PFAS Destruction in Water, Fluids and Spent Granular Activated Carbon by the AMEOX™ Treatment Technology

YB Technologies, LLC/Yost Brothers, LLC

Striding to break the PFAS cycle…

THE AMEOX™ TECHNOLOGY:

PFAS Destruction: AMEOX™ Treatment Technology for Water, Fluids, Concentrates and Spent Granular Activate Carbon

The AMEOX™ technology is patent(s) pending in the US and abroad

AMEOX™ Technology for PFAS Destruction

- Targets recalcitrant constituents in spent GAC and/or fluid concentrates including:
  - Degraded organic & “forever” compounds, e.g., ***PFAS**, others*
  - Non-reactive organic acids
  - Sulfolane; “Burnt” Polymers (Frac Water)
  - Metals with multi-valent states
  - Endocrine disruptors/pharmaceuticals

- Dimensionally stable Boron-Doped Diamond electrodes, electric powered and mechanical system with geometrically oriented components…all coupled with other enabling inducements

- Destroys PFAS constituents with manufactured mixed oxidants with latency and elevated oxidation potentials within process fluid that attack PFAS and other stable compounds

AMEOX Technology Studies:

Bench/Engineering Treatment Viability Studies

- Technology Treatments, Sampling, and Analyses by Yost Brothers
  - 500ml – 300 gallons of water and fluids carrying PFAS
  - 50 – 300 lbs. Spent GAC (AMEOX)
- PFAS Analyses by ALS Environmental – Holland, MI (for YB)

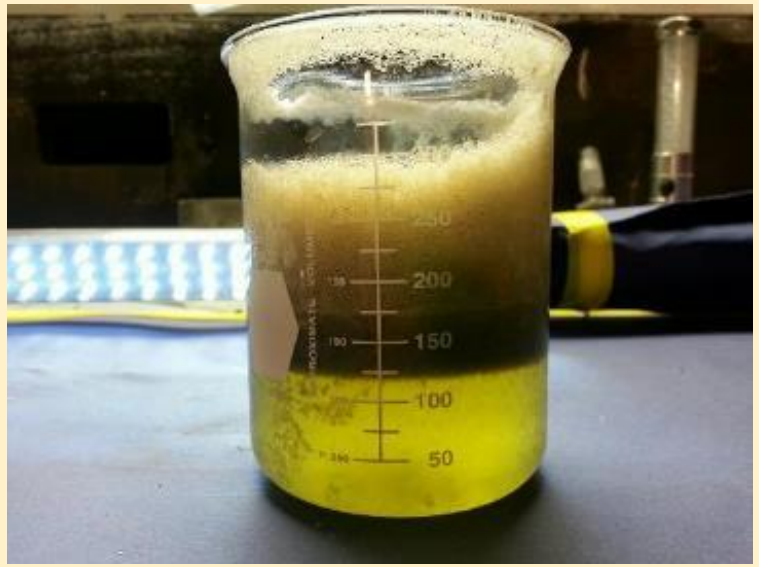
Full-Scale Pilot Study

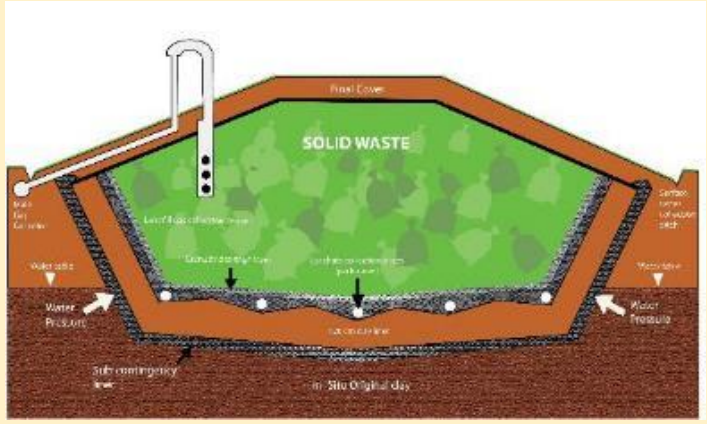
- Spent water treatment system GAC from 2 sites (Drinking water & Groundwater)
- ~1000 lbs. of spent GAC from each site
- PFAS Analyses by ALS Environmental (for YB) and Trace/Fibered (for FTCH)

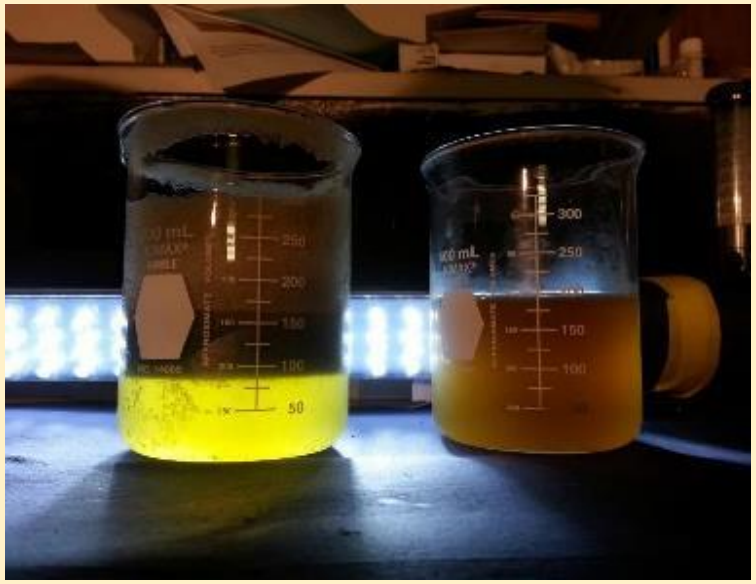
How AMEOX™ Originated

Subtitle D Landfill Leachate Treatment for Chemical Oxygen Demand Loading

(before PFAS was known to be present)

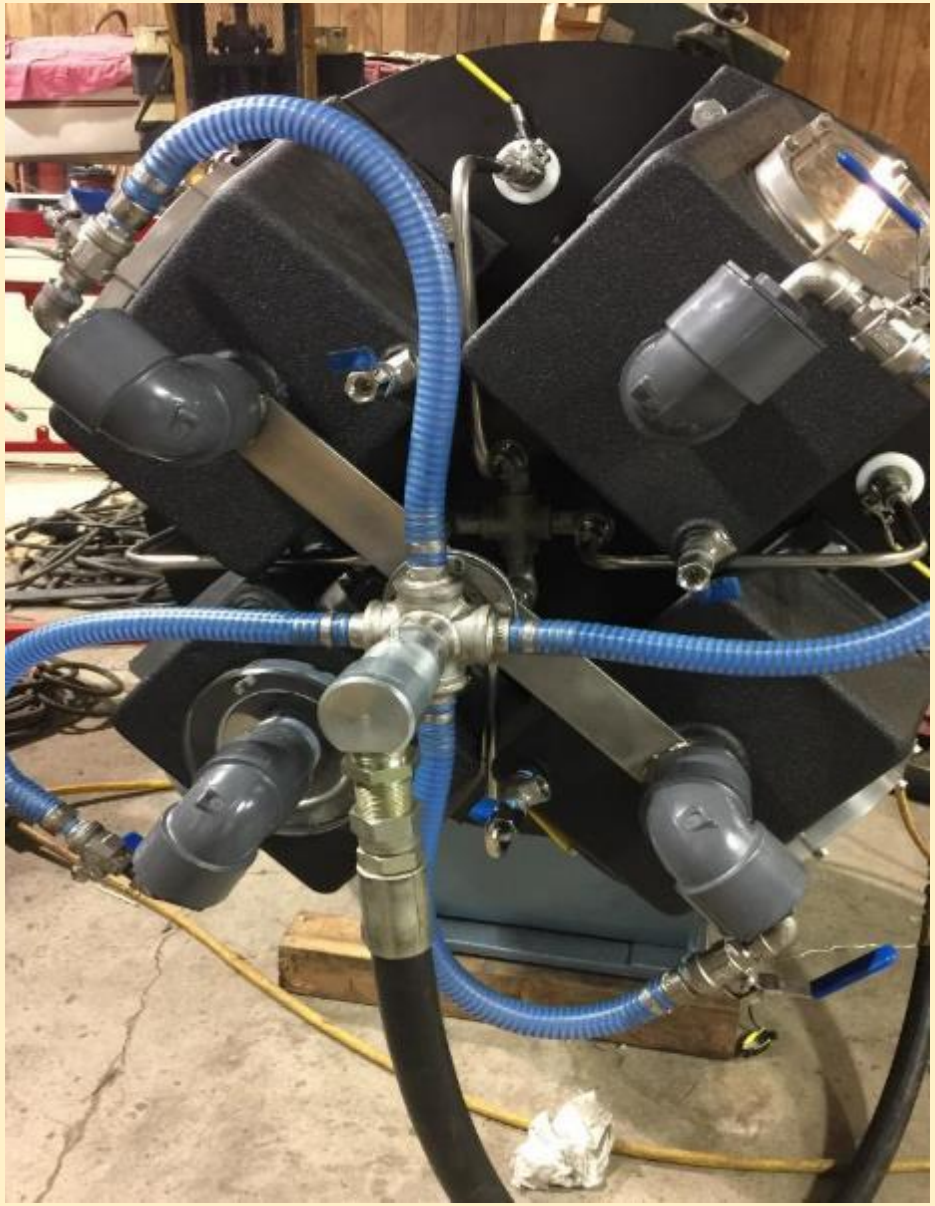






Subtitle D Landfill Leachate:
DAF/AOP Trial (2015)

- Non-Hazardous Landfill - OR
- Target Parameters: ***COD, TSS, pH***
- September 2015 (prior to PFAS knowledge)
- ~250 gallon sample volume
- Treated w/air and mixed oxidants – 5 minutes
- Foam out and above tank hatch – 15 mins
- Study Halted – uncontrollable foam generation
- Lab/Bench Studies initiated to mitigate foaming



Landfill Leachate Treatment Technology Solution:

Advanced Neutralization™ (AN) technology modified for pH control, surfactant disruption, and enhanced oxidation

Major modifications to AN technology platform precipitated creation of the AMEOX™ Treatment Technology for stable, non-reactive constituents in leachate (e.g., humic/fulvic acids, tannins/lignin and other compounds

(First PFAS lab/bench system and treatment trials in 2017-18)

Sample ID	Result (mg/L)
Untreated	7375
AN-1	2275
AN-2	1650
AN-3	2600
AN-4	225

- AN™ Treated Subtitle D Landfill Leachate (Oregon - 2015)
- Left: Untreated; Right: AN Viability Beaker Bench Tests (4)
- Far Right: Treated Leachate for COD (AN-4)
- (Realization of technology suitability for PFAS (2017)

AMEOX – RO Processed Michigan Groundwater (2018)

		Untreated MI Groundwater		Untreated GW RO Permeate		Untreated RO Reject Concentrate			AMEOX Treated RO Reject Concentrate		
MI Groundwater RO Fluids		Untreated		18-47332		18-47332			19-00529		
Sample ID		09062018-E-1430		12212018-1145		12212018-1335		Conc Factor	01042019-1800		
Parameter	**Acronym**	**ng/L**	**ug/L**	**ng/L**	**ug/L**	**ng/L**	**ug/L**	**X Untrt'd**	**ng/L**	**ug/L**	**% Change**
Perfluorooctanesulfonic acid	PFOS	**255000**	255	<40	<0.04	**468,000**	468	1.84X	56,700	57	**-87.9%**
Perfluorooctanoic Acid	PFOA	**80700**	80.7	60.0	0.0600	**133,000**	133	1.65X	49,500	50	**-62.8%**
Perfluorononanoic Acid	PFNA	**<2000**	<2	<20	<0.02	**427**	0.427	N/A	<100	<1	**N/A**
Perfluorohexanesulfonic acid	PFHXS	**4990**	4.99	<30	<0.03	**9170**	9.17	1.84X	1,510	1.51	**-83.5%**
Perfluoroheptanoic acid	PFHPA	**8420**	8.42	<10	<0.01	**13,400**	13.4	1.59X	12,600	12.6	**-6.0%**
Perfluorobutanesulfonic acid	PFBS	**<9000**	<9	<90	<0.09	**6950**	6.95	N/A	<4500	<4.5	**N/A**
PFAS - SUM (assumes BDL = 0)		**349,110**	349.11	60	0.060	**630,947**	630.9	~1.8X	120,310	120.3	**-80.9%**

<u>AMEOX</u> Viability Results: Spent Refinery GAC (coconut)

AMEOX Viability Treatment of Spent Refinery GAC

PFAS; Total Petroleum Hydrocarbons; PAH/cPAH Parameter Analytes

		Untreated Spent GAC	AMEOX GAC Treatment Viability - 1		AMEOX GAC Treatment Viability - 2	
Analyte Parameter	**Units**	**Result**	**Result**	**% Destruction**	**Result**	**% Destruction**
PFAS						
PERFLUOROOCTANOIC ACID (PFOA)	mg/Kg	0.0325	0.0138* (BMDL)	57.5%	<0.015	>53.8%
PERFLUOROOCTANESULFONIC ACID (PFOS)	mg/Kg	0.161	<0.015	>90.7%	<0.015	>90.7%
PERFLUORONONANOIC ACID (PFNA)	mg/Kg	<0.01	<0.015		<0.015	
PERFLUOROHEXANESULFONIC ACID (PFHXS)	mg/Kg	<0.02	<0.03		<0.03	
PERFLUOROHEPTANOIC ACID (PFHPA)	mg/Kg	<0.01	<0.015		<0.015	
PERFLUOROBUTANESULFONIC ACID (PFBS)	mg/Kg	<0.04	<0.06		<0.06	
Total Petroleum Hydrocarbons						
DIESEL (C12 - C24)	mg/Kg	27,400	16,300	40.5%	9300	66.1%
GASOLINE (C8 - C12)	mg/Kg	8900	5,080	42.9%	2260	74.6%
HEAVY HYDROCARBONS (>C24)	mg/Kg	<180	<180	--	<180	--
PAH's/cPAH's (not detected if not listed)						
1-METHYLNAPHTHALENE	mg/Kg	6274	4266	32.0%	2736	56.4%
2-METHYLNAPHTHALENE	mg/Kg	3800	2429	36.1%	1553	59.1%
ACENAPHTHYLENE	mg/Kg	<45	<45	--	<45	--
ACENAPTHENE	mg/Kg	213	155	27.2%	85.9	59.7%
FLUORENE	mg/Kg	103	71.5	30.6%	<45	>67.0
NAPHTHALENE	mg/Kg	1053	575	45.4%	381	63.8%
TOTAL PAH/cPAH	**mg/Kg**	**11,443**	**7,496.5**	**34.5%**	**4,755.9**	**58.4%**

BMDL = Below Minimum Detection Limit

AMEOX TREATMENT OF SPENT GAC FROM AFFF FIRE PIT WATER

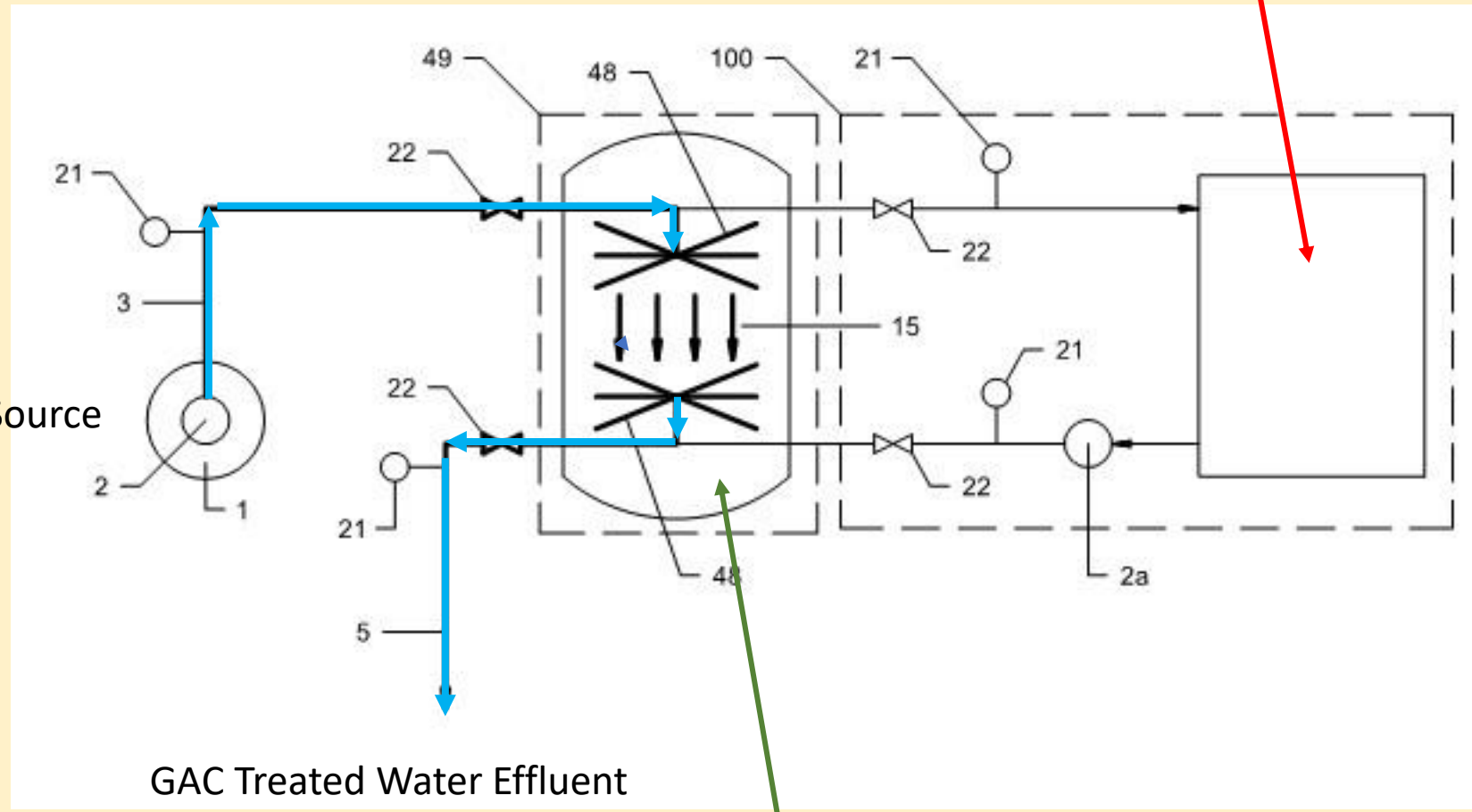
REMEDIAL WATER TREATMENT SYSTEM

Bench/Engineering-Scale Program

PFAS - Telomere (Analyte)	Acrnym	Units	Untreated	Treated
Perfluorodeconoic acid	PFDA	ug/Kg	4.88	<1.5
Perfluoroundecanoic acid	PFUnDA	ug/Kg	6.16	<1.5
Perfluorobutanesulfonic acid	PFBS	ug/Kg	6.91	<1.5
Perfluoroheptanoic acid	PFHPA	ug/Kg	12.5	<3
Perfluorohexanoic acid	PFHA	ug/Kg	62.1	<10
Perfluorooctanoic acid	**PFOA**	**ug/Kg**	**170**	**<20**
Perfluorononanoic acid	PFNA	ug/Kg	207	<30
Perfluorohexanesulfonic acid	PFHXS	ug/Kg	209	<60
Perfluorooctanesulfonic acid	**PFOS**	**ug/Kg**	**1730**	**<20**
Perfluorododecanoic acid	PFDOA	ug/Kg	<1.5	<1.5
Perfluorotridecanoic acid	PFTriA	ug/Kg	<1.5	<1.5
Perfluorotetradecanoic acid	PFTeA	ug/Kg	<1.5	<1.5

On-site AMEOX Spent GAC Processing

AMEOX™ System (off-line)

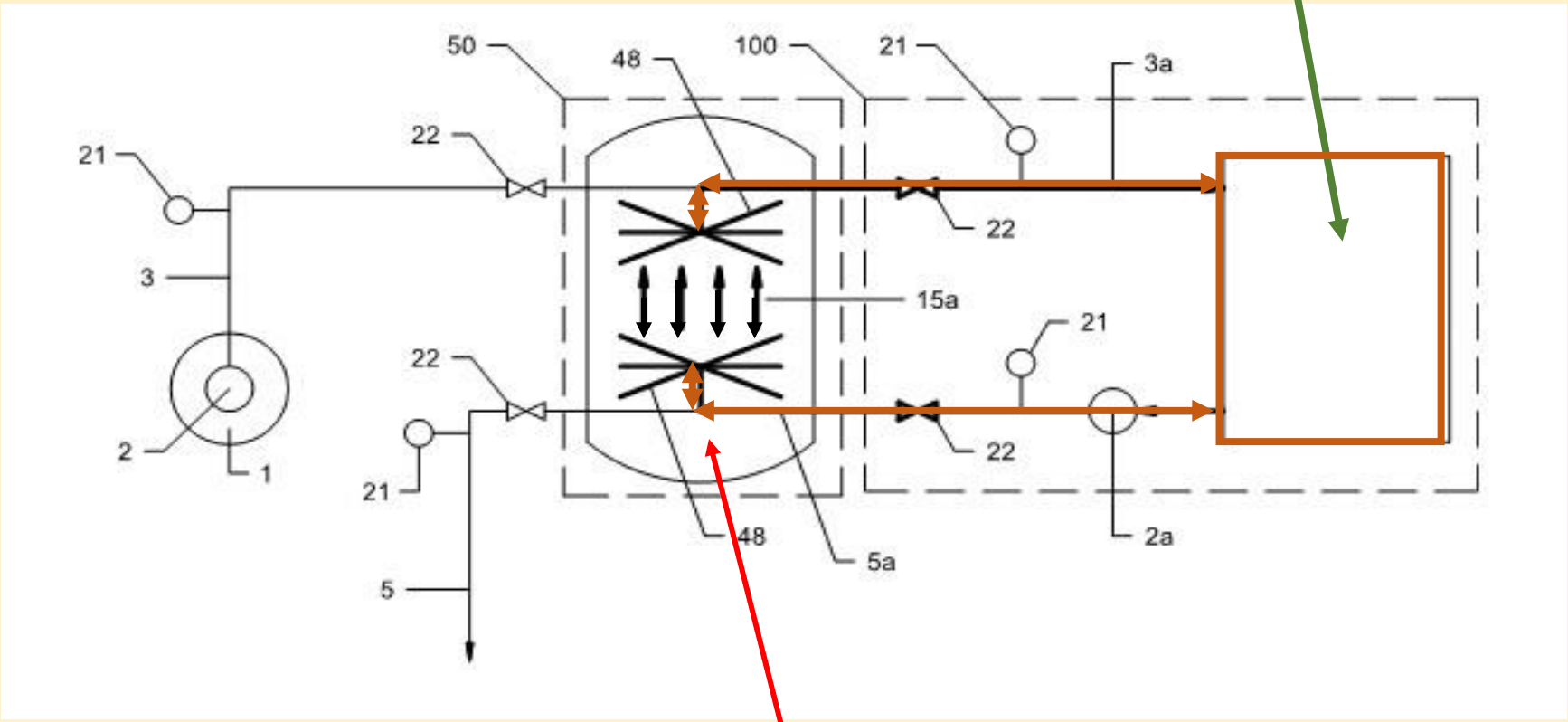


Raw Water Source

GAC Adsorber (on-line/in-service)

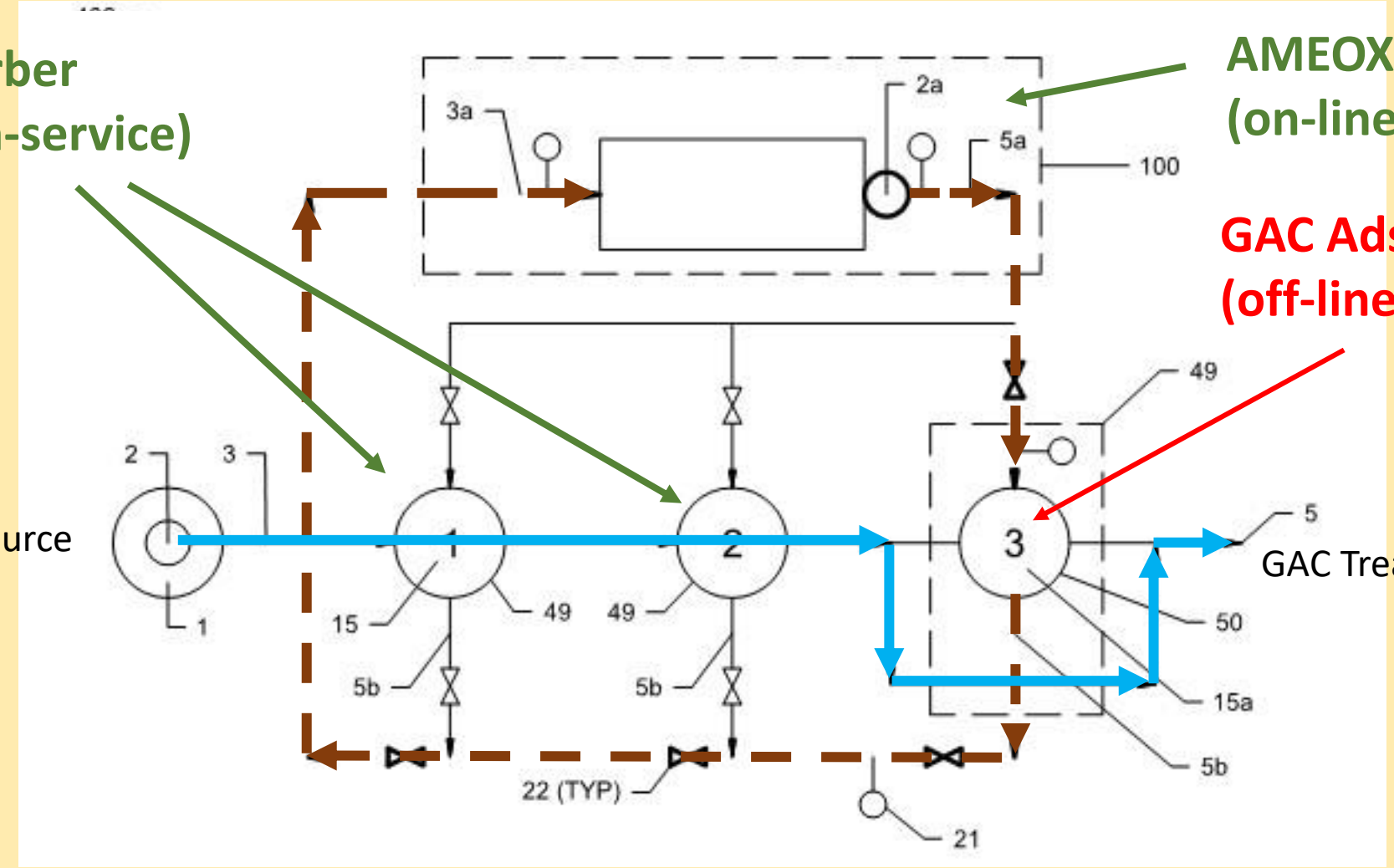
On-site AMEOX Spent GAC Processing

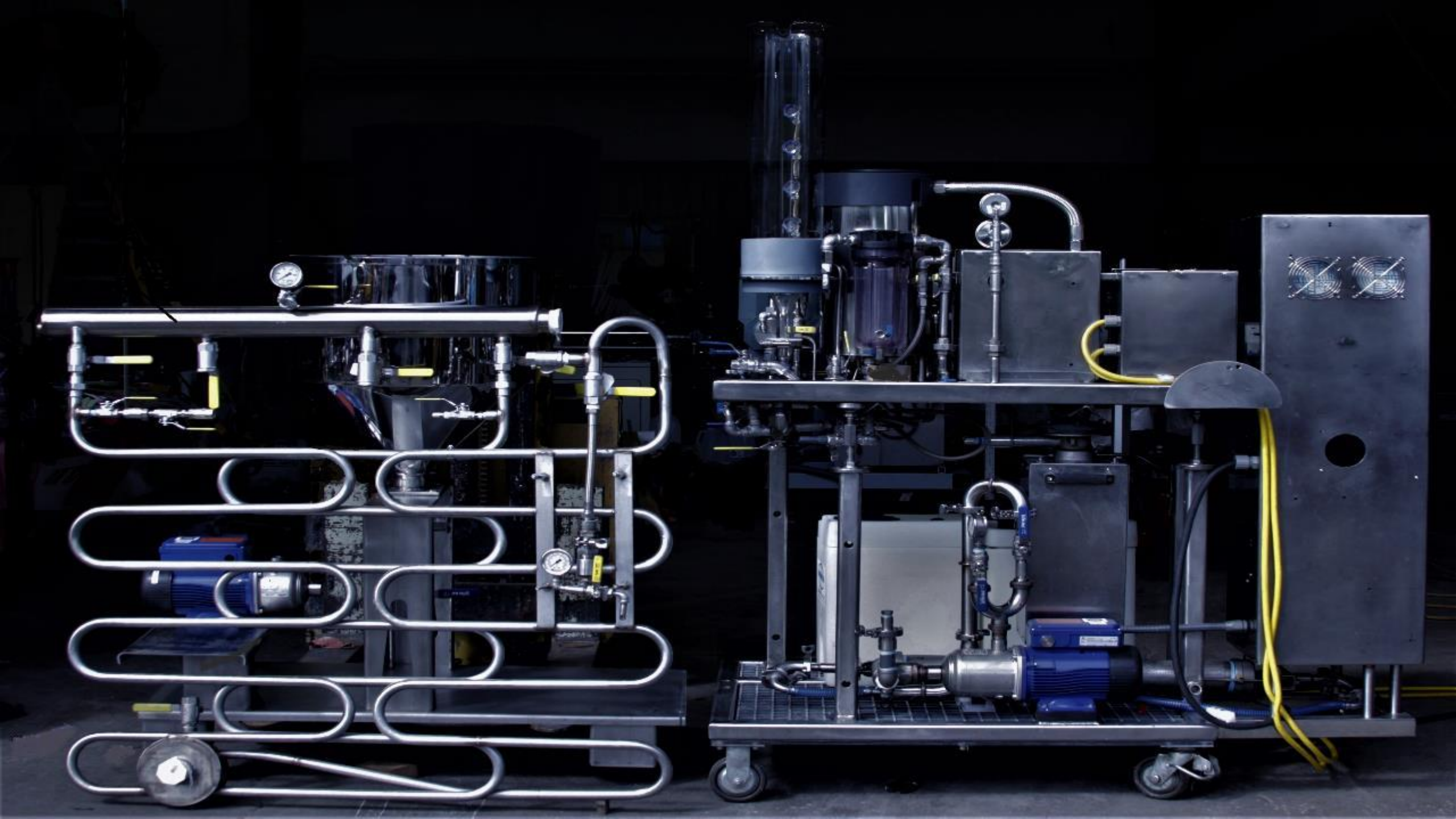
AMEOX™ System (on-line/in-service)



GAC Adsorber (off-line/out of service/in treatment)

On-site AMEOX Spent GAC Processing – Adsorber Train





AMEOX – SPENT GAC PILOT

AMEOX Equipment Readiness Testing

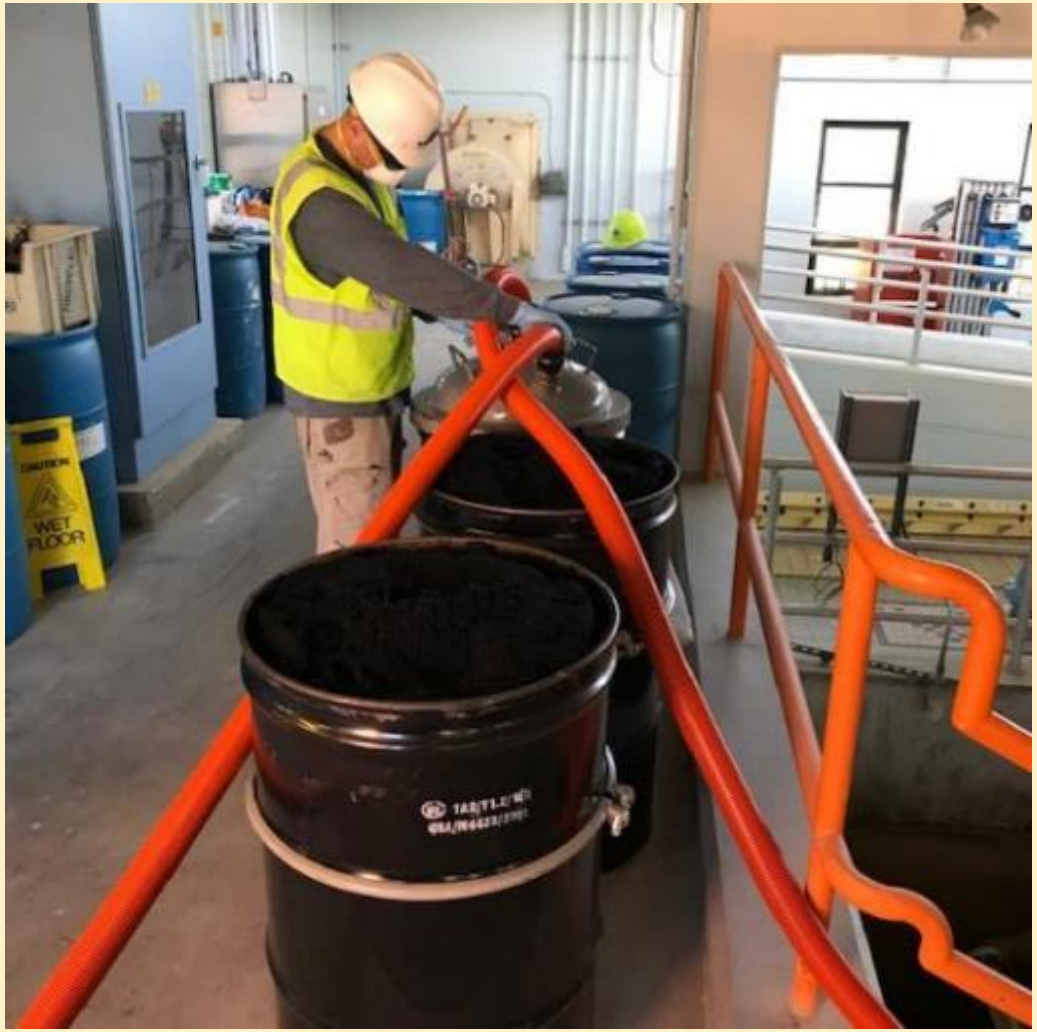
AMEOX Equipment Mobilization Load-Out

AMEOX – SPENT GAC PILOT

Production Plated Plastics, Richland MI - Groundwater Remediation GAC Collection

AMEOX – SPENT GAC PILOT

Drinking Water Treatment Plant, City of Ann Arbor, MI - GAC Collection



AMEOX – SPENT GAC FIELD TRIAL PILOT

AMEOX System Set-up – Prineville, OR

AMEOX – Pilot Treatment Conditions:

1. Treatment Location: Prineville, OR (Pacific Coast Carbon, Inc.)
2. Oregon Forest Fires (within 10 miles of fabrication shop/roads closed)
3. Pilot Dates: October 11-23, 2020
4. 1000 lbs. Spent GAC per treatment via parameters from bench work without optimization or up-scaled process evaluation
5. AMEOX Fluid Flow Rate Range through GAC reactor: (2 – 6.5 gpm)
6. Heater installed and operational in pm of 10/15/2020. ~39-55°F > 95-115°F
7. PPP – Groundwater GAC (processed ~12-24 hrs. per day over 3-4 days)
8. AA – Drinking Water GAC (processed 4-7 hrs. per day for 3 days)
9. AMEOX Fluid (the same ~400 gallons prepared and used for **both** materials)

AMEOX Pilot Data: Production Plated Plastics Groundwater Remediation System GAC

		Source:	EGLE Production Plated Plastics Groundwater Remediation GAC							
		Sample Type:	UNTREATED - PFAS GAC				AMEOX Treated GAC			
		Analytes:	PFAS - Totals				PFAS Totals			
		Matrix:	Coal Carbon - Spent/Used				Coal Carbon - AMEOX Treated			
		Treatability Phase:	CHARACTERIZATION				AMEOX PILOT TREATMENT (Preliminary)			
		Lab:	YB: ALS-Holland	FTCH: Trace-Fibertec	YB: ALS-Holland	FTCH: Trace-Fibertec	YB: ALS-Holland*			
		Sample ID:	06092020-1130 PPP-GW		10/11/2020-1530		10142020-1320	10152020-1250**	10162020-0846	
		Method:	D7968-17a	D7968-17a (dry-wt)	D7968-17a	D7968-17a (dry-wt)	D7968-17a			Total %
		Units:	(ng/Kg)	(ng/Kg)	(ng/Kg)	(ng/Kg)	(ng/Kg)	(ng/Kg)	(ng/Kg)	Reduction
Telomere	**Chemical Name**	**C Atoms**	**Result**	**Result**	**Result**	**Result**	**Result**	**Result**	**Result**	**Result**
PFBA	Perfluorobutanoic Acid	C4	3,200	25,000	12,000	16,000	4,600	3,700	3,300	-72.5%
PFPeA	Perfluoropentanoic Acid	C5	2,800	17,000	12,000	21,000	4,500	4,000	3,600	-70.0%
PFHxA	Perfluorohexanoic Acid	C6	12,000	41,000	29,000	48,000	11,000	9,700	8,000	-72.4%
PFHpA	Perfluoroheptanoic Acid	C7	9,800	24,000	17,000	25,000	6,900	6,700	5,600	-67.1%
PFOA	**Perfluorooctanoic Acid**	**C8**	**34,000**	**110,000**	**59,000**	**91,000**	**26,000**	**25,000**	**21,000**	**-64.4%**
PFNA	Perfluorononanoic Acid	C9	410	4,200	770	3,500	270	300	<260	
PFDA	Perfluorodecanoic Acid	C10	650	1,500	<2900	<2400	<1200	<1300	<1300	
PFUnA	Perfluoroundecanoic Acid	C11	380	<430	<2900	<600	<1200	<1300	<1300	
PFBS	Perfluorobutanesulfonic Acid	C4	17,000	59,000	38,000	86,000	13,000	11,000	8,900	-76.6%
PFPeS	Perfluoropentanesulfonic Acid	C5	9,900	57,000	15,000	74,000	6,000	5,300	4,300	-71.3%
PFHxS	Perfluorohexanesulfonic Acid	C6	7,700	130,000	95,000	390,000	38,000	36,000	30,000	-68.4%
PFHpS	Perfluoroheptanesulfonic Acid	C7	45,000	120,000	59,000	180,000	23,000	23,000	18,000	-69.5%
PFOS	**Perfluorooctanesulfonic Acid**	**C8**	**20,000,000**	**19,000,000**	**11,000,000**	**56,000,000**	**4,800,000**	**4,800,000**	**3,600,000**	**-67.3%**
PFNS	Perfluorononanesulfonic Acid	C9	570	25,000	3,300	13,000	<1200	<1300	<1300	
PFDS	Perfluorodecanesulfonic Acid	C10	240	<860	<590	1,200	<240	<260	<260	
PFOSA	Perfluorooctanesulfonaminde	C8	120	350	<590	<600	<240	<260	<260	
N-EtFOSSA	N-Ethylperfluorooctranesulfonic amidoacetic Acid	C12	160	<430	<2900	<600	<1200	<1300	<1300	
		Summation of PFOA and PFOS:	**20,034,000**	**19,110,000**	**11,059,000**	**56,091,000**	**4,826,000**	**4,825,000**	**3,621,000**	**-67.3%**
		Summation of PFAS Telomere Totals:	20,143,930	19,614,050	11,340,070	56,948,700	4,933,270	4,924,700	3,702,700	-67.3%

Data at BDL for all samples by telomere - not shown. Full MI List analyzed

*FTCH AMEOX Treatment Data In-Progress by Trace/Fibertec

** 7500W heater operational in the pm of 10/15/2020

AMEOX Pilot Data: City of Ann Arbor Drinking WTP GAC

		Source:	City of Ann Arbor Drinking WTP GAC					
		Sample Type:	**UNTREATED - PFAS GAC**		**AMEOX Treated GAC**			
		Treatability Phase:	CHARACTERIZATION		AMEOX Treated GAC			
		Analytes:	PFAS - Totals		PFAS - Totals			
		Matrix:	Coal Carbon - Spent/Used		Coal Carbon - AMEOX Treated			
		Lab:	YB: ALS-Holland	FTCH: Trace-Fibertec	YB: ALS-Holland*			
		Method:	D7968-17a	D7968-17a (dry-wt)	D7968-17a			Total %
		Sample ID:	06082020-0945 AA-DW		Day-1: 10/20/20-1030	Day-2: 10/21/2020-0930	Day 3: 10/22/2020-1445	
		Units:	(ng/Kg)	(ng/Kg)	(ng/Kg)	(ng/Kg)	(ng/Kg)	Reduction
Telomere	**Chemical Name**	**C Atoms**	**Result**	**Result**	**Result**	**Result**	**Result**	**Result**
PFBA	Perfluorobutanoic Acid	C4	3,500	36,000	6,400	2,600	1500	-57.1%
PFPeA	Perfluoropentanoic Acid	C5	8,200	21,000	9,200	1,700	1800	-78.0%
PFHxA	Perfluorohexanoic Acid	C6	16,000	48,000	14,000	4,100	2400	-85.0%
PFHpA	Perfluoroheptanoic Acid	C7	23,000	74,000	18,000	7,900	2700	-88.3%
PFOA	**Perfluorooctanoic Acid**	**C8**	**7,600**	**37,000**	**6,100**	**3,700**	**1000**	-86.8%
PFNA	Perfluorononanoic Acid	C9	1,900	14,000	1,500	1,000	350	-81.6%
PFDA	Perfluorodecanoic Acid	C10	990	7,100	<1200	<1300	<1300	
PFBS	Perfluorobutanesulfonic Acid	C4	3,700	16,000	3,700	1,100	530	-85.7%
PFPeS	Perfluoropentanesulfonic Acid	C5	380	1,100	<240	<270	<250	
PFHxS	Perfluorohexanesulfonic Acid	C6	1,900	12,000	<1200	<1300	<1300	
PFHpS	Perfluoroheptanesulfonic Acid	C7	150	900	<1200	<1300	<1300	
PFOS	**Perfluorooctanesulfonic Acid**	**C8**	**19,000**	**55,000**	**13,000**	**12,000**	**2400**	-87.4%
FtSA 6:2	Fluorotelomer Sulfonic Acid 6:2	C8	21,000	110,000	19,000	11,000	3,100	-85.2%
FtSA 8:2	Fluorotelomer Sulfonic Acid 8:2	C10	<120	460	<1200	<1300	<1300	
PFOSA	Perfluorooctanesulfonaminde	C8	30	<380	<240	<270	<250	
N-EtFOSSA	N-Ethylperfluorooctranesulfonic amidoacetic Acid	C12	<120	2,400	<1200	<1300	<1300	
		Summation of PFOA and PFOS:	**26,600**	**92,000**	**19,100**	**15,700**	**3,400**	**-87.2%**
		Summation of PFAS Telomere Totals:	**107,350**	**436,240**	**90,900**	**45,100**	**15,780**	**-85.3%**

Data at BDL for all samples by telomere are not shown. Full MI List analyzed

*FTCH AMEOX Treatment Data in Progress by Trace/Fibertec

AMEOX Pilot: Fluoride Data*

1) Spent PPP GAC: <0.1 mg/Kg
2) AMEOX Treated PPP GAC: 0.21 mg/Kg
3) Spent AA GAC: <0.1 mg/Kg
4) AMEOX Treated AA GAC: <0.1 mg/Kg
5) AMEOX Fluid (post PPP and AA treatment: <0.1 mg/L)

Low concentration fluoride analytical methods needed with PFAS at ng/Kg and ng/L levels for mass balance determinations

* Fluoride data by Edge Analytical, Burlington, WA

AMEOX Technology - Supplemental Data

- Spent GAC backflushed & dewatered fines w/MBT treatment for leachability
- AMEOX Fluid* pre (July 2020) and post GAC Bench, Engineering, & Pilot Treatments (November 2020)

Untreated Characterization and MBT™ Viability Treatment Data for Spent Granular Activated Carbon (GAC) Fines

		Sample:	GAC Fines	GAC Fines	AMEOX™ Fluid	AMEOX™ Fluid
		AMEOX™ Treatability Phase:	Characterization	MBT™ Treated	Pre-Treatment	Post-Treatment
		Units:	(ng/Kg)	TCLP (ng/L)	(ng/L)	(ng/L)
Telomere	**Chemical Name**	**C Atoms**	**Result**	**Result**	**Result**	**Result**
PFBA	Perfluorobutanoic Acid	C4	12,000	94	52	49
PFPeA	Perfluoropentanoic Acid	C5	39,000	<49	<50	<49
PFHxA	Perfluorohexanoic Acid	C6	65,000	<49	<50	<49
PFHpA	Perfluoroheptanoic Acid	C7	24,000	<9.8	<9.9	<9.8
PFOA	**Perfluorooctanoic Acid**	**C8**	**190,000**	**<9.7**	**24**	**22**
PFNA	Perfluorononanoic Acid	C9	2,400	<9.7	<9.9	<9.8
PFDA	Perfluorodecanoic Acid	C10	<120	<49	<50	<49
PFUnA	Perfluoroundecanoic Acid	C11	<120	<49	<50	<49
PFDoA	Perfluorododenoic Acid	C12	<120	<49	<50	<49
PFTriA	Perfluorortridecanoic Acid	C13	<120	<49	<50	<49
PFTeA	Perfluortetradecanoic Acid	C14	<120	<49	<50	<49
PFBS	Perfluorobutanesulfonic Acid	C4	3,100	<9.7	<9.9	<9.8
PFPeS	Perfluoropentanesulfonic Acid	C5	840	<9.7	<9.9	<9.8
PFHxS	Perfluorohexanesulfonic Acid	C6	4,700	<49	<50	<49
PFHpS	Perfluoroheptanesulfonic Acid	C7	950	<49	<50	<49
PFOS	**Perfluorooctanesulfonic Acid**	**C8**	**170,000**	**<9.7**	**660**	**600**
PFNS	Perfluorononanesulfonic Acid	C9	<120	<50	<50	<50
PFDS	Perfluorodecanesulfonic Acid	C10	<25	<9.7	<9.9	<9.8
FtSA 4:2	Fluorotelomer Sulfonic Acid 4:2	C6	3,700	<49	<50	<49
FtSA 6:2	Fluorotelomer Sulfonic Acid 6:2	C8	100,000	<49	<50	<49
FtSA 8:2	Fluorotelomer Sulfonic Acid 8:2	C10	1,000	<49	<50	<49
PFOSA	Perfluorooctanesulfonaminde	C8	70	<9.7	<9.9	<9.8
EtFOSSA	N-Ethylperfluorooctanesulfon amidoacetic Acid	C12	<120	<49	<50	<49
MeFOSAA	N-Methylperfluorooctanesulfon amidoacetic Acid	C11	<120	<49	<50	<49
F-53BMin	11Cl-Pf3OUds	C10	<25	<9.7	<9.9	<9.8
ADONA	4,8-Doxa-3H-perfluorononanoic Acid (?	C8	<25	<9.7	<9.9	<9.8
F-53BMaj	9Cl-PF3ONS	C8	<25	<9.7	<9.9	<9.8
---	Hexafluoropropylene	C3	<120	<49	<50	<49
pH (S.U.)	pH (S.U.)	--				
	Summation of PFOA and PFOS:		360,000	ND	**684**	**622**
	Summation of PFAS Telomere Totals (MI "24"):		616,760	94	736	671

* *AMEOX fluid archived and re-utilized for treatment of nearly 5000 lbs of spent GAC including numerous bench and engineering scale studies for all of 2020 without discharge or disposal.*

AMEOX – SPENT GAC PILOT

AMEOX – SPENT GAC PILOT

AMEOX – Process Control & Cost Variables:

1. GAC Quality (Coal, Coconut/Other, Re-agglomerated, etc.)
2. Water Chemistry (treated by GAC and used for AMEOX Fluid)
3. AMEOX Treatment Duration
4. Flow Rate and Recirculation Volume
5. Operating Pressure and Control
6. Operating Temperature Range (Pilot @ 35°F – 125°F)
7. BDD electrode pairing, surface area/cell geometry
8. Power Intensity, Frequency, and Modulation
9. AMEOX fluid mixing and intimacy of contact
10. PFAS Concentrations and Mass of GAC per Reactor Batch: 500 – 5000; 10,000; 20,000+ (???) lbs.
11. Desired end GAC use/performance objectives (Reuse Reactivation, Internment, Subsequent Processing)
12. 10-yr AMEOX Equipment Life Expectancy (w/pumps @ 3-4 years with servicing)
13. Level of automation: monitoring and process control

QUESTIONS?

Karl Yost
YB Technologies, LLC
karlyost@ybtechs.com