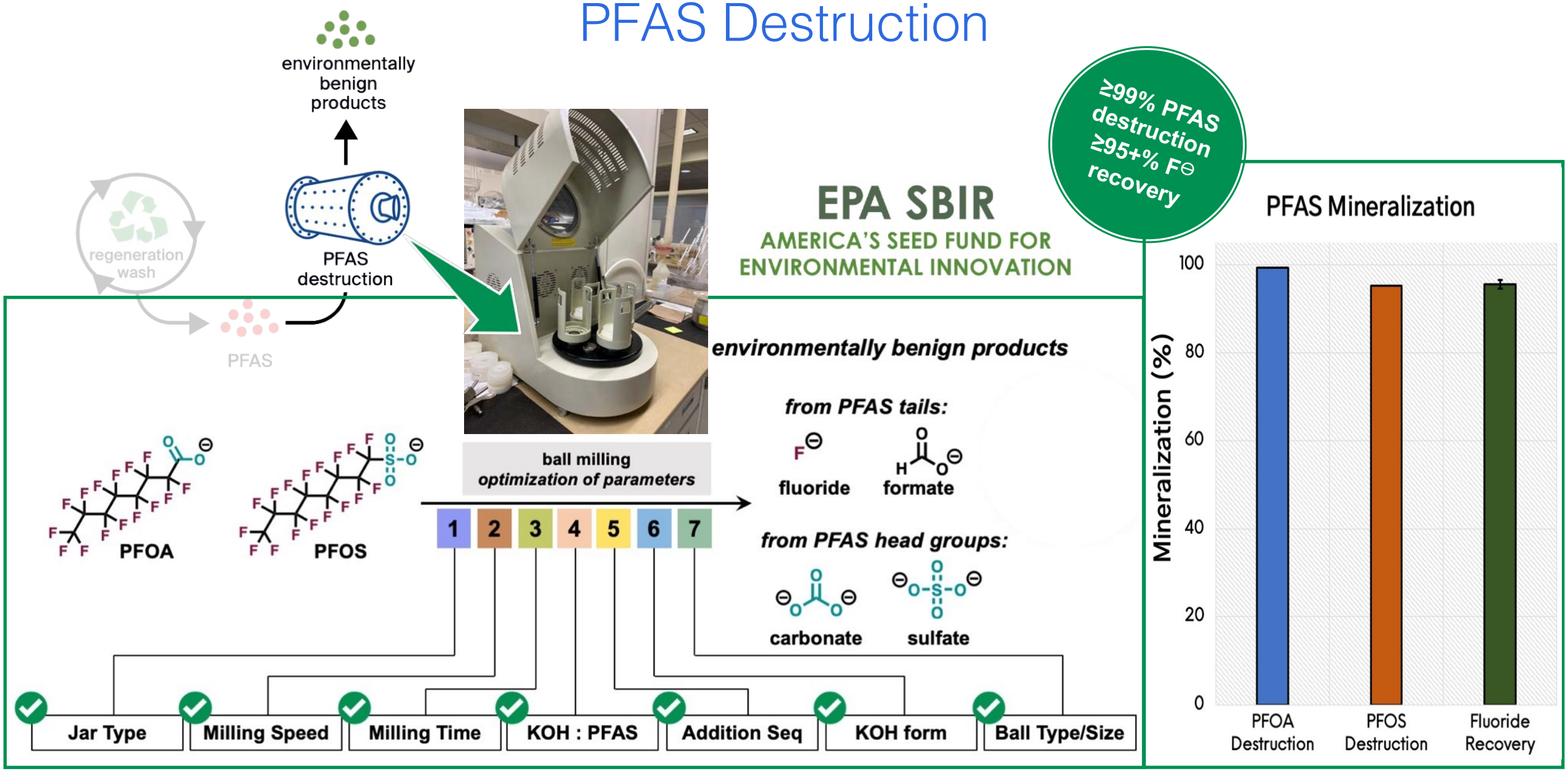
Capacity

Reusability

Sustainability

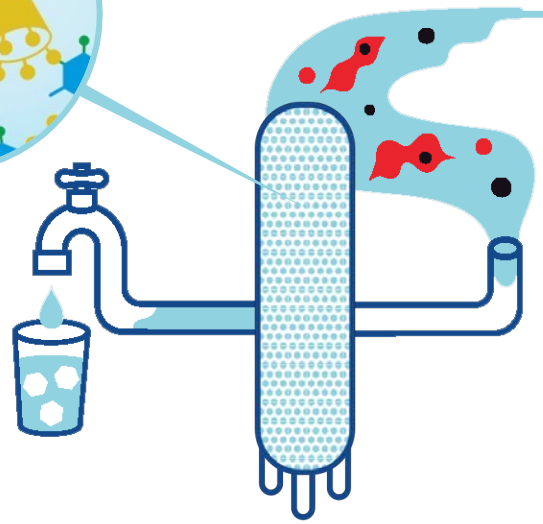


PFAS Destruction



DEXSORB Minimizes PFAS Wastestream

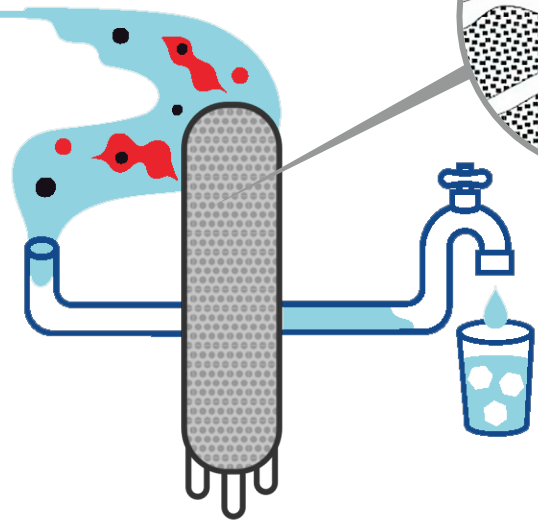
~5,000 kg
DEXSORB®



Treat 1 MGD for 1 year
(365 million gallons)
PFAS-contaminated water
From 100 ppt to non-detect

Regenerated DEXSORB can be used with full capacity.

140 grams
solid waste



~25,000 kg
GAC

single use

Environmental Engineering Group

Group Expertise

Engineering System

- ✓ Bench-Scale
  - Batch tests
  - RSSCT - Column tests
- ✓ Pilot-Scale
  - Packed bed filtration system
  - Fluidized bed system
  - Continuous stirred-tank reactor system
- ✓ Full-Scale System
- ✓ Fluid Dynamics and Hydraulic Modeling

Environmental Monitoring

- ✓ Grab sampling and passive sampling
- ✓ Suspect screening

Group Projects

PFAS Pilots

- **HDR**: North Carolina – Gravity filter at DWTP
- **GHD**: Michigan – PBF of industrial groundwater
- **Tetra Tech**: Virginia – PBF for NASA WWTP
- **AECOM**: California – PBF for Travis AFB
- **Hydranautics**: Pennsylvania – Leachate RO concentrate

Micropollutants Pilot

- **Witteveen + Bos**: Netherlands – PBF for WWTP

Yuhan Ling
Director, Environmental Engineering

Email: yling@cyclopure.com

- Dr. Ling **leads the application of DEXSORB** in engineered treatment systems and directs Cyclopure's Environmental Engineering pilot and field project program..
- He is an expert in the **design and implementation** of **adsorbents** in **water purification** applications, with extensive experience in the treatment of PFAS and other emerging contaminants.
- Dr. Ling is a co-inventor of DEXSORB, and received his Ph.D. in Environmental Engineering from Cornell University.

Selected Publications

First Author, *Chapter 14: Novel Cyclodextrin Polymer Adsorbents for PFAS Removal*, **Forever Chemicals**, 2021, Taylor & Francis Group, 291–313.

Co-Author, *Chapter: Water Quality in the Twenty-First Century: New Tools for the Characterization and Remediation of Emerging Chemical Contaminants*, **Technology, Science, and Culture: A Global Vision, Volume II**, 2020, IntechOpen, 27–41.

Ri Wang
Environmental Engineer

Email: rwang@cyclopure.com

- Ms. Wang manages **municipal projects** involving use of DEXSORB for PFAS removal in drinking water, wastewater, groundwater, and landfill leachate.
- She has extensive experience in **advanced analytical methods** and manages Cyclopure's **environmental monitoring projects**.
- Ms. Wang has developed an advanced suspect screening method for PFAS, earned a Masters in Environmental Engineering from Cornell University.

Selected Publications

First Author, *Evaluating the Removal of Per- and Polyfluoroalkyl Substances from Contaminated Groundwater with Different Adsorbents Using a Suspect Screening Approach.* **Environmental Science & Technology Letters**. 2020, 7, 12, 954-960.

Co-Author, *Evaluation, Optimization, and Application of Three Independent Suspect Screening Workflows for the Characterization of PFASs in Water*. **Environmental Science: Processes & Impacts**. 2021, 23, 1554-1565.