Electrochemical Destruction of PFOA and PFOS in Landfill Leachate

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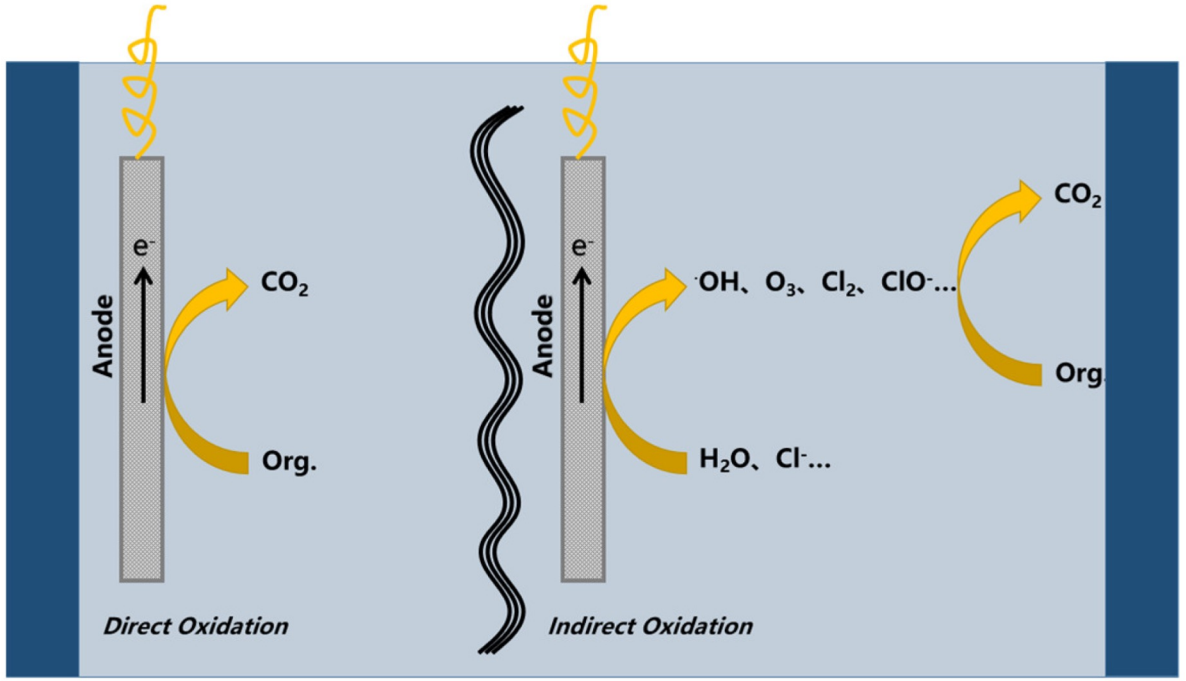
PFAS & ELECTROCHEMICAL OXIDATION (EOX) BACKGROUND

Destructive Technologies for PFAS:

-Electrochemical Oxidation (EOx)
-Supercritical Water Oxidation
-Plasma Oxidation
-Hydrothermal Alkaline Treatment
-Reductive Defluorination
-Photochemical

How EOx Works:

-Free electrons generated on the electrode surface break C-F bonds resulting in CO_2, F^-
-Mixed oxidants generated in-situ treat a broad range of difficult contaminants at lower power than conventional electrodes



Direct and Indirect Oxidation, (Liu et al., 2022)

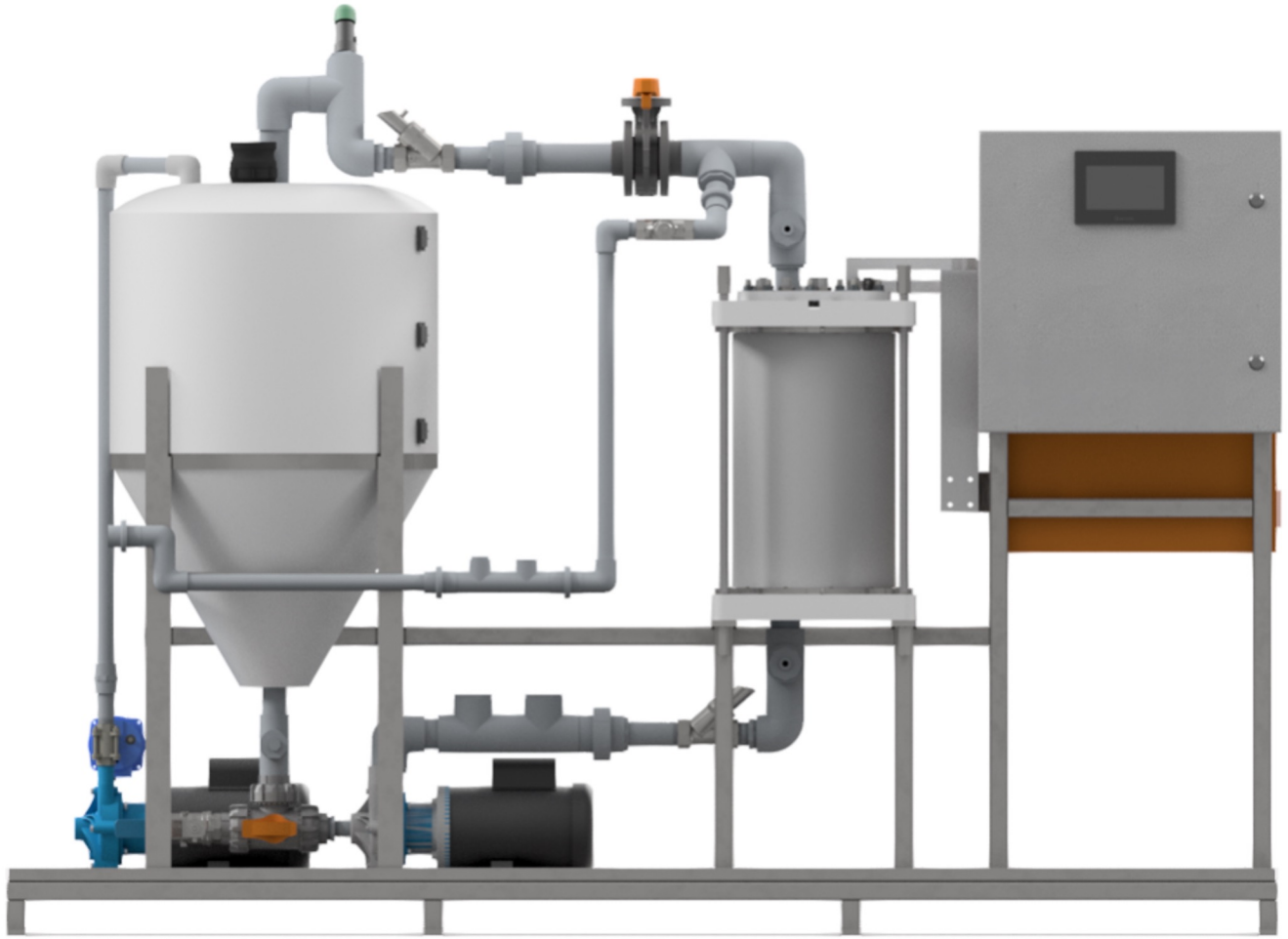
DEPLOYMENT OBJECTIVES

EOx Mobile Field Deployment: 4 week treatment at a consolidated water treatment facility in Michigan

Objective 1: demonstrate that continuous flow EOx treatment can destroy Perfluorooctanoic Acid (PFOA) and Perfluorooctane Sulfonic Acid (PFOS) in landfill leachate streams to below the local permit limits of 2,300 ng L^{-1} for PFOA and 60 ng L^{-1} of PFOS

Objective 2: determine optimal operating parameters for a full scale application treating two streams - 180,000 gpd and 43,200 gpd of raw landfill leachate

MOBILE FIELD DEPLOYMENT SKID



MOBILE FIELD DEPLOYMENT TRAILER

TESTING MATRIX

Three leachate streams, 15 tests total

Two main types of tests:

Voltage scan - a single flow rate was selected, and the voltage varied in 0.5V increments

Flow variation - the applied voltage was fixed and the throughput was varied in 0.5 gpm increments

Sampled every 30 minutes and analyzed on-site with an LCMS using ASTM D-7979 for short and long chain PFAS

Other analyses:
Total Kjeldahl Nitrogen
Nitrate & nitrite
Total Nitrogen
Alkalinity
Total Organic Carbon
Aluminum, calcium, and magnesium
Chromium, iron, and manganese
Semivolatiles & Volatiles

Date	Leachate	Testing Type	Conditions
9/28	3	Voltage Scan	1 gpm, Low-High Voltage (V)
9/29	1	Flow Variation	0.5-2 gpm, Low V
9/30	1	Flow Variation	0.5-2 gpm, Moderate V
10/3	3	Voltage Scan	2 gpm, Low-Moderate V
10/4	2	Voltage Scan	1 gpm, Low-Moderate V
10/5	2	Other	1 gpm, Moderate V
10/6	2	Flow Variation	1-2 gpm, Moderate V
10/7	1	Voltage Scan	1 gpm, Low-Moderate V
10/11	2	Other	Moderate V
10/12	1	Flow Variation	0.5-1.5 gpm, Moderate V
10/13	1	Extended Run	1 gpm, Moderate V
10/14	2	Low Tank Level	1 gpm, Moderate V
10/18	1	Extended Run	1 gpm, Moderate V
10/19	1	Foam Mitigation	1 gpm, High V
10/20	1	Extended Run	1 gpm, Moderate V

STREAM 1 VOLTAGE SCAN

PFAS concentration permit limits of 2,300 ng/L PFOA and 60 ng/L PFOS

Green: below limit

Red: above limit

Stream 1 Voltage Scan,at 1 gpm, Low-Moderate V

Flow (gpm)	Applied Power (W-hr/gal)	PFOA (ng/L)	PFOS (ng/L)
0	0.0	1500	370
1	0.0	1700	240
1	2.1	1500	130
1	10.7	1200	63
1	26.2	1000	37

26.2 W-hr/gal achieved PFOS permit limit.
PFOS first-order kinetic decay rate of 7.5×10^{-3}/min

STREAM 1 FLOW VARIATION

2 tests at different voltages, same variation of flow, both reached below detection limit at 1 gpm

Increasing flow above 1 gpm results in higher concentration of PFOA and PFOS

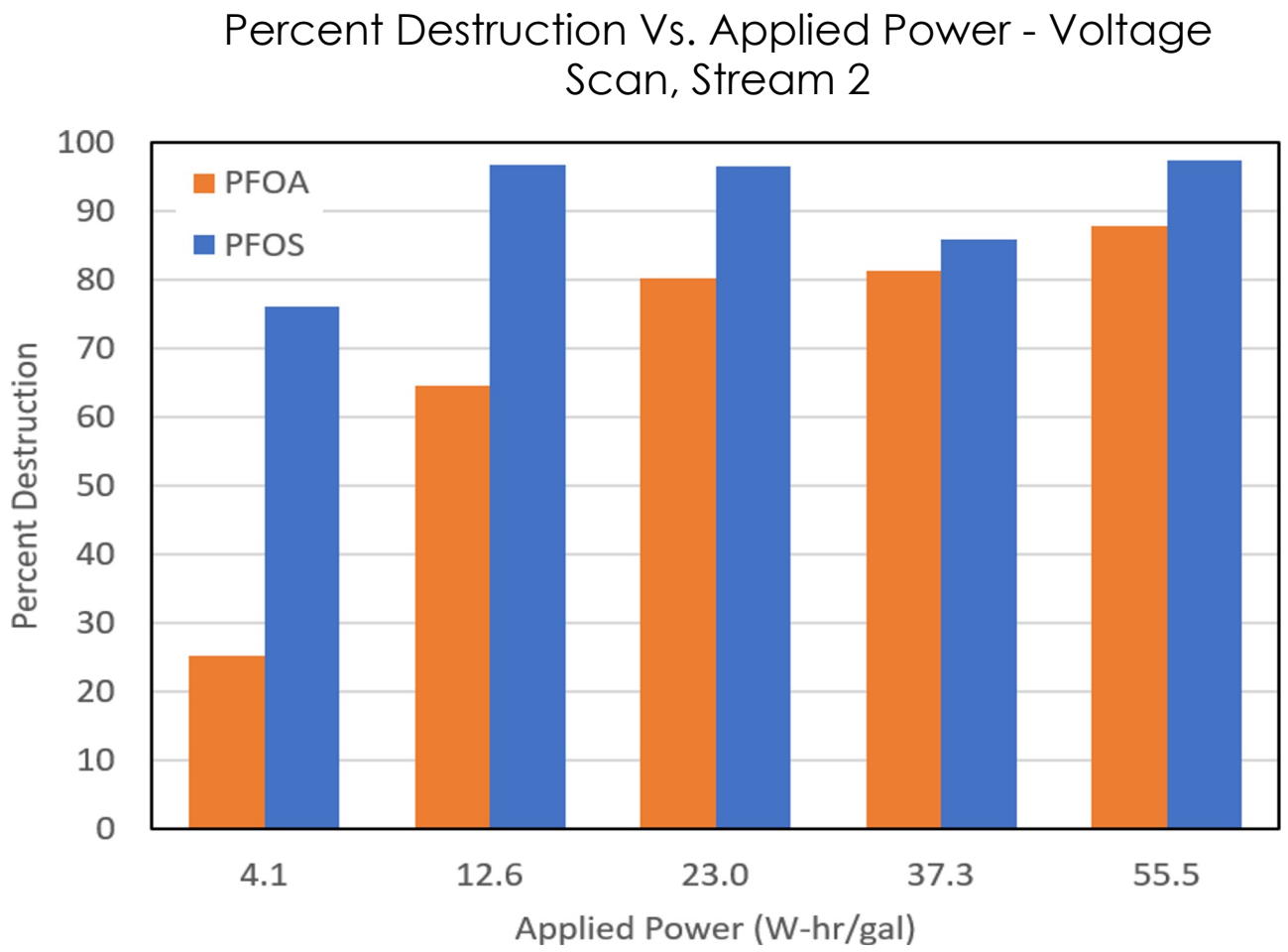
Flow (gpm)	Applied Power (W-hr/gal)	PFOA (ng/L)	PFOS (ng/L)
0	0.0	1594.6	422.3
0.5	7.5	411.9	24.6
1	3.8	524.4	<21
2	2.0	625.8	33.3
0	0.0	1641	339
0.5	52.2	106.9	67.5
1	24.3	107.4	<21
2	10.9	151.2	44.9

PFOS 1st order rate constant: 3.5 x 10^{-2}/min

Increased flow = less degradation

STREAM 2 PERCENT DESTRUCTION VS. APPLIED POWER

- PFOS destroyed to below detection limits
- PFOA destroyed to below regulatory limits
- ~50 W-hr/gallon was exhibited at the time of 96% destruction
- This low power usage equated to very low OpEx costs



FULL SCALE MODELING

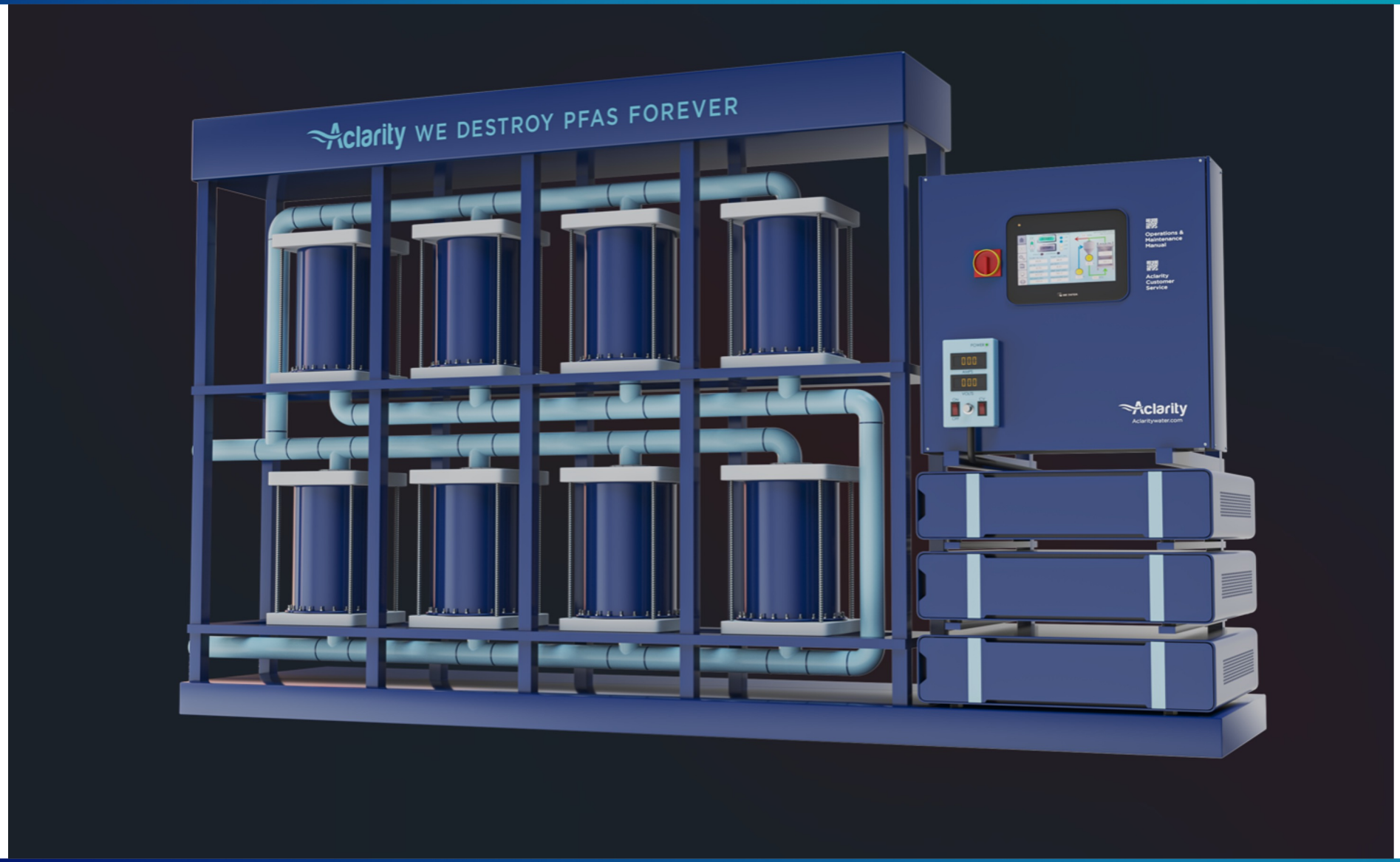
PFOS had a lower rate constant at the chosen power level and was therefore the controlling contaminant

Higher flow modeled 8 skids, each containing 8 reactors and associated equipment (pumps, power supplies, HMI, sensors, etc)

Full Scale System Modeling

Case	Initial C (ng/L)	Target C (ng/L)	Flow (GPD)	# Skids	OPEX ($/kgal)
PFOS	557	60	180000	8	Lower
PFOS	557	60	43200	2	Higher

FULL SCALE MODELING



Free Consultation

FULL SCALE MODELING

SUMMARY

1. PFOA & PFOS permit limits were achievable under multiple different operating conditions
2. The basis of design for a full-scale system has been selected

Full Scale Design Parameters

Parameter	Value
Design Flow Rate (gpd)	180,000
Maximum Instantaneous Flow (gpm)	300
Raw Water PFOS Concentration (ng/L)	450
Target PFOS Concentration (ng/L)	40
Raw Water PFOA Concentration (ng/L)	<2,300
Target PFOA Concentration (ng/L)	<2,300
Applied Potential (DC Volts)	Moderate
PFOS Kinetic Decay Rate (min-1)	0.035
Local Electrical Cost ($/kW-hr)	0.173

Thank you

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Deployment Site Facility & Staff
for ensuring site safety, LCMS operation, and allowing for the presentation of this data

QUESTIONS

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ALL PFAS RESULTS

Compound	Average Raw Water Concentration (ng/L)	Maximum Raw Water Concentration (ng/L)	Removal
FTS 4:2	22.2	34.5	Low
FTS 6:2	1204.8	2146.3	Very good to excellent
FTS 8:2	40.4	96.0	Very good to excellent
NEtFOSAA	105.0	240.0	Very good to excellent
NMetFOSAA	136.8	260.0	Very good to excellent
PFBA	1833.7	24000.0	Low to moderate
PFBS	11068.3	18651.2	Low
PFDA	44.8	66.0	Good to very good
PFDoA	8.6	10.0	Mixed
PFDS	14.7	46.8	Mixed
PFHpA	542.0	779.2	Good to very good
PFHpS	29.9	88.5	Low
PFHxA	2645.6	4292.9	Low to moderate
PFHxS	1138.8	1972.5	Good to very good
PFNA	63.8	113.9	Very good to excellent
PFNS	21.2	75.0	Mixed
PFOA	1273.4	2323.1	Very good to excellent
PFOS	310.3	501.0	Excellent
PFOSA	15.3	25.2	Very good to excellent
PFPeA	589.3	3800.0	Mixed
PFPeS	152.7	264.5	Mixed
PFTreA	6.2	10.5	Too low to assess
PFTriA	1.2	7.5	Too low to assess
PFUnA	15.6	25.5	Too low to assess

Low indicated <25% removal
Moderate 25-50%
Good 50-75%
Very Good 75-90%
Excellent >90%