YB TECHNOLOGIES, LLC

PFAS LEACHABILITY STUDY TRIALS:

MBT TREATMENT OF CONTAMINATED SITE SOIL

Prepared by: YB Technologies, LLC
Media: Soil
Location: Remediation Site - Michigan

YBT

Technologies for a Cleaner Future

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MBT Key Highlights for Leachable PFAS in Soil:

Core Capabilities

- Sequesters and fixates PFAS in soils and solids, preventing mobility and off-site migration.
- Mitigates PFAS transport to groundwater, including PFAS from AFFF-impacted soils.
- Reduces PFAS leachability under multiple regulatory extraction protocols (EPA Methods 1311 TCLP, 1312 SPLP, and modified 1312 fluids such as DI water, landfill leachate, and PFAS-impacted groundwater).

Performance & Stability

- Produces a stable treated end-product suitable for onsite management or disposal in RCRA Subtitle D or Subtitle C landfills.
- Demonstrated PFAS stability in treated soils:
  - <70 ppt leachable PFAS in SPLP (acid rain) testing, optimizable to < MDL.
  - <70 ppt leachable PFAS in TCLP landfill leachate testing, also optimizable to < MDL.
- Treated soils can retain PFAS under environmental exposure and, when optimized, can remove additional PFAS telomeres from landfill leachate or PFAS-contaminated groundwater contacting the treated material.

Treatment Flexibility

- Ex situ treatment: Batch or continuous feed systems with throughput from <1 to >250 tons/hour.
- In situ treatment: Applicable from near-surface lifts down to >50 feet with appropriate mixing equipment.
- Reagents do not chemically alter PFAS, meaning no PFAS degradation by-products or intermediates are generated.

Proven Testing & Scalability

- Bench and engineering-scale demonstrations completed on 300 g to 50 lb soil, sediment, and biosolid samples.
- Treatability studies tailor the process to project-specific leachability targets and regulatory test requirements.

Licensing

- MBT is licensed to Yost Brothers, LLC, with treatability studies, field trials, and full-scale applications delivered through YB Technologies, LLC.

Project Overview

These projects aim to assess the performance of MBT (Molecular Bonding Technology) in reducing leachable PFAS concentrations in impacted soils. Testing will be conducted on soil samples originating from a remediation sites in Michigan. The study will be performed at bench to engineering scale using batch-mode treatment processes. Post-treatment leachability will be evaluated under multiple regulatory and field-relevant conditions to determine treatment efficacy across a range of environmental scenarios.

Technology Description

Technology: MBT Technology for Sequestration of PFAS
Treatment Scale:

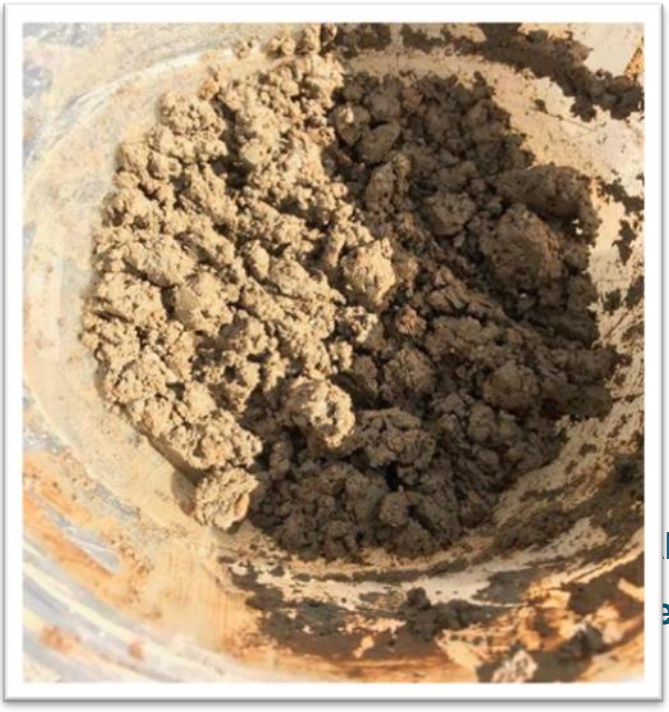
- Bench to engineering scale
- Batch mode treatment
- Sample mass per batch: **300 g to 25 kg**

Treatment Objectives: To evaluate PFAS leachability pre- and post-treatment

Regulatory Leach Tests

- EPA Method 1311 – TCLP (Toxicity Characteristic Leaching Procedure)
- EPA Method 1312 – SPLP (Synthetic Precipitation Leaching Procedure)

Results Summary-All studies show reduction in PFAS.



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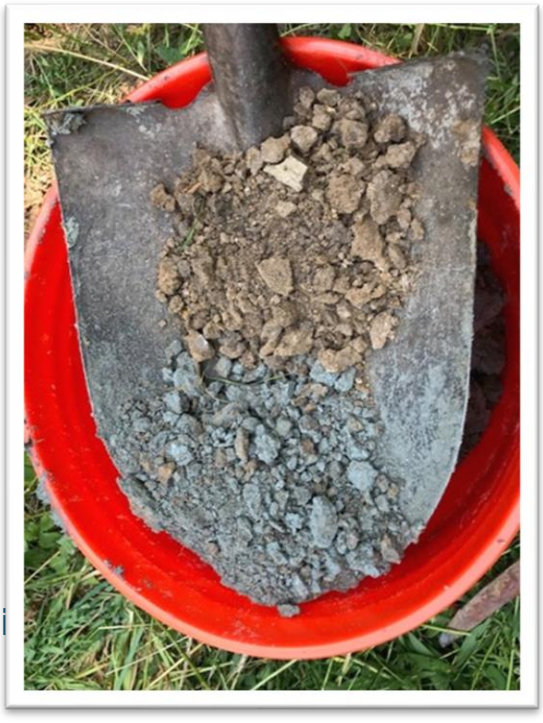

TRIAL #1
Eastern Michigan Remediation Site Soil

PFAS Leachability: Method 1311 (TCLP) & ASTM D7979-17

			UNTREATED Soil	MBT TREATED Soil			
Telomere	Chemical Name	C Atoms	Totals in Soil Extract (ng/L)	F-1 Soil Extract (ng/L)	F-2 Soil Extract (ng/L)	F-3 Soil Extract (ng/L)	F-4 Soil Extract (ng/L)
PFHxA	Perfluorohexanoic Acid	C6	4.15J	<4.0	<4.0	<4.0	<4.0
PFHpA	Perfluoroheptanoic Acid	C7	<4.0	<4.0	<4.0	<4.0	<4.0
PFOA	Perfluorooctanoic Acid	C8	<4.0	<4.0	<4.0	<4.0	<4.0
PFNA	Perfluorononanoic Acid	C9	<4.0	<4.0	<4.0	<4.0	<4.0
PFDA	Perfluorodecanoic Acid	C10	<4.0	<4.0	<4.0	<4.0	<4.0
PFUnA	Perfluoroundecanoic Acid	C11	<4.0	<4.0	<4.0	<4.0	<4.0
PFDoA	Perfluorododenoic Acid	C12	<4.0	<4.0	<4.0	<4.0	<4.0
PFTriA	Perfluorortridecanoic Acid	C13	<4.0	<4.0	<4.0	<4.0	<4.0
PFTeA	Perfluortetradecanoic Acid	C14	<4.0	<4.0	<4.0	<4.0	<4.0
PFBS	Perfluorobutanesulfonic Acid	C4	<4.0	<4.0	<4.0	<4.0	<4.0
PFHxS	**Perfluorohexanesulfonic Acid**	**C6**	**14.3**	**<4.0**	**<4.0**	**<4.0**	**<4.0**
PFOS	**Perfluorooctanesulfonic Acid**	**C8**	**105**	**<4.0**	**16.7**	**<4.0**	**<4.0**

PFAS Totals: EPA 537M

			UNTREATED Soil	MBT TREATED Soil			
Telomere	Chemical Name	C Atoms	Totals in Soil (ug/Kg)	F-1 Soil (ug/Kg)	F-2 Soil (ug/Kg)	F-3 Soil (ug/Kg)	F-4 Soil (ug/Kg)
PFHxA	Perfluorohexanoic Acid	C6	<.21	<.23	<.22	<.24	<.23
PFHpA	Perfluoroheptanoic Acid	C7	<.26	<.29	<.28	<.30	<.29
PFOA	Perfluorooctanoic Acid	C8	<.26	<.29	<.28	<.30	<.29
PFNA	Perfluorononanoic Acid	C9	<.26	<.29	<.28	<.30	<.29
PFDA	Perfluorodecanoic Acid	C10	<.26	<.29	<.28	<.30	<.29
PFUnA	Perfluoroundecanoic Acid	C11	<.26	<.29	<.28	<.30	<.29
PFDoA	Perfluorododenoic Acid	C12	<.26	<.29	<.28	<.30	<.29
PFTriA	Perfluorortridecanoic Acid	C13	<.26	<.29	<.28	<.30	<.29
PFTeA	Perfluortetradecanoic Acid	C14	<.26	<.29	<.28	<.30	<.29
PFBS	Perfluorobutanesulfonic Acid	C4	<.26	<.29	<.28	<.30	<.29
PFHxS	**Perfluorohexanesulfonic Acid**	**C6**	**0.837J**	**0.307J**	**0.543J**	**<.30**	**<.29**
PFOS	**Perfluorooctanesulfonic Acid**	**C8**	**13.90**	**3.93**	**7.21**	**2.77**	**2.76**
EtFOSSA	N-Ethylperfluorooctrane	C12	<.52	<.58	<.56	<.60	<.59
MeFOSAA	N-Methylperfluorooctrane	C11	<.52	<.58	<.56	<.60	<.59

Note: J - analyte was positively identified, but numeric value reported was approximated.

Trial 1 Notes – Effects of MBT Treatment to Leachable TCLP and Total PFAS in Soil:

a. Soil provided by Job Site Services, Inc. of Bay City, MI was sourced from a remediation site in eastern Michigan.

b. A site soil grab-composite sample collected in a 5-gallon bucket was thoroughly mixed at the lab with a small cement mixer. 500g aliquots of soil were subsampled from the mixed sample matrix and treated for each process run. Soil was placed in tared beakers on a top-load analytical balance. MBT reagent blends were added on a gravimetric % weight basis to mixed as-received soil. Water was added for mixing to achieve an apparent "loose" soil consistency, but with no free liquids. MBT reagents, soil, and water were mixed to apparent homogeneity with a spatula by folding and knifing to replicate blending achievable in the field.

c. Test methods included EPA 537-M for PFAS as totals in soil, Method 1311-TCLP for soil extraction, and ASTM 7979-17 for PFAS in water and extraction fluids.

d. Untreated and MBT treated soil samples were characterized for PFAS telomeres as totals in soil and in the soil's TCLP extract. Leachable PFOS was found in TCLP extract of untreated soil at a 105ng/L (ppt), above the USEPA advisory level of 70ppt for drinking water.

e. Two (2) MBT treatment reagent families were applied with MBT System A reagents to samples F-1 and F-3, and MBT System B reagents to samples F-2 and F-3. Variations within each of the MBT reagent systems related to reagent component blend ratio's, and blended reagent dose rate (wt. %) to untreated soil.

f. Treated samples were allowed to react for a period of 2-4 hours before transfer to a sample container and shipment under Chain-of-Custody protocols to the analytical laboratory.

g. All MBT treated soils resulted in the reduction of PFAS leachability compared to untreated material, and to below the USEPA advisory level of 70ppt for drinking water. While MBT treated sample F-2 sample did contain leachable PFOS at 16.7 ng/L, MBT treatments F-1, F-3 and F-4 reduced the leachability of PFAS to below the analytical detection limit. Notably, leachable PFOS was reduced by >96% compared to untreated material in these treatments.

h. MBT treatment also reduced total PFAS concentration where PFOS in samples F-3 and F-4 was reduced by ~80%. MBT treatment technology does NOT destroy PFAS, but it is likely that the MBT treated soil retained PFAS in a manner such that PFAS was not readily eluted from the soil using the methanol solvent eluant prescribed by the analytical method (EPA 537-M).

TRIAL #2
Western Michigan Remediation Site Soil

PFAS Leachability: (MODIFIED) Method 1312 (Deionized Water Extraction Fluid)

			UNTREATED Soil					MBT TREATED Soil	
Telomere	Chemical Name	C Atoms	Totals in Soil (ng/Kg)	Totals in Soil (Replicate) (ng/Kg)	Totals in Soil (avg.) (ng/Kg)	Totals in DI Water (ng/L)	Totals in Soil Extract (ng/L)	T-1 Soil Extract (ng/L)	T-2 Soil Extract (ng/L)
PFBA	Perfluorobutanoic Acid	C4	<0.27	264	264	ND	<49	<50	<50
PFOA	**Perfluorooctanoic Acid**	**C8**	**618**	**453**	**536**	**ND**	**13**	**<10**	**<10**
PFDA	Perfluorodecanoic Acid	C10	1,300	1,050	1,175	ND	<49	<50	<50
PFDoA	Perfluorododenoic Acid	C12	474	313	394	ND	<49	<50	<50
PFTeA	Perfluortetradecanoic Acid	C14	1270	<0.25	1,270	ND	<49	<50	<50
PFOS	**Perfluorooctanesulfonic Acid**	**C8**	**34,400**	**24,800**	**29,600**	**ND**	**660**	**<10**	**<10**
PFNS	Perfluorononanesulfonic Acid	C9	438	254	346	ND	<49	<50	<50
PFDS	Perfluorodecanesulfonic Acid	C10	864	665	765	ND	<9.7	<10	<10
PFOSA	Perfluorooctanesulfonaminde	C8	7,240	5,290	6,265	ND	110	<10	<10
EtFOSSA	N-Ethylperfluorooctrane	C12	5,100	3,010	4,055	ND	69	<50	<50

Notes: Trial 2 – (modified) Method 1313 – DI Water Extraction:

a. Study soil was obtained from a PFAS remediation site in Western Michigan.

b. Michigan list of "24" PFAS telomeres were analyzed as totals in soils using EPA Method 537M-ID. Telomeres below detection limits in untreated soil as totals are not listed.

c. Thoroughly mixed untreated soil was subsampled in replicate and each replicate was analyzed to evaluate heterogeneity of PFAS telomere concentrations within the matrix.

d. The average of replicate sample total PFAS telomere results for untreated material are utilized for comparison in other extraction data tables, herein.

e. PFAS leachability in untreated and MBT treated soil was evaluated using USEPA (modified) Method 1312 where laboratory-grade deionized water was used as the method extraction fluid, replacing acid-rain for the eastern US; and ASTM Method D7979-17 was utilized to evaluate PFAS telomere in the resultant extracts.

f. Presented PFAS in DI water data was from the laboratory QA/QC report

g. MBT treatments T-1 and T-2 were applied to duplicate ~2000 Kg split samples of thoroughly mixed untreated material.

h. MBT treatments T-1 and T-2 were analyzed using other extraction methods and fluids in subsequent analytical evaluations with data presented in the accompanying tables.

i. PFOS and PFOSA telomeres did leach from untreated soil using (modified) Method 1312 – DI water at concentrations that exceeded the USEPA PFAS advisory level of 70ppt for drinking water, and where PFOA and EtFOSSA were present at levels above the detection limit, but below the advisory level.

j. PFAS telomeres in treated material extracts were all below the EPA advisory level of 70ppt, and the analytical detection limits by telomere as indicated.

PFOS leachability, in particular, was reduced from MBT treatment by over 98.4% from its level in untreated soil

PFAS Leachability: Method 1312 (SPLP: acid rain - Eastern U.S.)

	UNTREATED Soil		MBT TREATED Soil	
Telomere	Totals in Soil (avg.) (ng/Kg)	Totals in SPLP Extract (ng/L)	T-1 Soil SPLP Extract (ng/L)	T-2 Soil SPLP Extract (ng/L)
PFBA	264	<4.0	<50	<50
PFOA	**536**	**16.9**	**<10**	**<10**
PFDA	1,175	23.2	<50	<50
PFDoA	394	<4.0	<50	<50
PFTeA	1270	<4.0	<50	<50
PFOS	**29,600**	**742**	**<10**	**<10**
PFNS	346	5.95	<50	<50
PFDS	765	5.09	<10	<10
PFOSA	6,265	172	<10	<10
EtFOSSA	4,055	87.7	<50	<50

Notes: Trial 2 – Method 1312 – SPLP (acid-rain) Extraction:

a. Untreated soil and MBT treated soil split samples of T-1 and T-2 from the previous study were evaluated for PFAS leachability using Method 1312 – SPLP (acid rain for the eastern US) with PFAS telomere concentrations quantified in resultant extracts.

b. PFOS and EtFOSSA telomeres leached from untreated soil into SPLP (acid rain) extraction fluid at levels that exceeded the USEPA advisory level of 70ppt for drinking water while other telomeres were quantified at lower levels, but above the analytical detection limits.

c. No PFAS telomere leached from MBT treated soil into SPLP acid rain extraction fluid in excess of the EPA advisory limit for drinking water, or in excess of the analytical detection limit.

d. PFOS leachability was reduced by MBT treatment by over 98.6% in both samples T-1 and T-2.

e. The data allows for consideration of onsite management options for MBT treated material vs. offsite disposal in that PFAS will not leach from treated materials when exposed to acid rain.

f. Data supports technology use to mitigate PFAS migration at release/spill sites (such as from AFFF used for fighting fires) from near surface soils to underlying groundwater due to percolation of surface water and precipitation (rain and snow melt).

PFAS Leachability: Method 1311 (TCLP)						
	UNTREATED Soil		MBT TREATED Soil			
	Totals in Soil (avg.)	Totals in TCLP Extract	T-1 Soil Extract	T-2 Soil Extract	T-3 Soil Extract	T-4 Soil Extract
Telomere	(ng/Kg)	(ng/L)	(ng/L)	(ng/L)	(ng/L)	(ng/L)
PFBA	264	50,000	49,000	50,000	<50	<50
PFOA	**536**	**4,400**	**1,800**	**1,000**	**<10**	**<10**
PFDA	1,175	<50	<50	<50	<50	<50
PFDoA	394	<50	<50	<50	<50	<50
PFTeA	1270	<50	<50	<50	<50	<50
PFOS	**29,600**	**1,700**	**1,500**	**630**	**<10**	**<10**
PFNS	346	<50	<50	<50	<50	<50
PFDS	765	<50	<50	<50	<10	<10
PFOSA	6265	<50	20	<50	<50	<50
EtFOSSA	4,055	62	<50	<50	<50	<50

Notes: Trial 2 – Method 1311 – TCLP Extraction:

a. MBT treated soil split samples of T-1 and T-2 from the previous study were evaluated for PFAS leachability using Method 1311 – TCLP with PFAS telomere concentrations quantified in resultant extracts.

b. MBT treatments T-3 and T-4 were performed based on results from analyses of T-1 and T-2. T-3 and T-4 MBT treatments applied the MBT treatment reagent family regimens used in T-1 and T-2, respectfully, however reagent component ratio's and overall dosing to the soil was adjusted. The PFAS leachability differences between T-1 and T-2 when analyzed by the synthetic landfill leachate of the TCLP extraction method clearly demonstrates the enhanced severity of the test method over those of Method 1312 -SPLP and the modified version using deionized water. The chemistry of the TCLP fluid caused more PFAS to leach from the untreated material, as well as in the MBT treated samples T-1 and T-2. The leachability of PFOA and PFOS telomeres was significantly in untreated and both T-1 and T-2 treated materials

c. MBT treatments T-3 and T-4 both effectively reduced all PFAS telomere leachability from soil into the synthetic landfill leachate of Method 1311 – TCLP. Leachable PFAS telomeres from treated soil were reduced to below the EPA advisory level of 70ppt in TCLP extract, and also to below analytical method detection limits.

d. PFOA leachability was reduced by MBT treatment by over 99.7% and PFOS leachability was reduced by over 99.4%

e. The data indicates that the MBT treated material using the regimes of T-3 or T-4 is suitable for acceptance and disposal by licensed RCRA Subtitle D non-hazardous waste landfill facilities.

PFAS Leachability: (Modified) Method 1312 with Subtitle D Landfill Leachate Extraction Fluid

		UNTREATED Soil and Subtitle D Landfill Leachate			MBT TREATED Soil		
Telomere	Chemical Name	Totals in Soil (avg.) (ng/Kg)	Totals in Landfill Leachate (ng/L)	Totals in Soil Extract (ng/L)	T-2 Soil Extract (ng/L)	T-3 Soil Extract (ng/L)	T-4 Soil Extract (ng/L)
PFBA	Perfluorobutanoic Acid	264	1,900	1,800	1,500	1,500	1,300
PFOA	**Perfluorooctanoic Acid**	**536**	**680**	**490**	**200**	**170**	**110**
PFDA	Perfluorodecanoic Acid	1,175	230	57	<50	<50	<50
PFDoA	Perfluorododenoic Acid	394	<50	<50	<50	<50	<50
PFTeA	Perfluortetradecanoic Acid	1270	<50	28	<50	<50	<50
PFOS	**Perfluorooctanesulfonic Acid**	**29,600**	**450**	**<10**	**52**	**38**	**33**
PFNS	Perfluorononanesulfonic Acid	346	<50	<50	<50	<50	<50
PFDS	Perfluorodecanesulfonic Acid	765	<10	<10	<10	<10	<10
PFOSA	Perfluorooctanesulfonaminde	6265	<10	28	<10	<10	<10
EtFOSSA	N-Ethylperfluorooctrane	4,055	<10	<50	<50	<50	<50

Notes: Trial 2 – (modified) Method 1312 – Subtitle D landfill Leachate Extraction:

a. Leachate from a licensed RCRA Subtitle D non-hazardous waste landfill leachate collection system was used as the substitute extraction fluid for synthetic acid rain in (modified) Method 1312.

b. The leachate was analyzed for PFAS telomeres as a separate liquid sample prior to extraction of any samples. PFBA, PFOA, PFDA, and PFOS telomeres were identified in the leachate at concentrations that exceeded the EPA advisary level of 70ppt, at 1900, 680, 230, and 450 ng/L (ppt), respectively.

c. Untreated soil and MBT treated samples T-2, T-3, and T-4 were all extracted using (modified) Method 1312 with the landfill leachate as the extraction fluid and PFAS telomeres were quantified in the resultant extracts.

d. Data indicated that the untreated soil was able to remove some of the PFAS telomeres from the landfill leachate during the extraction process, however, ~28 ng/L of PFOSA was leached from the soil by the fluid.

e. PFAS telomeres in the landfill leachate extracts of all MBT treated samples were at concentrations that were less than their respective concentrations in the leachate used for the extractions, and in the leachate extract of untreated soil.

f. PFBA in extracts of treated samples was not significantly reduced in concentration from its concentration in the landfill leachate, thus requiring further optimization of the MBT process.

g. The MBT treatment regime as applied in sample T-4 reduced leachable PFAS to a larger degree than the regimen applied to T-2 and T-3, with PFOA reduced by >83%, PFDA by >78%, and PFOS by >92% from their respective concentrations in the actual landfill leachate.

h. MBT treated soil reduced PFAS telomere leaching into leachate to levels below both those found in untreated soil extracts, and in the leachate fluid obtained directly from the landfill

i. With optimization, MBT treated material will retain its PFAS and can remove PFAS from leachate that contacts the interned material in a Subtitle D landfill.

PFAS Leachability: (MODIFIED) Method 1312 (Site Groundwater Extraction Fluid)

	UNTREATED Soil and Groundwater			MBT TREATED Soil	
Telomere	Totals in Soil (avg.) (ng/Kg)	Totals in Groundwater Extract (ng/L)	Totals in Soil Extract (ng/L)	T-2 Soil Extract (ng/L)	T-4 Soil Extract (ng/L)
PFBA	264	640	620	144	144
PFOA	**536**	**100,000**	**94,000**	**220**	**89**
PFNA	<0.26	86	70	<10	<10
PFDA	1,175	96	57	<50	<50
PFDoA	394	<50	<50	<50	<50
PFTeA	1270	<50	<50	<50	<50
PFOS	**29,600**	**390,000**	**190,000**	**230**	**121**
PFNS	346	<50	<50	<50	<50
PFDS	765	<10	<10	<10	<10
PFOSA	6,265	63	120	<10	<10
EtFOSSA	4,055	<50	140	<50	<50

Notes: Trial 2 – (modified) Method 1312 – Subtitle D landfill Leachate Extraction:

a. Contaminated groundwater was collected from a monintoring well at the western Michigan site where the PFAS impacted soil was obtained for this study.

b. Site groundwater was analyzed for PFAS telomeres as totals in the fluid. PFOA and PFOS were present at concentrations of 100,000 and 390,000 ppt, respectively, with other telomeres also present at much lower concentrations.

c. Site groundwater was substituted for the synthetic acid rain extraction fluid of Method 1312 as a method modication for analytical sample preparations of untreated and MBT treated site soils.

d. Untreated and MBT treated soil samples T-2 and T-4 were extracted with the site groundwater and PFAS telomeres were quantified in the resultant extracts.

e. As also evident in the previous landfill leachate sample data, leachable PFAS telomere concentrations were reduced during the extraction of the untreated site soil. However, PFOA and PFOS were still present in the extract fluid at 94,000 and 190,000 ppt, respectively.

f. PFAS telomeres in the site groundwater extractions of MBT treated samples T-2 and T-4 were significantly reduced in leachability.

g. In T-2, PFOA was reduced by >99.7% from its concentration in both groundwater and the groundwater extract of untreated material. For PFOS, the reduction was over 99.9% relative to the groundwater and the groundwater extract of untreated material. In T-4, leachable PFOA and PFOS were reduced by >99.9% relative to both fluids.

h. MBT treatments T-2, and to a larger degree T-4, can be readily optimized to meet the EPA 70ppt advisary limit for drinking water in site groundwater extracts.

i. MBT treated material will retain its hosted PFAS telomeres and remove PFAS from contaminated groundwater that may contact treated soil should the soil be managed onsite, and such that MBT treatment end-product may be potentially used in a site remedy design to control PFAS migration via contaminated groundwater.

Conclusion

MBT (Molecular Bonding/Binding Treatment) is a proven stabilization technology designed to sequester and immobilize PFAS in soils, sediments and solids, focusing on preventing PFAS migration rather than chemically altering the compounds. Results from this study show that MBT dramatically reduces PFAS leachability—even under site-representative extraction using highly contaminated groundwater—achieving >99.7% to >99.9% reductions in PFOA and PFOS compared to untreated soils. With its ability to meet or be optimized to meet strict regulatory thresholds, produce a stable end-product, and avoid creating chemical by-products, MBT provides a scalable, reliable, and defensible solution for PFAS impact mitigation at remediation sites.