In-Situ and Ex-Situ Destruction of PFAS Using a Novel Approach to Catalyzed Chemical Oxidation

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AGENDA

Advanced Oxidation (Hot ISCO™) Technology Introduction

Bench and Pilot Scale Performance

- AFFF Derived PFAS
- Plastics Derived PFAS

Full Scale Ex-Situ Demonstration

- Investigation Derived Waste and Plant Waste Treatment

INTRODUCTION TO HOT ISCO

- WHAT IS HOT ISCO?
  HOT ISCO is an in situ and ex-situ PFAS destruction technology that uses low thermal energy combined with catalyzed oxidant activation

- WHAT TYPE OF CATALYST?
  HOT ISCO uses bimetal silver iron catalyst

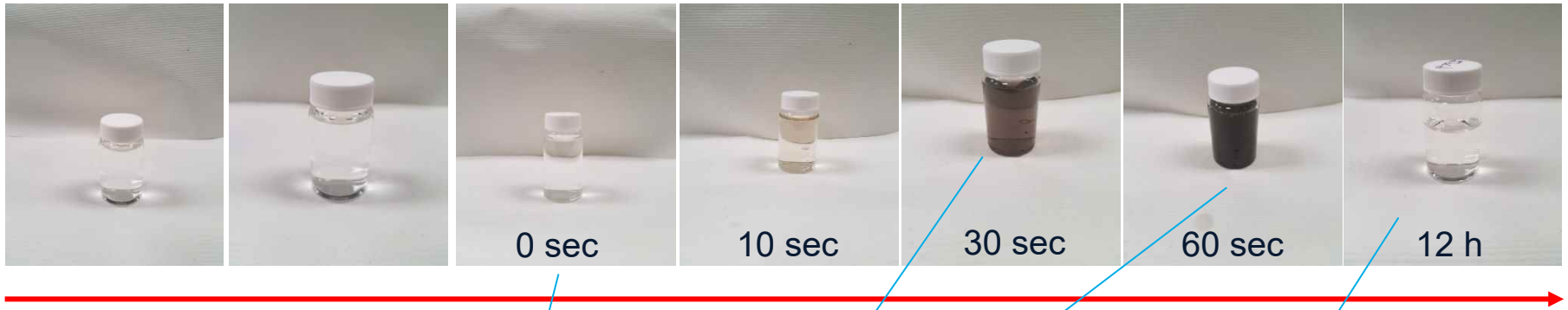
- WHAT TYPE OF OXIDANT?
  HOT ISCO uses commercially available persulfate based oxidant

- WHAT TEMPERATURE RANGE IS APPLICABLE?
  HOT ISCO has been demonstrated on a wide range of temperatures from 20°C (ambient conditions) to 60°C. Most reactions have been carried out at 30°C - 40°C (85 °F - 100 °F)

LAB DEVELOPMENT WORK AND REACTION PARAMETERS

- Development work started in 2021 with lab studies to document that PFAS can be destroyed oxidatively. It can but reaction rates are slow and transformation is incomplete
- Development work continued through 2022-2023 to find the best match of catalysts, lowest possible temperature, and oxidant loading
- All studies (41 to date) were completed in triplicate with 3rd party analytical work
- Analysis: 537 and 1633 supported by TOP, TOF, and TIF (commercial lab) to demonstrate PFAS destruction
- **Finally** an iterative process was developed consisting of one catalyst application followed by multiple oxidant applications to achieve the desired result

UNDERSTANDING THE CHEMISTRY



LEGEND

M^+ = catalyst +1 oxidation state

Ox = Oxidant

M^{2+} = catalyst +2 oxidation state

RCO_2H = Carboxylic PFAS

$$M^+ + Ox \rightarrow M^{2+} + Radical + Cation \qquad (1)$$

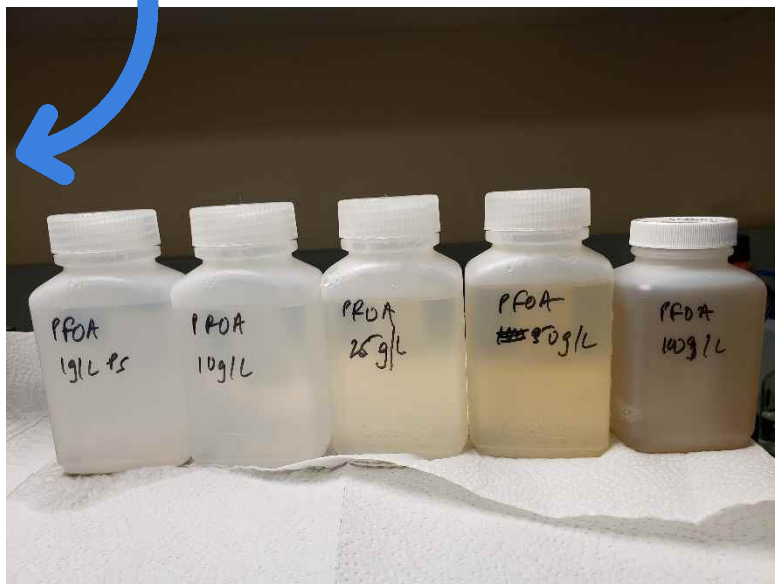
$$M^{2+} + Radical + RCO_2H \rightarrow M^+ + CO_2^{\bullet} + F^- + H^+ \qquad (2)$$

HOT ISCO APPLICATION PROCESS

Addition of catalyst

After 1st Ox injection- change in color

After 2nd Ox Injection- Cyclic reaction

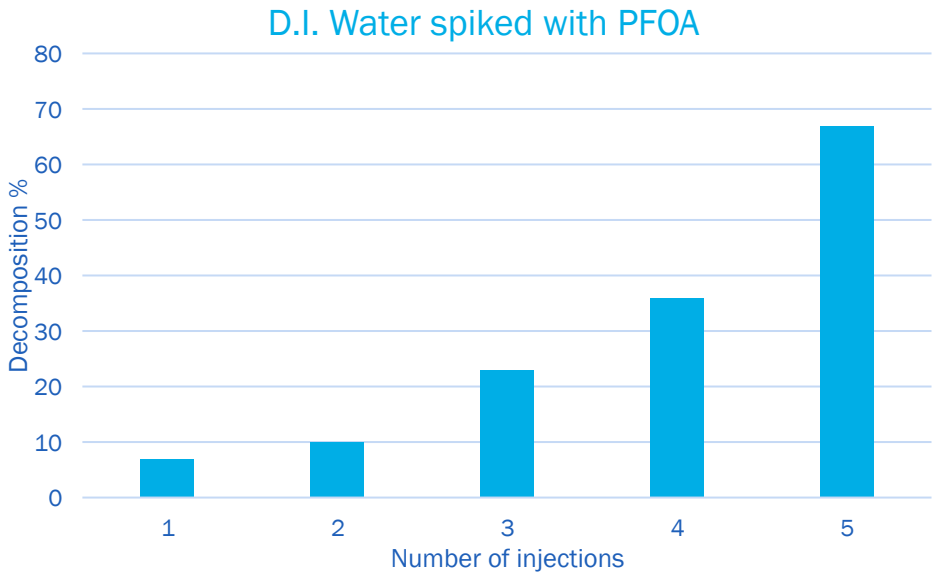


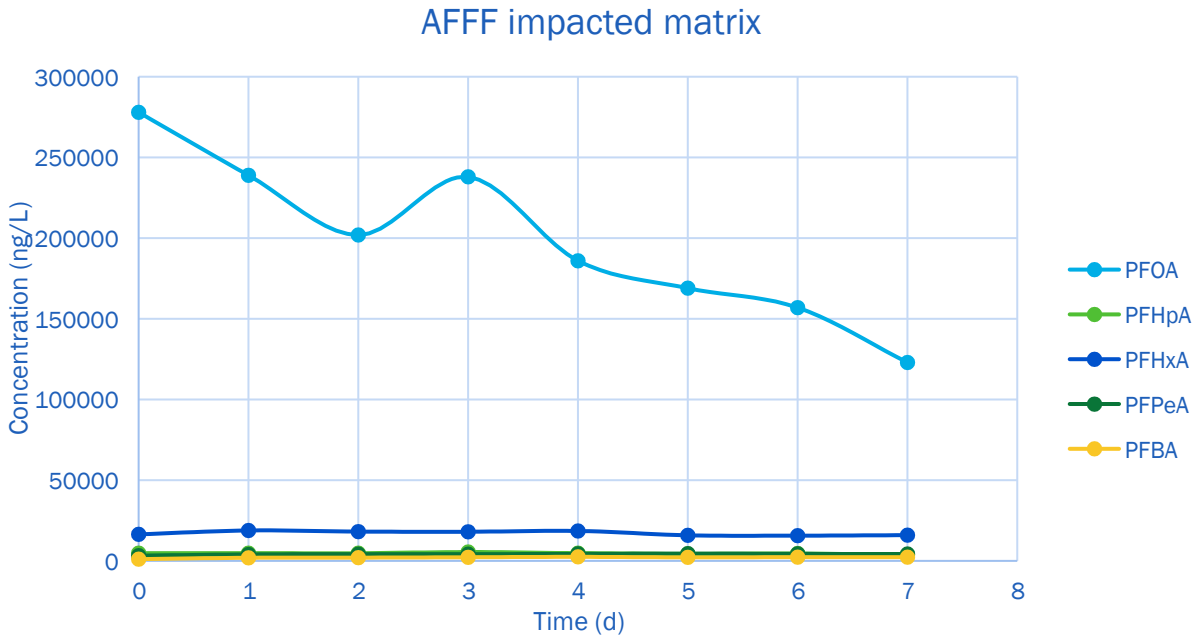
24 hours After 1st Ox injection- back to colorless

FIRE FIGHTING FOAM DERIVED PFAS RESULTS

DESTRUCTION OF PFOA IN AFFF IMPACTED MATRIX

- Lab scale studies were conducted using PFAS in pure water (Top right) and AFFF impacted site matrix (Bottom right)
- Single injection of catalyst followed by multiple oxidant injections
- Achieved ~70% destruction under both conditions
- Catalyst was recycled after **every** injection of oxidant
- Further studies achieved 99+% destruction and production of mass balanced inorganic fluoride



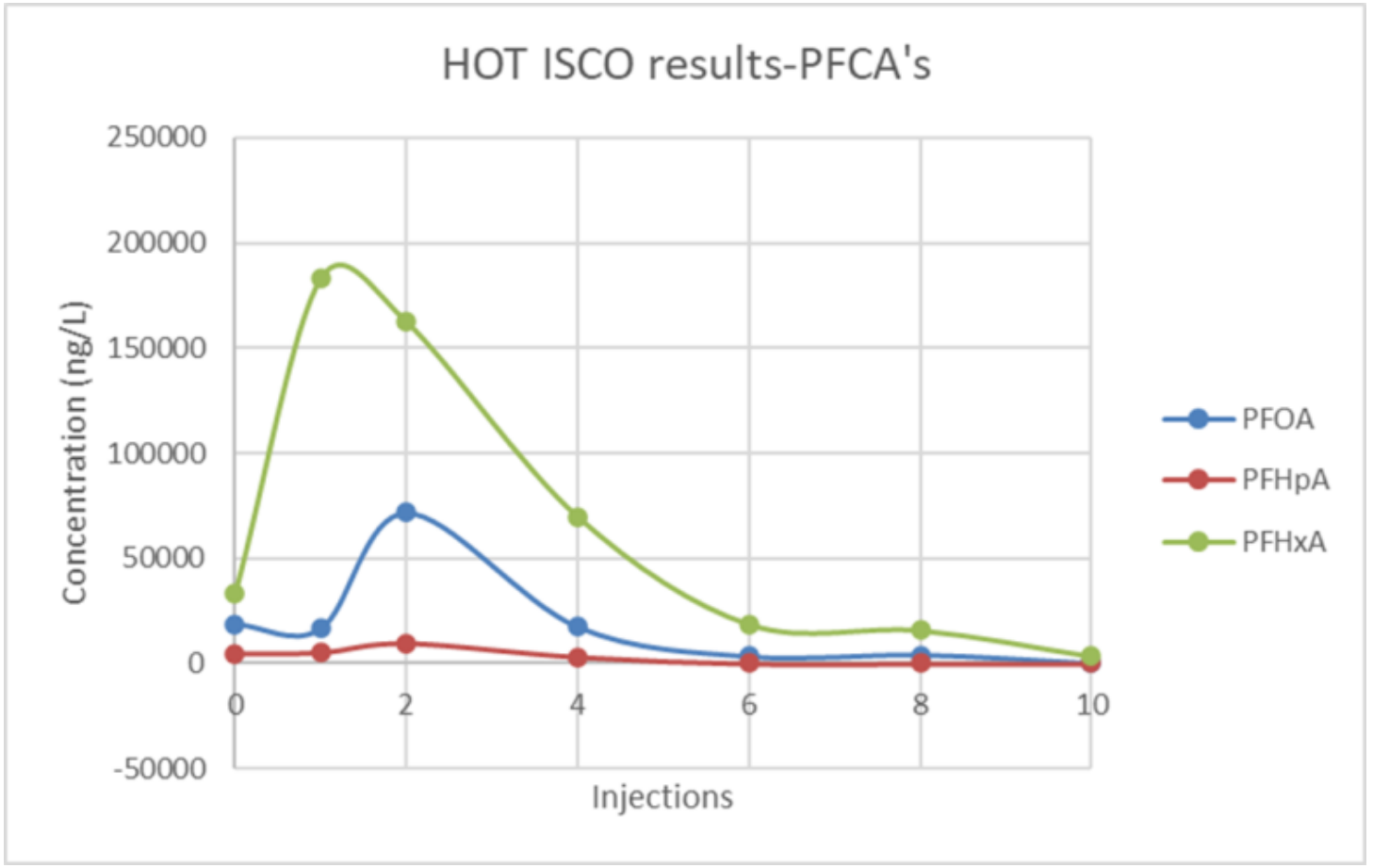


HOT ISCO CONFIDENTIAL CLIENT SAMPLES – PFCA'S

Key Takeaways:

- Significant formation of PFHxA (183,000 ng/L)
- Presence of PFCA forming precursors
- Degradation of the formed PFCAs

PFAS	% Degradation
PFOA	98%
PFHpA	100%
PFHxA	100%

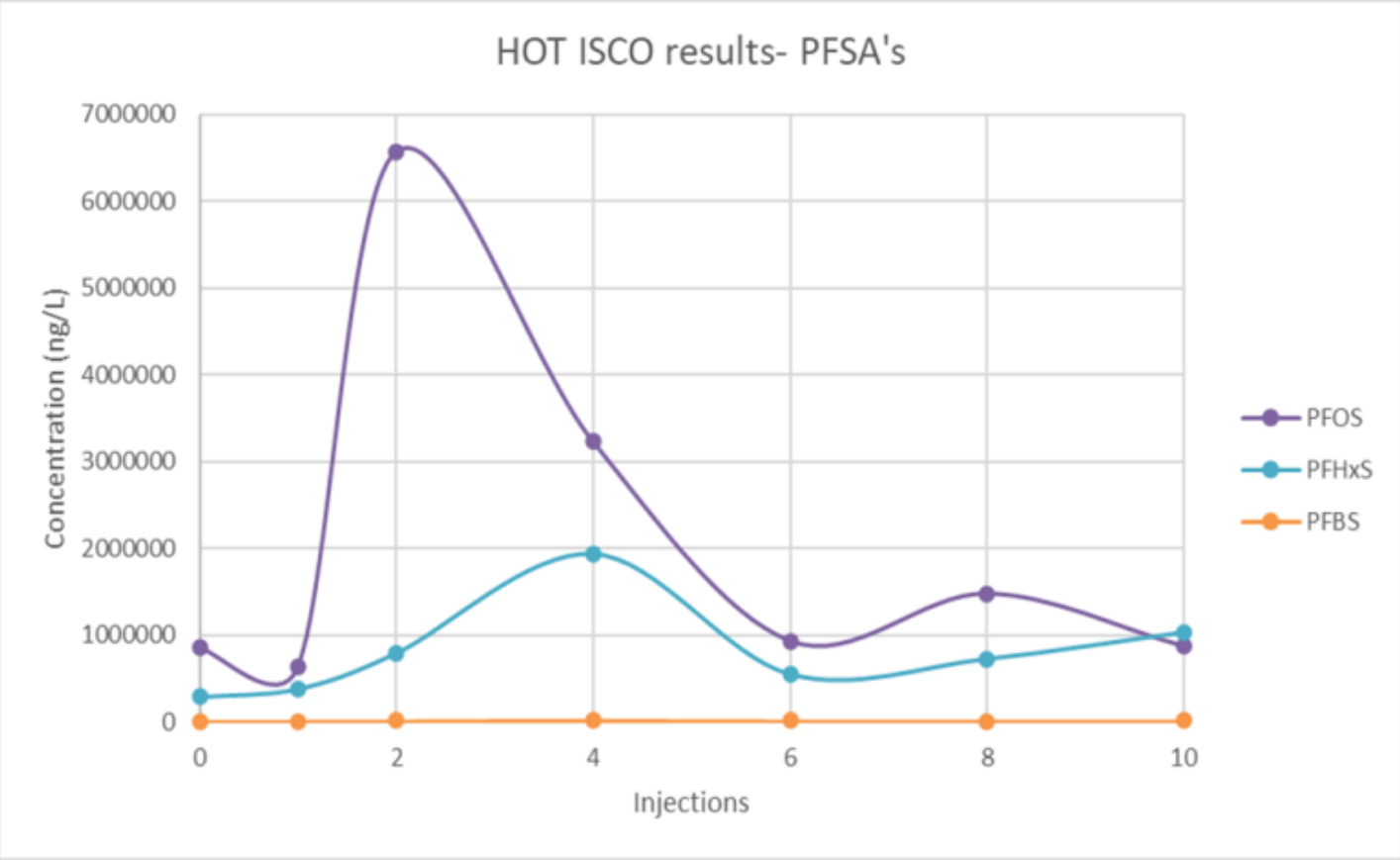


HOT ISCO CONFIDENTIAL CLIENT SAMPLES – PFSA'S

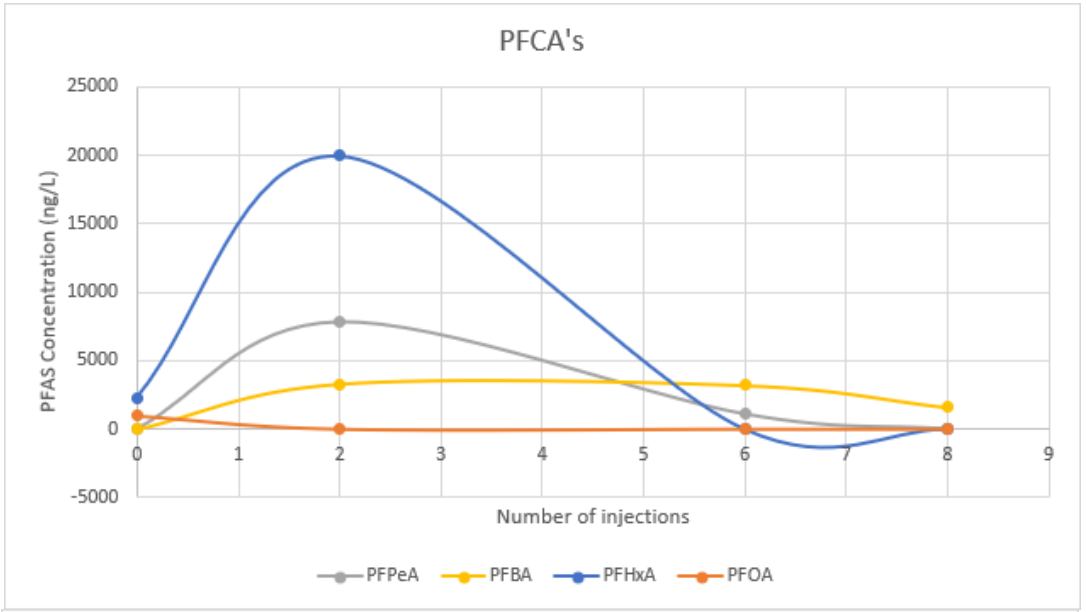
Key Takeaways:

- Significant formation of PFOS (6,576,667 ng/L or 6.5 ppm)
- Presence of PFSA forming precursors
- PFHxS was being removed & formed
- Degradation/Removal of the formed PFSAs

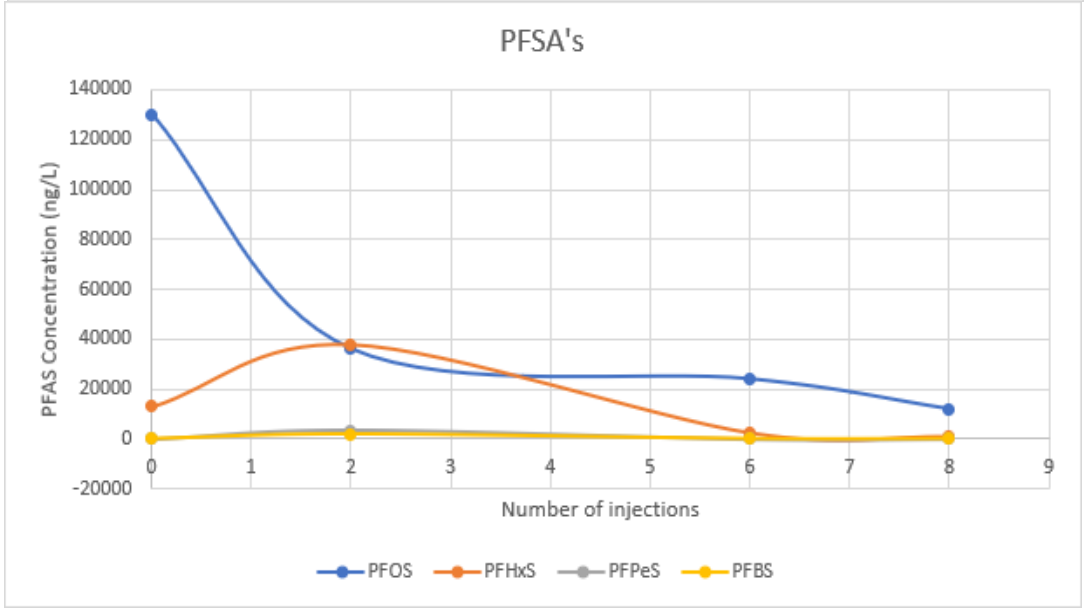
PFAS	% Degradation
PFOS	87%
PFHpS	47%
PFHxS	32%



PFAS IMPACTED INVESTIGATION DERIVED WASTE



PFAS	% Destruction
PFOA	>99.9%
PFBA	90% off peak
PFPeA	>99.9% off peak
PFHxA	>99.9% off peak



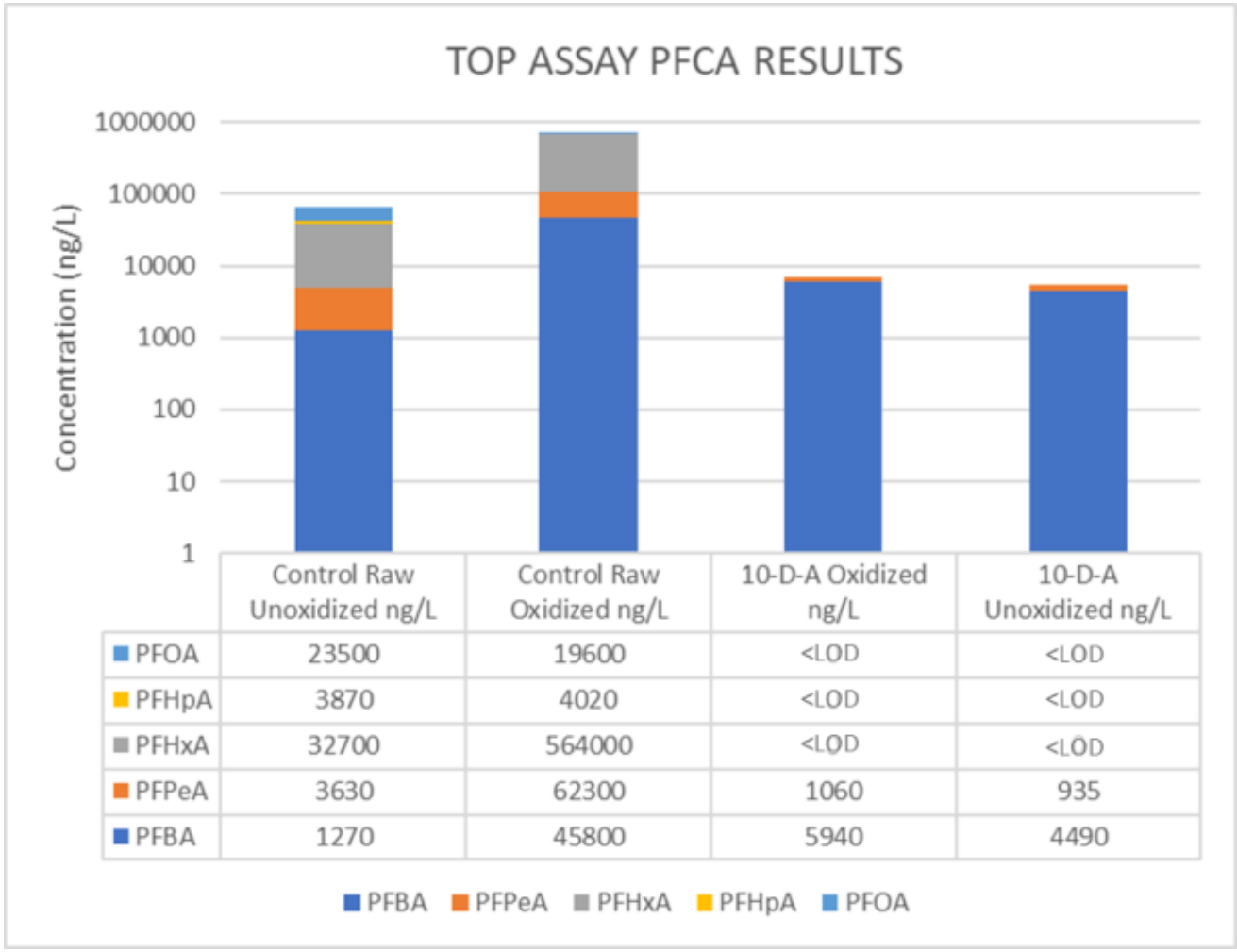
PFAS	% Destruction
PFOS	95.4%
PFBS	NA
PFPeS	>99.9% off peak
PFHxS	>99.9% off peak

HOT ISCO ON CONFIDENTIAL CLIENT SAMPLES – TOP ASSAY

Key Takeaways:

- Significant presence of PFCA forming precursors (control ox vs unox), degraded by OH•
- Near complete degradation of all PFCA's
- HOT ISCO oxidized all the precursors
- 90+% removal of short chain compounds

PFAS	% Reduction
PFOA	100%
PFHpA	100%
PFHxA	100%
PFPeA	99%
PFBA	90%



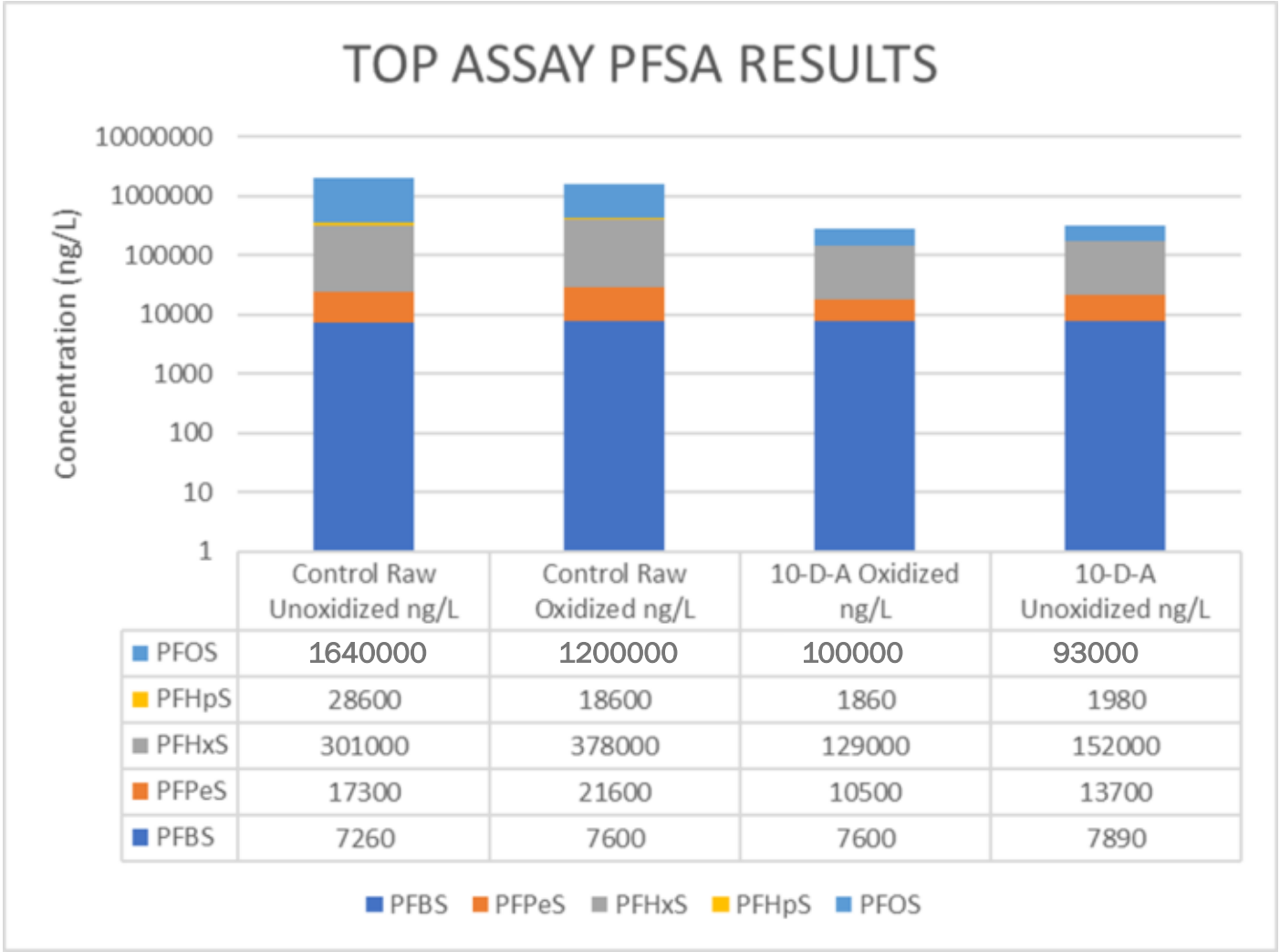
	Control Raw Unoxidized ng/L	Control Raw Oxidized ng/L	10-D-A Oxidized ng/L	10-D-A Unoxidized ng/L
PFOA	23500	19600	<LOD	<LOD
PFHpA	3870	4020	<LOD	<LOD
PFHxA	32700	564000	<LOD	<LOD
PFPeA	3630	62300	1060	935
PFBA	1270	45800	5940	4490

HOT ISCO ON CONFIDENTIAL CLIENT SAMPLES – TOP ASSAY

Key Takeaways:

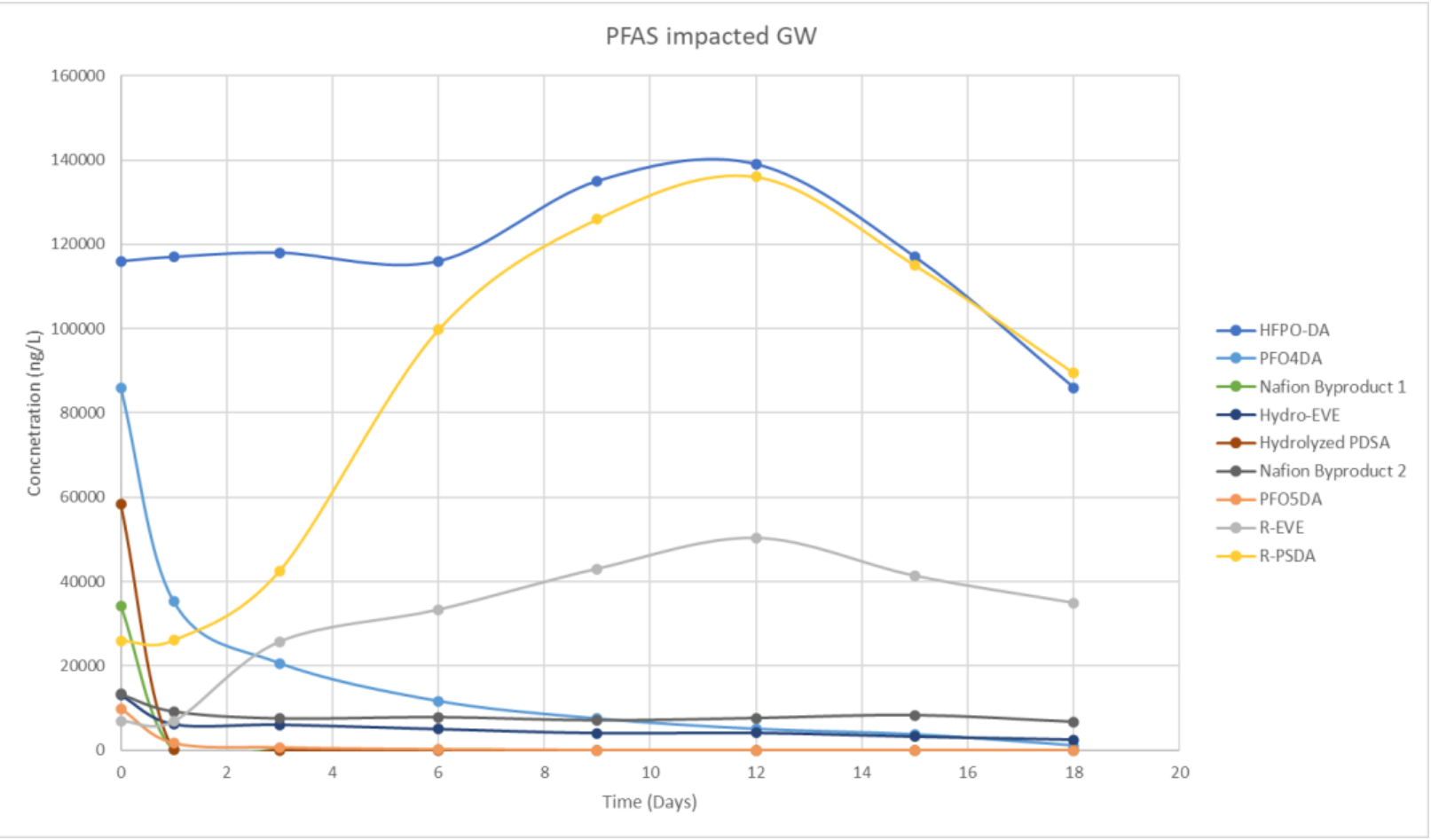
- TOP assay reduced concentration of PFOS & PFHpS in control samples
- TOP assay increased the concentration of PFHxS, PFPeS and PFBS

PFAS	% Reduction
PFOS	99+%
PFHpS	95%
PFHxS	67%
PFPeS	55%
PFBS	15%



GEN-X DERIVED PFAS RESULTS

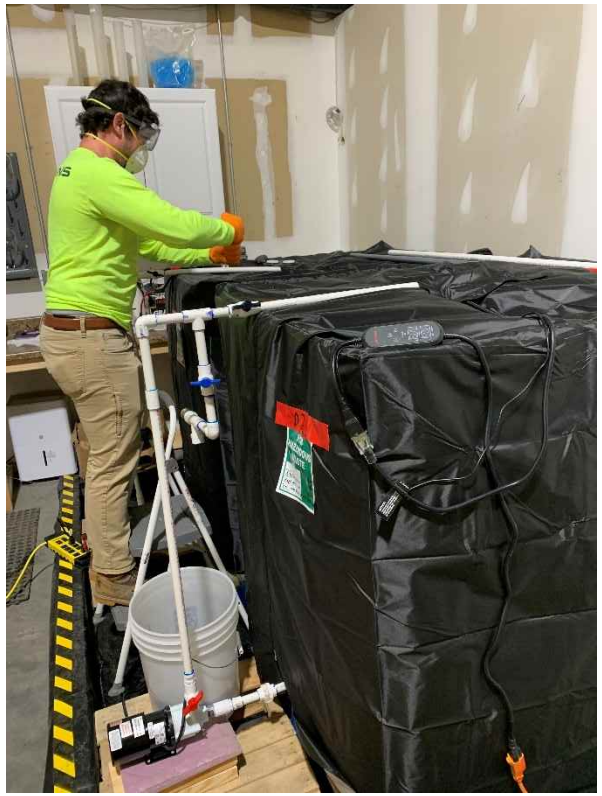
HOT ISCO LAB STUDY ON WATER FROM IMPACTED SURFACE WATER



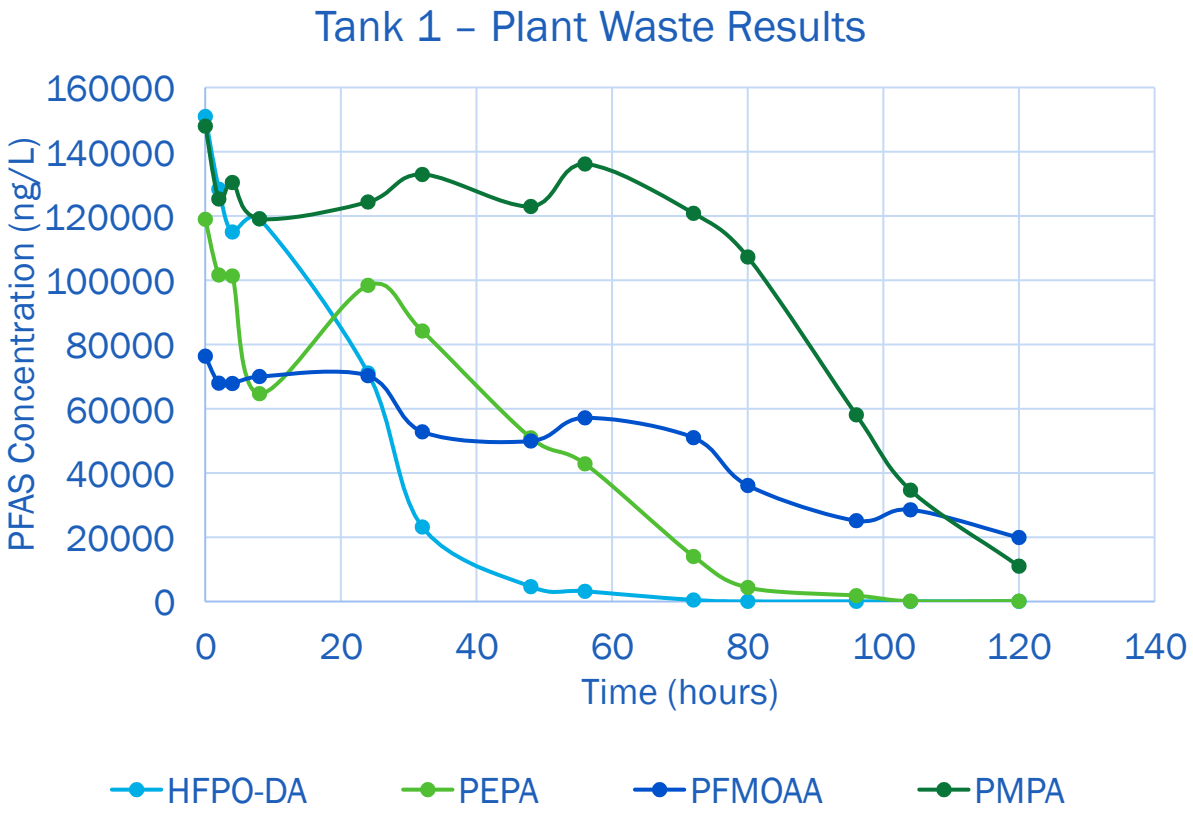
- Generation of HFPODA & R-PSDA followed by degradation
- Rapid destruction of 7 compounds present in ground water
- Catalyst was recycled after every injection of oxidant
- Proceeded to drum studies based on these results

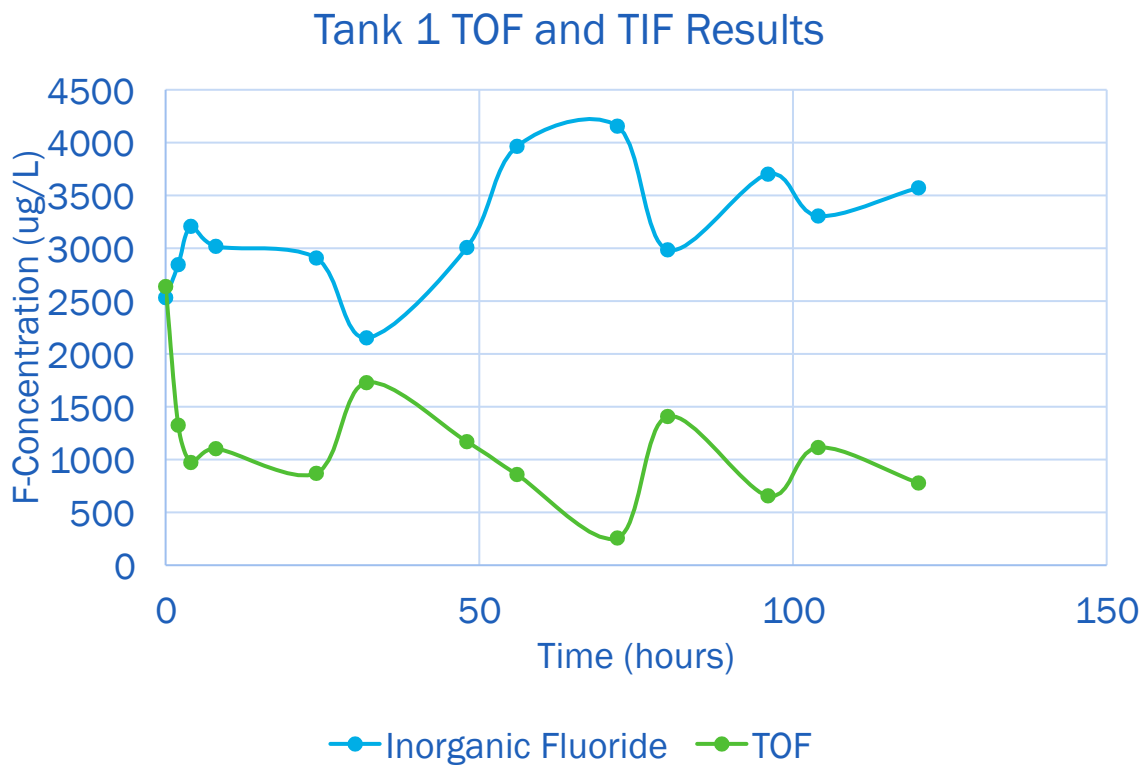
HOT ISCO HIGH CONCENTRATION PFAS TANK DEMONSTRATION

- Two high concentration waste streams (source area groundwater and plant waste)
- 225 gallons of each waste stream
- One catalyst and 10 applications of oxidant so far. 4 more oxidant applications planned.
- Study completion in March.
- Samples collected after each application for Specialty PFAS analysis, TOF, TIF, fluoride, and geochemistry.



HOT ISCO TANK STUDY RESULTS PLANT WASTE





CONCLUSIONS

- The Good!
  - HOT ISCO has been successfully demonstrated on a wide variety of matrices from impacted sites in 9 states
  - Results are validated by using robust study design with replicates, controls, and blanks and third party lab analysis using standard and non-standard methods
  - Destruction achieved:
    - PFCAs: 99.9+%
    - PFSAs: 95% - 99.9+%
    - GEN-X: 90% - 99.9+%

- The less good…
  - Oxidant demand is highly variable and can be very high at high organic sites or LNAPL sites – high cost
  - In-situ performance would be limited at silty clay sites due to distribution challenges
  - Hot ISCO is a source area technology and would not be cost effective in dilute plumes or deployed in a PRB

UPCOMING FIELD PILOTS AND LAB STUDIES

- Field demonstration at an AFFF impacted site in Michigan – July 2024
- Lab studies underway using water from a former coating facility and leachate from a closed landfill
- Catalyst recovery and reactant loading optimization laboratory studies underway
- Ex-Situ flow through system at lab demonstration stage (200 gallons per day)
- We are actively seeking partners to demonstrate PFAS destruction in the field!

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