12.05.2024

DEXSORB for PFAS

Materials Science | Analytics | Engineering

Founded in 2016

DEXSORB® Adsorbent for PFAS.

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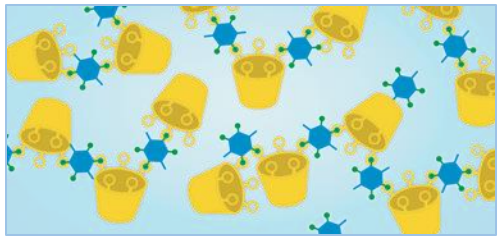
Technology Overview



Renewable beta-cyclodextrins designed for hydrophobic interaction with PFAS

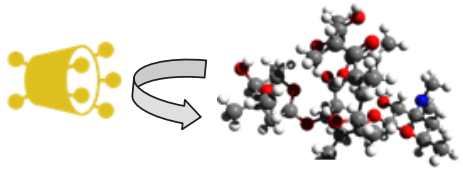
DEXSORB® Granules

- Flow through hydraulics
- Not affected by competing organics and ions
- Rapid kinetics and high capacity

Molecular Selectivity with High Capacity

PFAS

Uniform 0.78 nm cyclodextrin cups provide **Molecular Selectivity (150 to 1000 Daltons)** to all PFAS targeted in EPA Roadmap.



NOM, FOG & Ions

Size-Exclusion avoids competition by natural organic matter, FOG (fat, oil and grease), inorganic ions, pH and hardness.

DEXSORB Advantages

	DEXSORB Granules
Treatment Mechanism	Hydrophobic Adsorption with **Molecular Selectivity** for PFAS
System Footprint (Empty Bed Contact Time)	**Short** EBCT; Compact system design with **25% media loading** of GAC
Treatment Capacity (Media Operating Life)	**High** Treatment Capacity; Lead-vessel media replacement every **12 to 18 months**
Reusability & Waste	**Reusable** with Ambient Regeneration; **Small-volume**, concentrated PFAS waste
PFAS Waste Handling	**Efficient** PFAS Waste Processing by Destruction Technologies
Treatment Cost	**Low Cost Per Kgal**; Including DEXSORB Media, Media Regeneration, Waste Handling with **Certificate of Destruction**

DEXSORB® Commercial Use.

Water Testing | Residential Filtration | Engineered Systems

NSF 61 certified

Engineered System Market.

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Drinking Water

Surface Water

Groundwater Well

Distributor

Flow Rate > 2 MGD

large

kemira

Direct

AQUA
An Essential Utilities Company

RIVIERA UTILITIES
Serving South Baldwin County

NORTHERN UTILITY SERVICES

Contractor

Flow Rate ≤ 2 MGD (wells)

small

KURITA

Non-Drinking Water

Groundwater Remediation

Wastewater

Leachate

Contractor

Engineering Firms

AECOM

GES

GMC
Goodwyn Mills Cawood

GHD

BLACK & VEATCH

DoD

U.S. Department of Defense

DEFENSE INNOVATION UNIT

ESTCP

AIR FORCE CIVIL ENGINEER CENTER

Direct

WM
WASTE MANAGEMENT

REPUBLIC SERVICES

Operational Details

- Short empty bed contact time (EBCT) enables decreased footprint requirements:
  a) 10 minutes EBCT for groundwater remediation
  b) 4-6 minutes EBCT for drinking water treatment
  c) 10 minutes for municipal wastewater treatment

- Efficient One-Step Process:
  a) compatible with pressurized packed bed filtration and gravity filters

- Sustainable Use:
  a) Media Regeneration by Solution-based Desorption
  b) Desorption Waste Compatible with PFAS Destruction Technologies

- Minimal system O&M requirements for the clients:
  a) Smooth Hydraulics
  b) Low Pressure Prop
  c) Backwash Capable
  d) Temperature control to prevent freezing

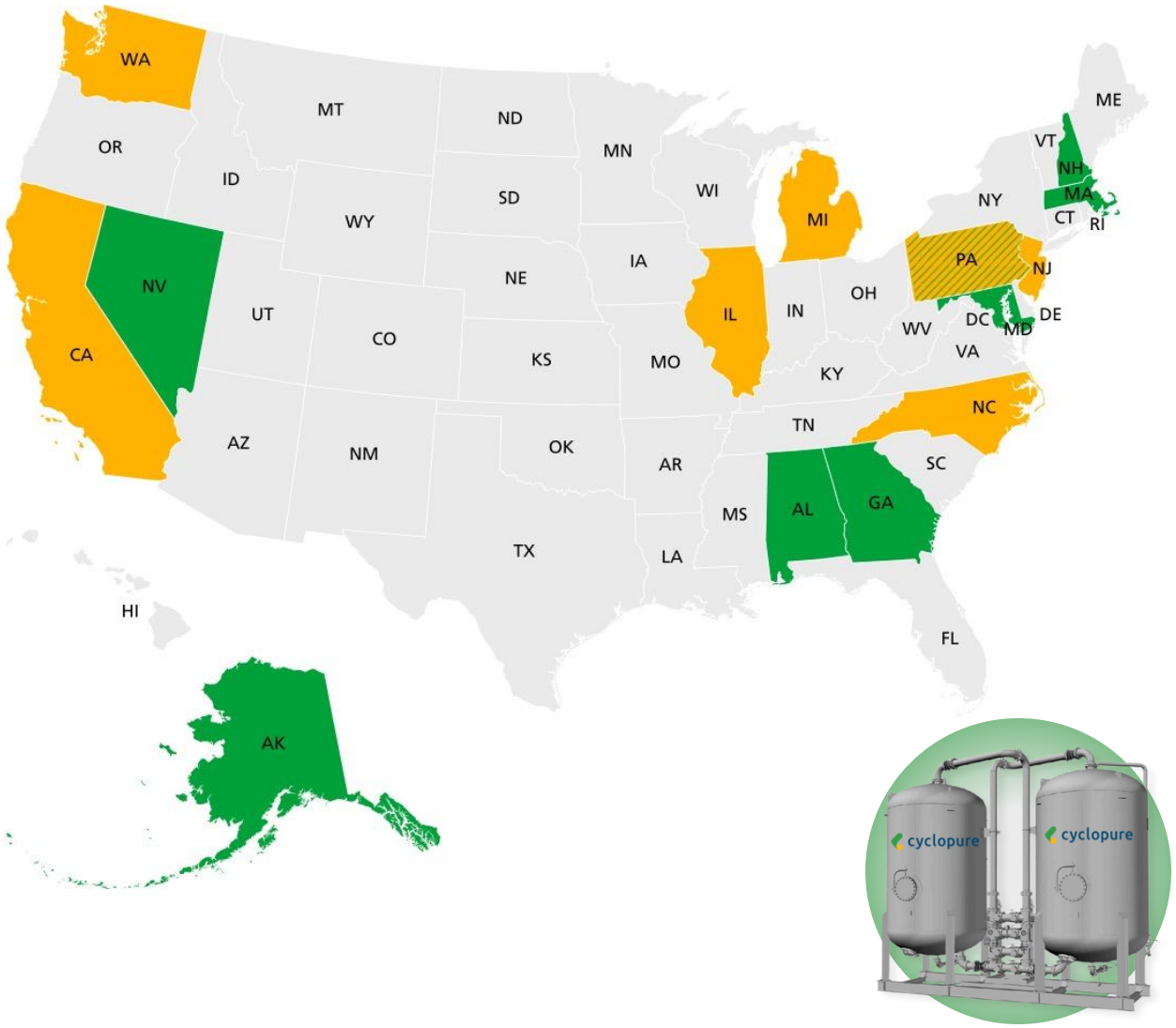
Treatability Study and Cost Estimate

- Quote with estimated costs can be provided with inputs on water quality parameters, flow rate, PFAS concentrations, and PFAS treatment target. Cyclopure offers Treatability Services, and on-site pilot validation at no charge to the client.

- Short turnaround time from order to operational installation.

DEXSORB PBF

Engineered Systems in the U.S.



	Engineering Firm	City	State	Water	Status
Drinking Water	AECOM	Newburyport	MA	Surface Water	Full-scale pending
	Tata & Howard	Lynnfield	MA	Groundwater	Pilot completed
	S.S. Papadopulos	Poolesville	MD	Groundwater	Pilot operating
	Riviera Utilities	Foley	AL	Groundwater	Pilot operating
	DOWL	Reno	NV	Groundwater	Pilot operating
	Environmental Partners	Randolph	MA	Surface Water	Full-scale scheduled
	Underwood Engineers	Merrimack	NH	Groundwater	Pilot scheduled
	Weston & Sampson		GA	Surface Water	Pilot scheduled
	Northern Utility Services	Nikiski	AK	Groundwater	Full-scale operating
	North Wales Water Authority	North Wales	PA	Groundwater	Pilot scheduled
	Passaic Valley Water Commission	Passaic	NJ	Surface Water	Pilot operating
	Kurita	Palm Beach	FL	Groundwater	Treatability Study Complete

	Client	City	State	Matrix	Status
Non-Drinking Water	HDR	Greensboro	NC	RO Concentrate	Pilot completed
	AECOM	Sacramento	CA	Groundwater	Pilot completed
	Flex-n-Gate Ventra	Ionia	MI	Wastewater	Pilot completed
	Waste Management	Rochester	NH	Landfill Leachate	Pilot operating
	Electro Chemical Finishing	Wyoming	MI	Wastewater	Full-scale operating
	Warminster Municipal Authority	Horsham	PA	Stormwater	Full-scale demo
	Defense Innovation Unit	Willow Grove	PA	Groundwater	Pilot operating
	GHD	Allen Park	MI	Landfill Leachate	Full-scale pending
	GES	Port Reading	NJ	Wastewater	Full-scale operating
	Waste Management	Zeeland	MI	Landfill leachate	Pilot completed
	Gerald Ford Airport	Grand Rapids	MI	Groundwater	Pilot scheduled
	Republic Services	Morgantown	PA	Landfill Leachate	Pilot complete
	WSP	Alpena	MI	Soil	Full-scale operating

Pilot-Scale DWTP Installations

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City of Newburyport
Surface Water Treatment in Newburyport, MA

MA PFAS6 Total = **63** ppt

Operation Period: **13** months

Performance: **No breakthrough** of MA PFAS6 with **5-min EBCT**

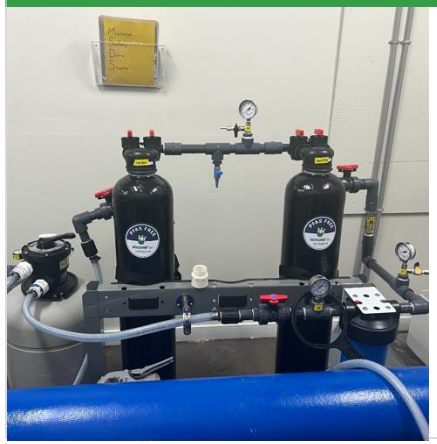
DOWL
Groundwater Treatment in Reno, NV

EPA PFAS6 Total: **56** ppt

Operation Period: **5** months

Performance: **No breakthrough** of EPA PFAS6 with **5-min EBCT**

Riviera Utilities
Groundwater Treatment in Foley, AL



EPA PFAS6 Total: **29** ppt

Operation Period: **17** months

Performance: **No breakthrough** of EPA PFAS6 with **5-min EBCT**

S.S. Papadopulos & Associates
Groundwater Treatment in Poolesville, MD

EPA PFAS6 Total: **69** ppt

Operation Period: **18** months

Performance: **No breakthrough** of EPA PFAS6 with **5-min EBCT**

Passaic Valley Water Commission
Surface Water Treatment in Totowa, NJ

EPA PFAS6 Total: **25** ppt

Operation Period: **4** months

Performance: **No breakthrough** of EPA PFAS6 with **5-min EBCT**

Scheduled DWTP Pilot Installations (Q1 2025)

- North Wales Water Authority: Groundwater Treatment in North Wales, PA
  - EPA PFAS6 Total: **29** ppt
- Underwood Engineers: Groundwater Treatment in Merrimack, NH
  - EPA PFAS6 Total: **89** ppt

Full-Scale DWTP Installations

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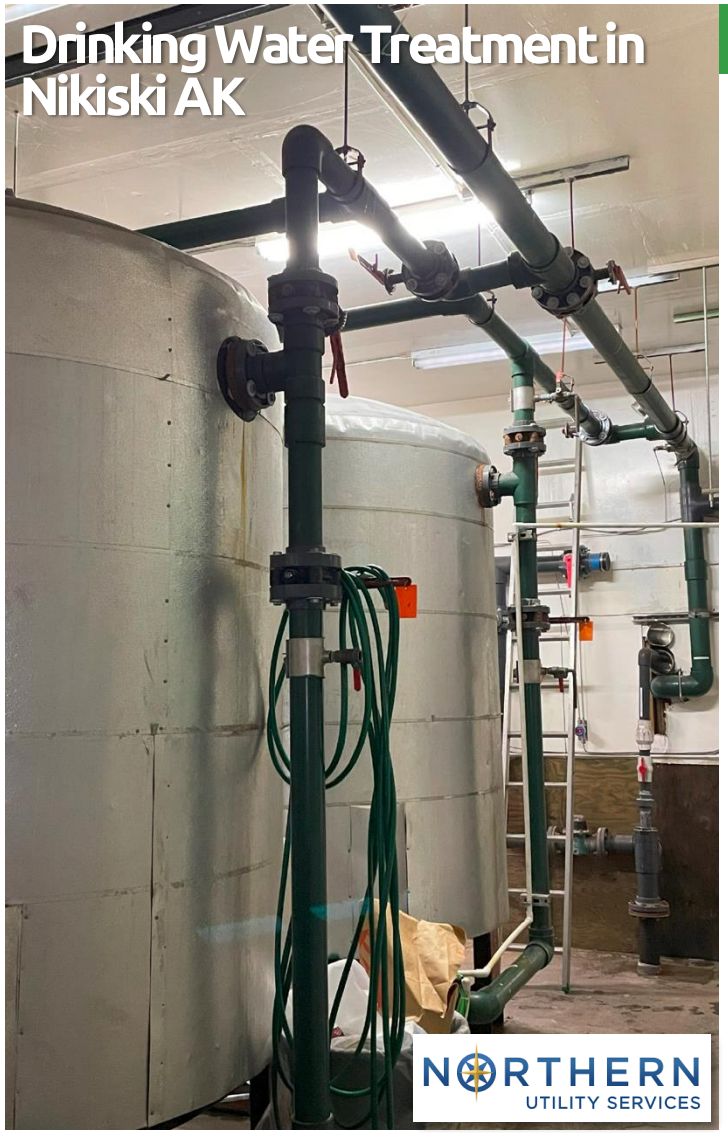

Operation Details

PFAS Background:
- PFOA = 67 ppt
- PFOS = 710 ppt

Flow Rate: **125** gpm

DEXSORB System:
- EBCT: **9** minutes
- Media Loading: **4,685** lbs

Operation Details

PFAS Background:
- Mass DEP PFAS6 = 17 to 31 ppt

Flow Rate: **240** gpm

DEXSORB System:
- EBCT: **4** minutes
- Media Loading: **3,968** lbs
- Gravity filter

DEXSORB is approved for use in DWTP by Mass DEP

MassDEP

Operation Details

PFAS Background:
- EPA PFAS6 = 19 ppt

Flow Rate: **1.3** MGD

DEXSORB System:
- EBCT: **5** minutes
- Media Loading: **20,688** lbs
- Gravity Filter

DEXSORB End to End: Remove | Concentrate | Destroy

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INFORMATIONAL SESSION AND TOUR

NASJRB Willow Grove & Biddle ANG Base
PFAS Treatment Demonstration Day

ESTCP DEFENSE INNOVATION UNIT

- TUESDAY, 20 AUGUST 2024

PFAS Removal

PFAS-impacted water

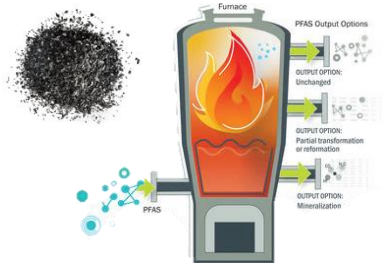
PFAS Concentration

Used Regeneration Solution

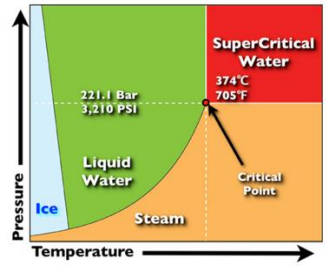
Solvent Recycling

Destruction

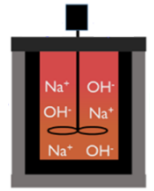
Thermal



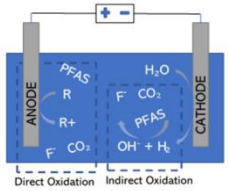
Supercritical Water Oxidation (SCWO)



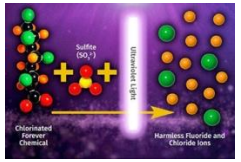
Hydrothermal Alkaline Treatment



Electrochemical Oxidation



Ultraviolet



PFAS Waste

Field Treatment Operation

Centralized Regeneration + Concentration Operation

Full-Service Operations – Mishawaka IN

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Vacuum Trucks

DEXSORB Inventory

Pilot Regeneration System

Treatability Services – Workflow & Material Use Rate Model

Cyclopure Engineering Workflow

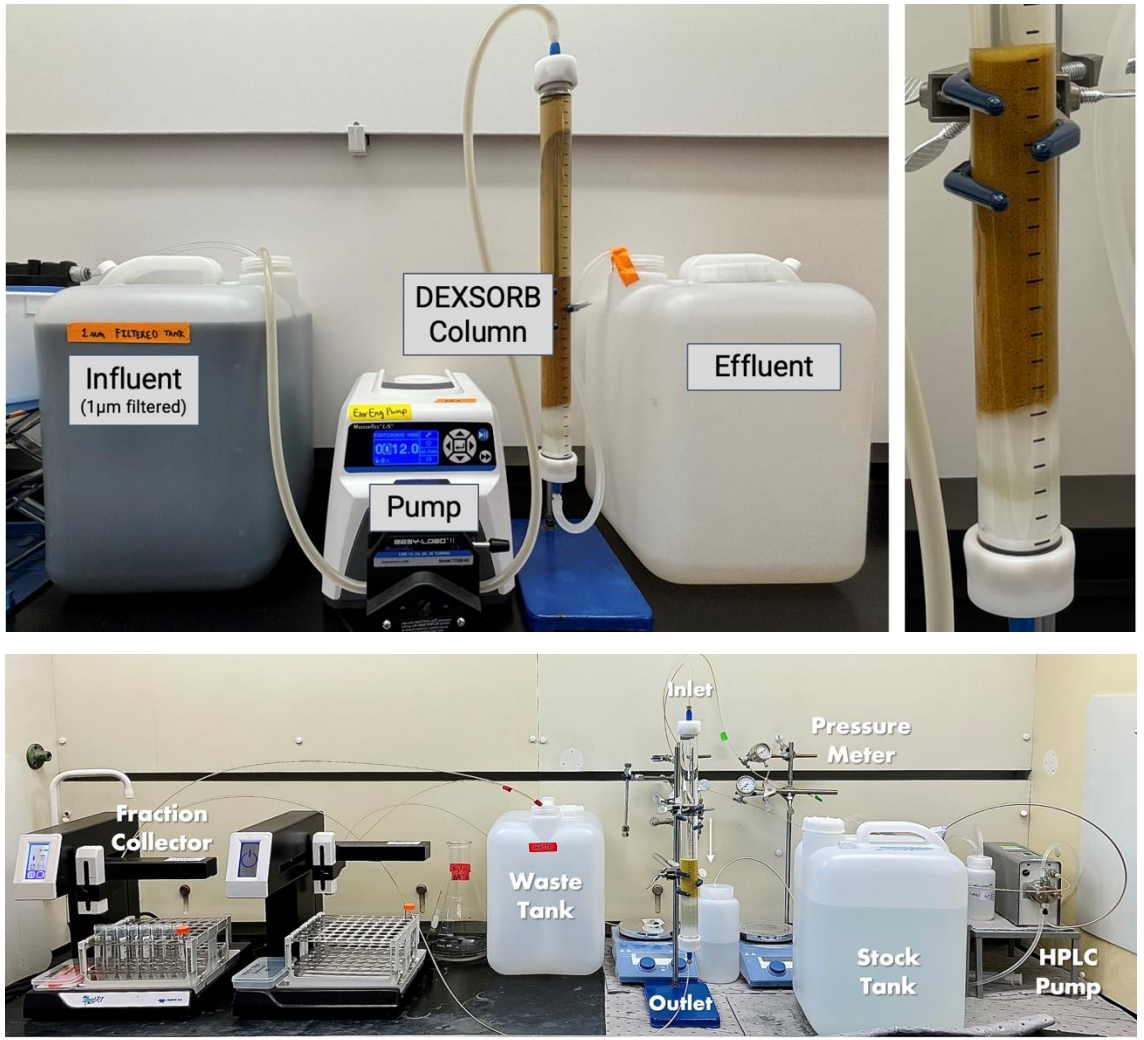
We provide comprehensive treatability services for each project: site analysis, lab-scale column tests, treatment capacity modeling, field pilot tests.

- **Site Analysis:** PFAS contamination profile, flow requirements, and survey existing infrastructure.
- **Sample Analysis**: Background PFAS analysis and lab-scale column testing.
- **Capacity Projection**: Apply material use rate model to project full-scale treatment capacity.
- **Field Piloting**: Pilot study at full-scale EBCT and HLR to validate effective PFAS treatment.

Material Use Rate Model

- Using field treatment data from over 30 projects, we have developed an accurate material use rate model based on Mass Transfer Theory.
- The modeling outcome has a confidence level of **95%** for wastewater processing.

Column Test Setup



Treatability Services – Field Pilot

Onsite Pilot Validation

Cyclopure engineers developed a compact, skid-mounted pilot system for field trial. Since 2022, we have deployed over 30 pilot DEXSORB system across the US for different water matrices.

- **Pilot System Design**: Using lab-scale column results, we design a pilot system to operate at full-scale EBCT and HLR.
- **Pre-Treatment**: If required by water characterization data, we design pilot scale pre-treatment for suspended solids.
- **Site Preparation**: Our engineers work with the client to create a split stream from the PFAS-impacted water source.
- **System Installation and Commission**: We procure and supply DEXSORB media and all system components required for pilot installation. Cyclopure engineers travel to the pilot location to supervise system assembly and commissioning.
- **Performance Monitoring**: Cyclopure provides PFAS sample analysis during the pilot free of charge to the client.

Field Pilot Systems

Municipal Wastewater

Industrial Wastewater

Landfill Leachate

Stormwater

Groundwater Remediation

Drinking Water

2024 August Proposal (Project 1)

Project 1 - GAC/Rurik Pretreatment for PFAS:

Flow Rate:

- *1,700 gpm = 2.45 mgd*
- *Well 5 = 750 gpm max; PFOA approx. 70 ppt; PFOS approx. 54 ppt;*
- *Well 6 = 950 gpm max; PFOA approx. 400 ppt; PFOS approx. 160 ppt.*

Lead/Lag

PFAS Treatment Goal. US EPA final PFAS drinking water MCL limits.

DEXSORB System Design

The DEXSORB system is designed to support an overall EBCT of 10 minutes with a total media loading of 71,000 lbs. DEXSORB media will be loaded into *two pairs* of pressurized vessels (a total of four vessels) to accommodate the flow capacity of 2.45 MGD (or 1,700 gpm). Each pair will consist of two 20,000-lb vessels arranged in a lead-lag configuration to treat a flow rate of 850 gpm, providing an overall EBCT of 10 minutes (5 minutes for the Lead vessel and 5 minutes for the Lag vessel). A Process Flow Diagram of this system is provided in **Process Flow Diagram.**

Based on the PFAS level and treatment goal, the DEXSORB system is projected to operate continuously for 18 months before the media replacement is required for the ***lead vessels.***

Spent Media Handling and Waste Disposal

In addition to the effectiveness and high capacity for PFAS removal, a unique feature of DEXSORB is that spent media can be regenerated under ambient conditions that isolates PFAS waste for efficient handling and destruction.

Following PFAS treatment, Cyclopure will regenerate spent DEXSORB media and concentrate the regeneration waste. Concentrated PFAS waste is compatible with destruction processes such as Hazardous Waste Incineration. Cyclopure will provide a Certificate of PFAS Destruction to Hartford County.

Table 1. DEXSORB System Design for Well 5&6 Groundwater.

Parameters		Unit
Overall System (Two Lead-Lag Units)		
Vessels	4	#
Lead-Lag Systems	2	#
Empty Bed Contact Time	10	min
Flow Rate	2.45	MGD
Total DEXSORB Loading	71,000	pounds
Max Pressure Drop	30	psi
Per Lead-Lag Unit		
Empty Bed Contact Time	10	min
Flow Rate	850	gpm
DEXSORB Loading	35,500	pounds
Per Vessel		
Empty Bed Contact Time	5	min
Hydraulic Loading Rate	7.5	gpm/ft²
Vessel ID	12	feet
Vessel Height	6.9	feet
Vessel Cross-section Area	113.1	ft²
Packed Bed Depth	5.0	ft
DEXSORB Loading	17,750	pounds
Empty Space Ratio	27	%
Estimated Pressure Drop	<15	psi

Cost Estimate

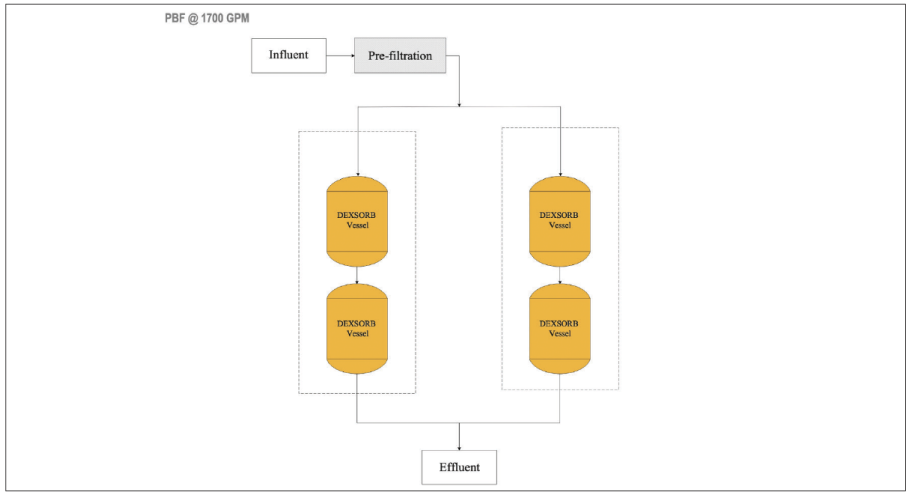
Item	Cost
Full-scale system installation costs are detailed below. The cost per 1,000 gallons treated[1] is the average media cost for the first three years. Costs include handling and destruction of PFAS in spent media.	
Initial Full-scale PFAS Treatment Install: Includes • Supply of two pairs of Tonka Water 20,000-lb Vessels with manifold, piping, valves and sensors of pressure and flow[2]; • 71,000 lbs of DEXSORB media for the groundwater treatment system, plus spent media handling and Certificate of Destruction for PFAS waste.	$ 1,200,000 (vessels) $ 1,127,189 (media)
Each Media Replacement Cost: Media change-out frequency is once *every 18 months for lead vessels only.* Includes DEXSORB media for two lead vessels (35,500 lbs), plus spent media handling and Certificate of Destruction for PFAS waste.	$ 563,594 (media)

[1] The unit treatment cost is estimated to be **$0.63 per 1,000 gallons water treated.**

[2] Each 20,000-lb vessel also includes:

- One (1) 24" round manway on sidewall
- One (1) 14" x 18" elliptical manway on top head
- Four (4) sample taps (sidewall (3): 25%/50%/75% media depth, effluent nozzle)
- Structural support legs
- Lifting lugs, as required
- Nozzles:
  - One (1) 10" influent water nozzle, flanged (top sidewall)
  - Eight (8) 10" effluent water effluent nozzles, flanged (bottom of head)
  - One (1) 4" top-sidewall Dexsorb fill, flanged
  - One (1) 4" bottom-head Dexsorb discharge, flanged
  - One (1) 2" air release/pressure release, threaded coupling
  - Three (3) ½" sample tap connections (sidewall), NPT, with SSTL sample taps and media retaining screens
  - Four (4) ½" pressure gauge/transmitter/sample connections (inlet (2) and outlet (2) nozzles), NPT (with gauge panels and pressure transmitters)

Process Flow Diagram



2024 August Proposal (Project 2 & 3)

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Project 2 - Drinking Water:

Assume 4 ppt total PFAS in influent

Flow Rates:

- *20 mgd*
- *30 mgd*
- *6 mgd*
- *4 mgd*

PFAS Treatment Goal. US EPA final PFAS drinking water MCL limits.

System Design and Cost Estimate.

The DEXSORB system is designed to support an overall EBCT of 4 minutes. For each design flow rate, DEXSORB media will be loaded into pressurized vessels arranged in a lead-lag configuration, providing *an overall EBCT of 4 minutes* (2 minutes for the Lead vessel and 2 minutes for the Lag vessel).

Based on the PFAS level and treatment goal, the DEXSORB system is projected to operate continuously for *18 months before the media replacement is required for the lead vessels*. It should be noted that the capacity projection is conservative towards the low end to guarantee performance.

Flow Rate		30 MGD	20 MGD	6 MGD	4 MGD
Capital	Number of Lead/Lag Systems	10	7	2	2
	Number of Vessels	20	14	4	4
	Vessel Type	20k-lb vessel	20k-lb vessel	20k-lb vessel	20k-lb vessel
	Total Vessel Cost	$6,000,000	$4,000,000	$1,200,000	$1,200,000
Media	Initial Install	$5,520,471	$3,680,314	$1,104,094	$736,063
	Each Changeout	$2,760,235	$1,840,157	$552,047	$368,031
	All Changeouts (3 years)	$2,760,235	$1,840,157	$552,047	$368,031
	Total Media Cost (3 years)	$8,280,706	$5,520,471	$1,656,141	$1,104,094
Unit Water Treatment Cost	$/kgal (Media only)	$0.25	$0.25	$0.25	$0.25

[1]Cost estimates based on the supply of Tonka Water vessels (ASME stamped) with manifold, piping, valves and sensors of pressure and flow.

Project 3 - Wastewater:

Assume 25 ppt total PFAS in influent

Flow Rates:

- *50 mgd*
- *20 mgd*
- *1 mgd*
- *0.1 mgd*

PFAS Treatment Goal. US EPA final PFAS drinking water MCL limits.

System Design and Cost Estimate.

The DEXSORB system is designed to support an overall EBCT of 10 minutes. For each design flow rate, DEXSORB media will be loaded into pressurized vessels arranged in a lead-lag configuration, providing *an overall EBCT of 10 minutes* (5 minutes for the Lead vessel and 5 minutes for the Lag vessel).

Based on the PFAS level and treatment goal, the DEXSORB system is projected to operate continuously for *15 months before the media replacement is required for the lead vessels.* It should be noted that the capacity projection is conservative towards the low end to guarantee performance.

Flow Rate		50 MGD	20 MGD	1 MGD	0.1 MGD
Capital	Number of Lead/Lag Systems	40	16	1	1
	Number of Vessels	80	32	2	2
	Vessel Type	20k-lb vessel	20k-lb vessel	20k-lb vessel	5k-lb vessel
	Total Vessel Cost[4]	$24,000,000	$9,600,000	$600,000	$70,800
Media	Initial Install	$23,001,961	$9,200,784	$460,039	$46,004
	Each Changeout	$11,500,981	$4,600,392	$230,020	$23,002
	All Changeouts (3 years)	$23,001,961	$9,200,784	$460,039	$46,004
	Total Media Cost (3 years)	$46,003,922	$18,401,569	$920,078	$92,008
Unit Water Treatment Cost	$/kGal (Media only)	$0.84	$0.84	$0.84	$0.84
	$/kGal (Media + Capital)	$1.26	$1.26	$1.36	$1.49

[4] Cost estimates based on the supply of Tonka Water vessels (ASME stamped) with manifold, piping, valves and sensors of pressure and flow.