Smoldering PFAS-Impacted Soils: From Laboratory to Full-Scale Applications

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Agenda

- Technology Overview
- PFAS Smoldering
- Laboratory & Pilot Treatment
- Full-Scale Treatment
- PFAS Technology Development
- Summary

Technology Overview

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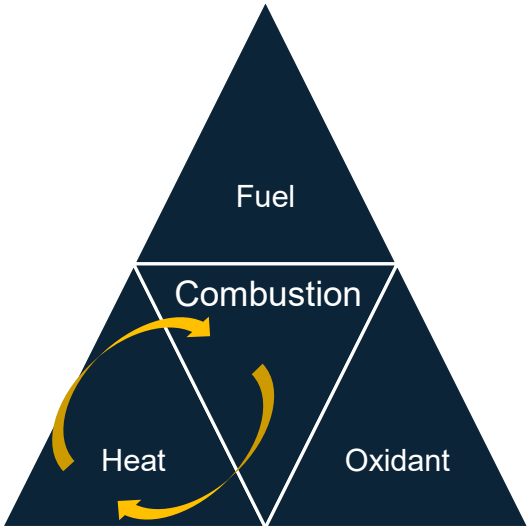
Smoldering Combustion

STAR/STARx is based on the principles of smoldering combustion



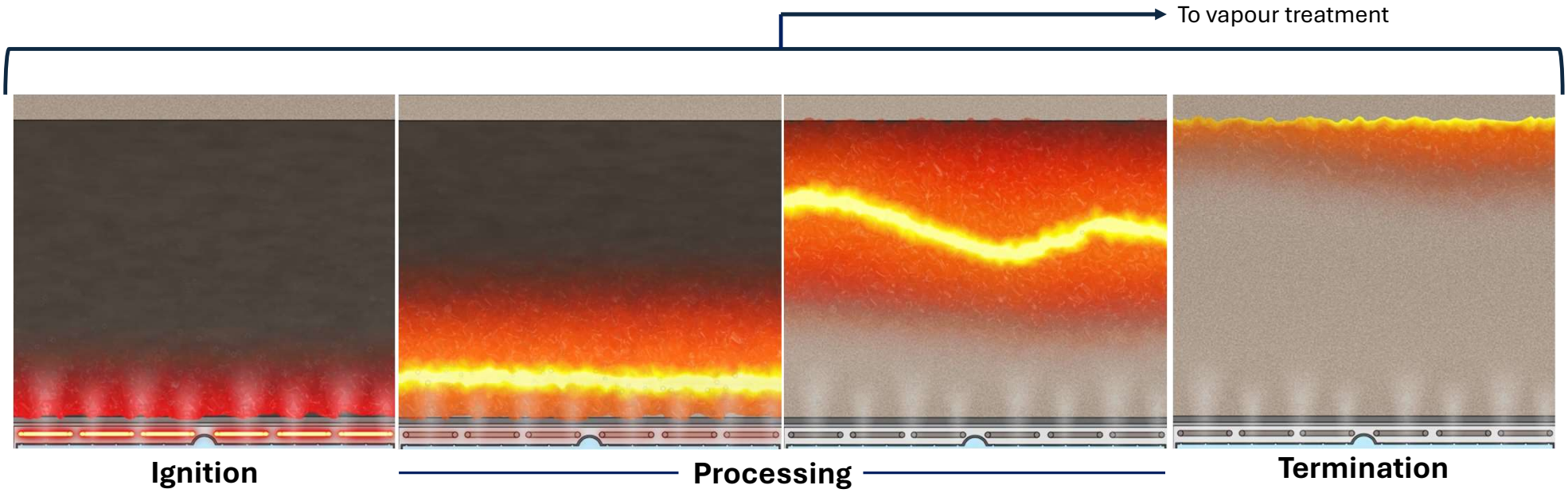
Fuel (contaminant in soil)

Oxidant (injection air)

Heat (via electric resistive heaters)

Only oxidant is required to propagate a flameless combustion front after initial short duration ignition event

Smoldering Combustion



Generated combustion gases are collected under vacuum and treated to regulatory requirements

In situ (vadose & saturated zones)

Applied via ignition points and portable heaters

Ex situ (above ground)

Soil/feedstock loaded in Hottpad™ or STARxpress™ mobile treatment units

Smoldering Combustion Treatment

Hydrocarbon-Impacted Soil

PFAS-Impacted Soil

PFAS Destruction - Laboratory and Pilot

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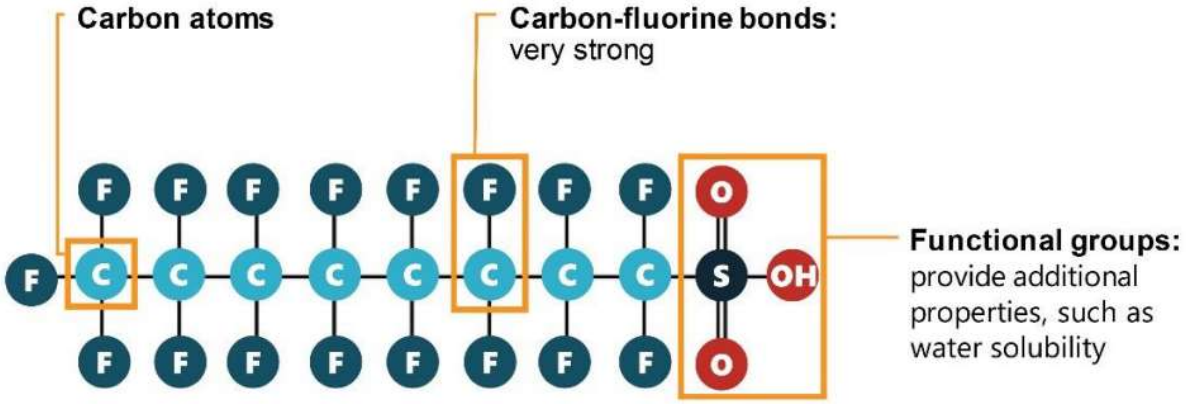
PFAS Destruction

Strong chemical and thermal stability

$$PFAS \xrightarrow{HEAT} HF + shorter\ chain\ compounds$$



(AAAS, 2021)

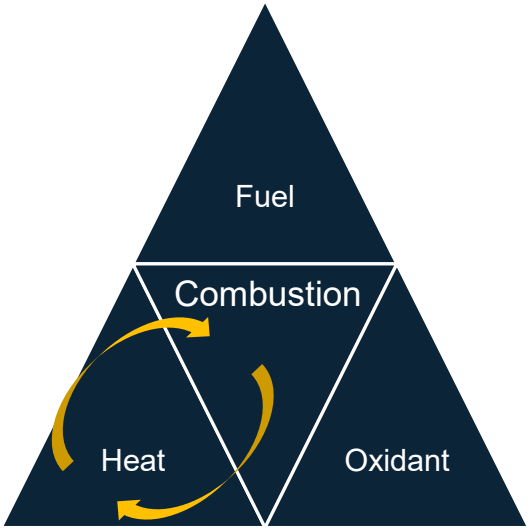
Mineralization

- Increases with Temp > 700°C
- Maximizes at Temp > 900°C

Vecitis et al., 2009; Wang et al., 2011; Watanabe et al., 2015; Yamada et al., 2005

PFAS Smoldering Combustion

PFAS calorific content does not promote self-sustaining smoldering



PFAS-Impacted Soil

Fuel (surrogate fuel (GAC) added to soil)

- ~5% by wt.
- Sustains reaction at high temperatures required for PFAS destruction

Catalyst (Calcium Oxide added to soil)

- ~0.25% by wt.
- Improves PFAS destruction and minimizes emissions byproducts[2]

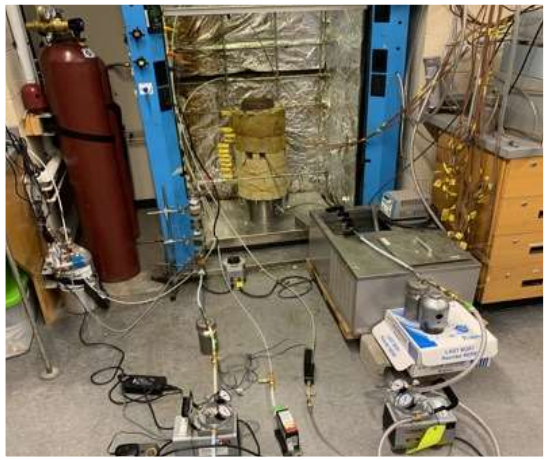
STAR/STARx targets PFAS destruction temperature of 700 – 900 °C[1]

1 – Duchesne, et al. 2020, 2 – Harrison, et al. 2022

PFAS Smoldering Scale Up

PROJECT OF THE YEAR 2021 SERDP ENVIRONMENTAL RESTORATION

Phase 1



Lab Column Tests

- Fluorine Mass Balance
- CaO Optimization

Phase 2

Pilot Scale Tests

- Scale Up
- Evaluate Field Soils

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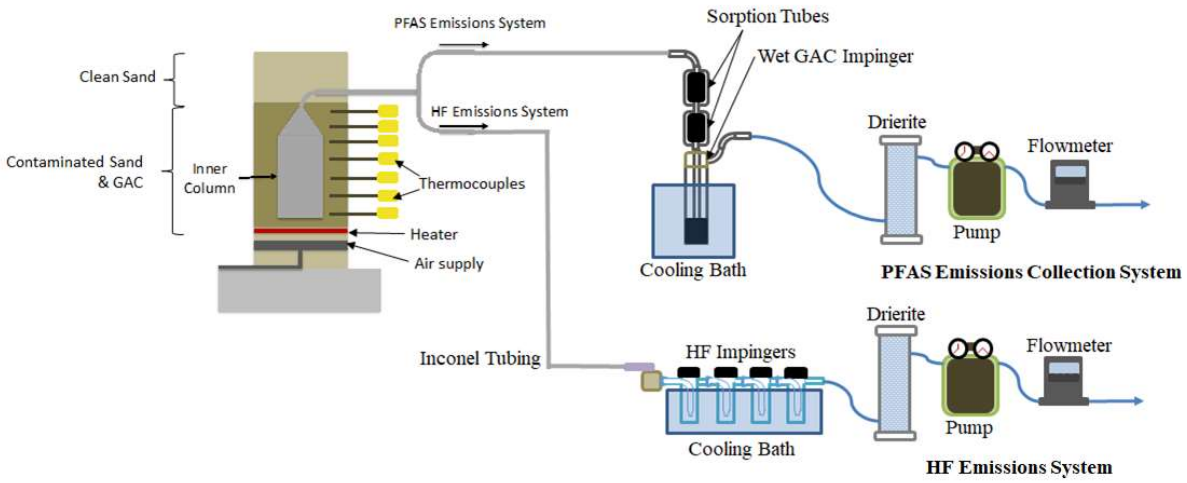
Phase 1 – Laboratory Study

Novel experimental design employed for detailed emissions analysis



Key Results

- All targeted PFAS <LOQ in post-treatment soil
- When CaO is added:
  - >90% reduction in total F in emissions
  - F retained in soil as CaF_2
- 80 – 128% mass balance achieved

Phase 2 - Pilot Test

Phase 2 - Pilot Test Results

Soil Results

- >99.9% reduction of PFAS (to near or below detection limits)
- Fluorine primarily retained as CaF_2

Emissions Results

- <0.2% of total fluorine emitted as PFAS
- <2% of total fluorine emitted as HF
- Fluorinated breakdown products can be captured via vapor-phase GAC

PFAS Destruction – Mobile Full Scale

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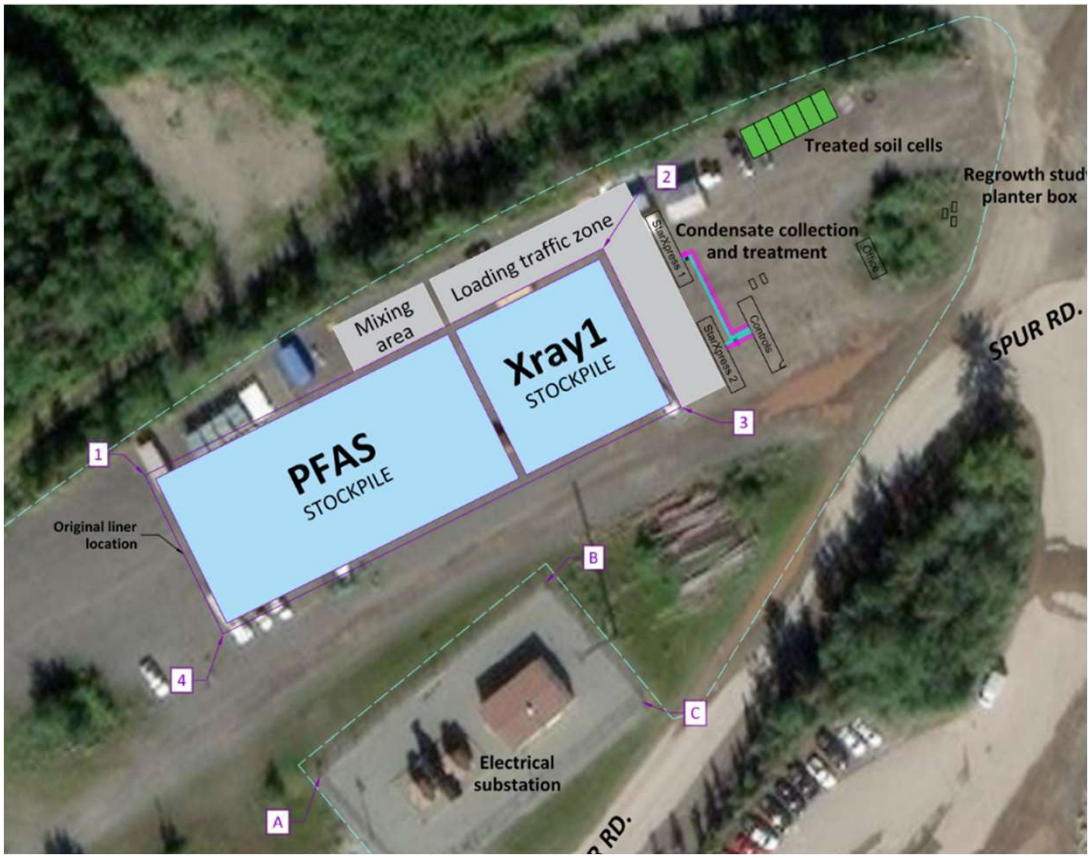
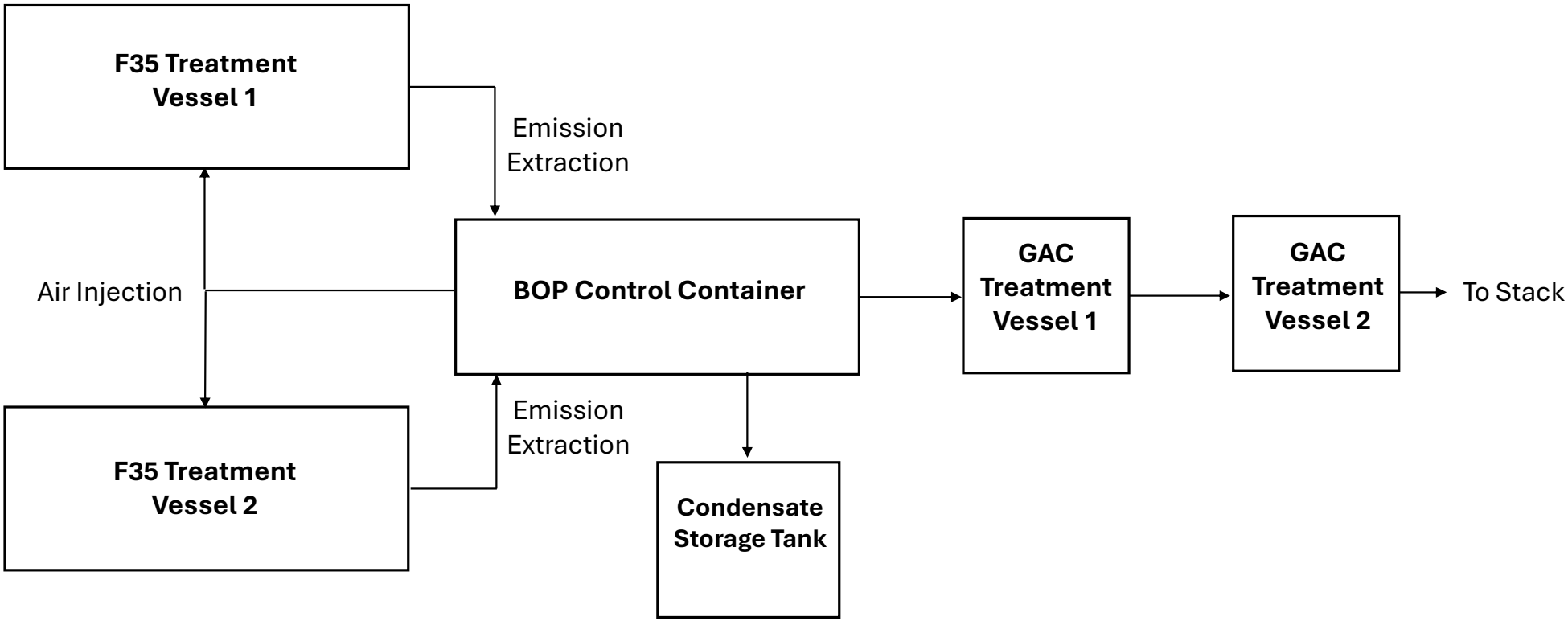
Joint Base Elmendorf-Richardson (JBER)



- **Design / fabricate rapidly deployable ex-situ STARxpress Plant**
- Stockpiled PFAS-impacted soils
- Demonstrate treatment of PFAS-impacted soil to below ADEC MTG criteria for PFOS and PFOA
- Generate technoeconomic, performance data and implementation experience

STARxpress Plant Design

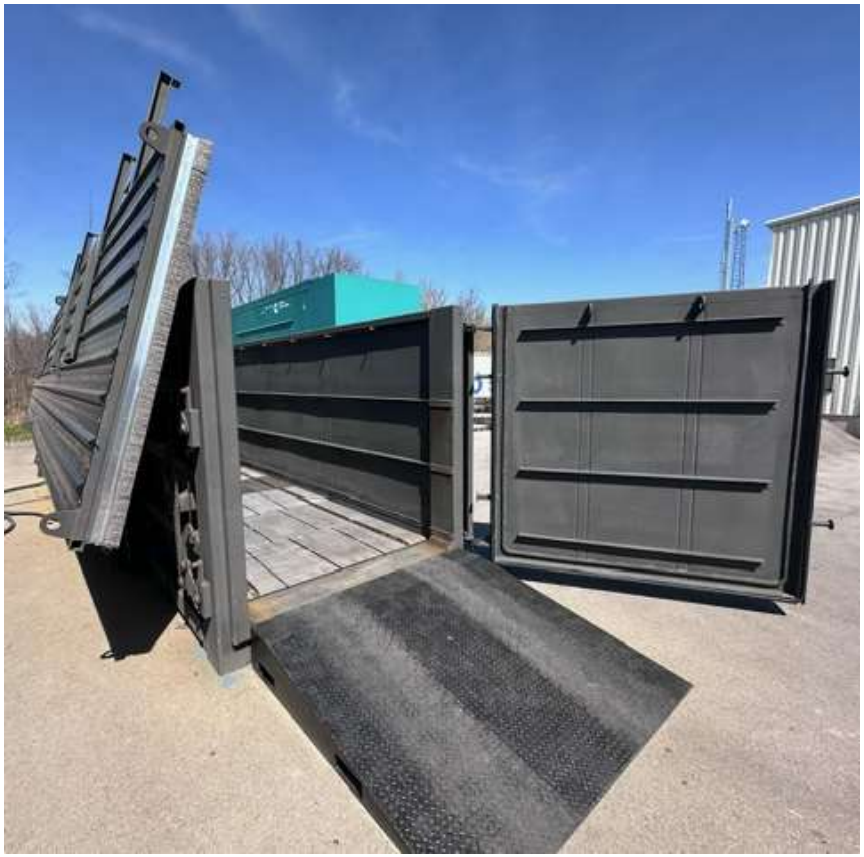


STARxpress Plant

2x F35 Treatment Units
(45 yd^3 capacity)

Balance of Plant (BOP) Control Container

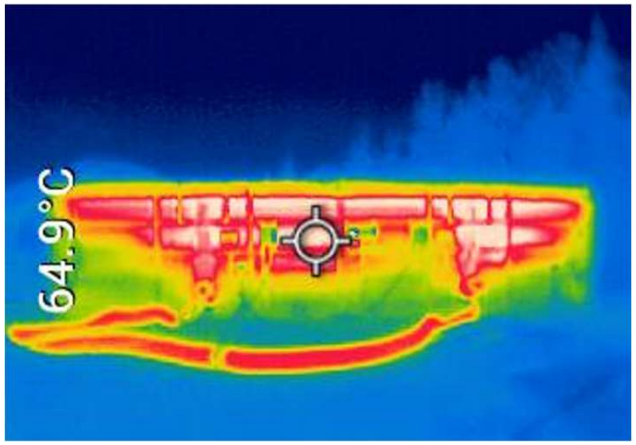
STARxpress Plant

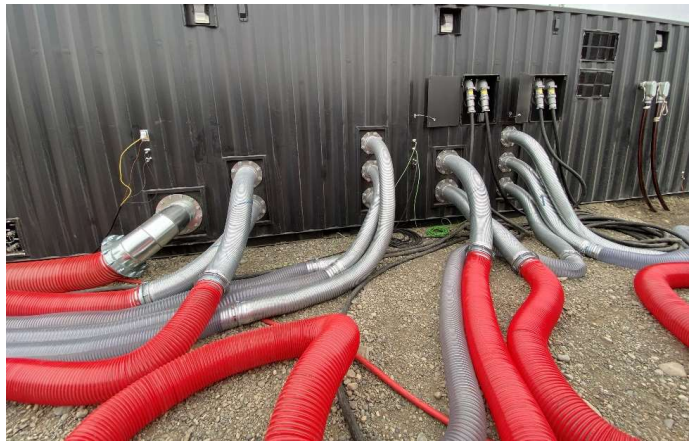


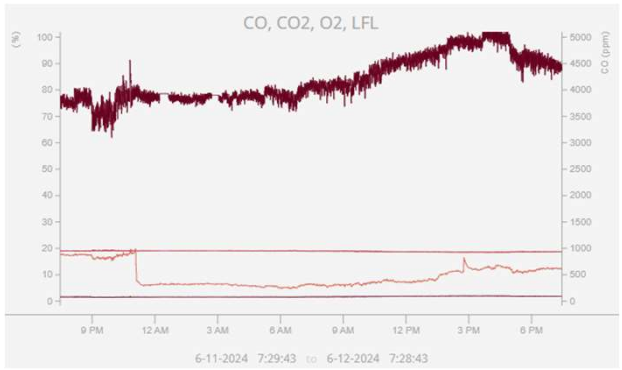
- Cantilever roof
- Double swing doors
- Integrated injection / extraction ducting
- ISO lifting points
- Containerized process equipment
- Onboard control room
- Requires 480V 500 A service

STARxpress Plant

STARxpress Field Operations

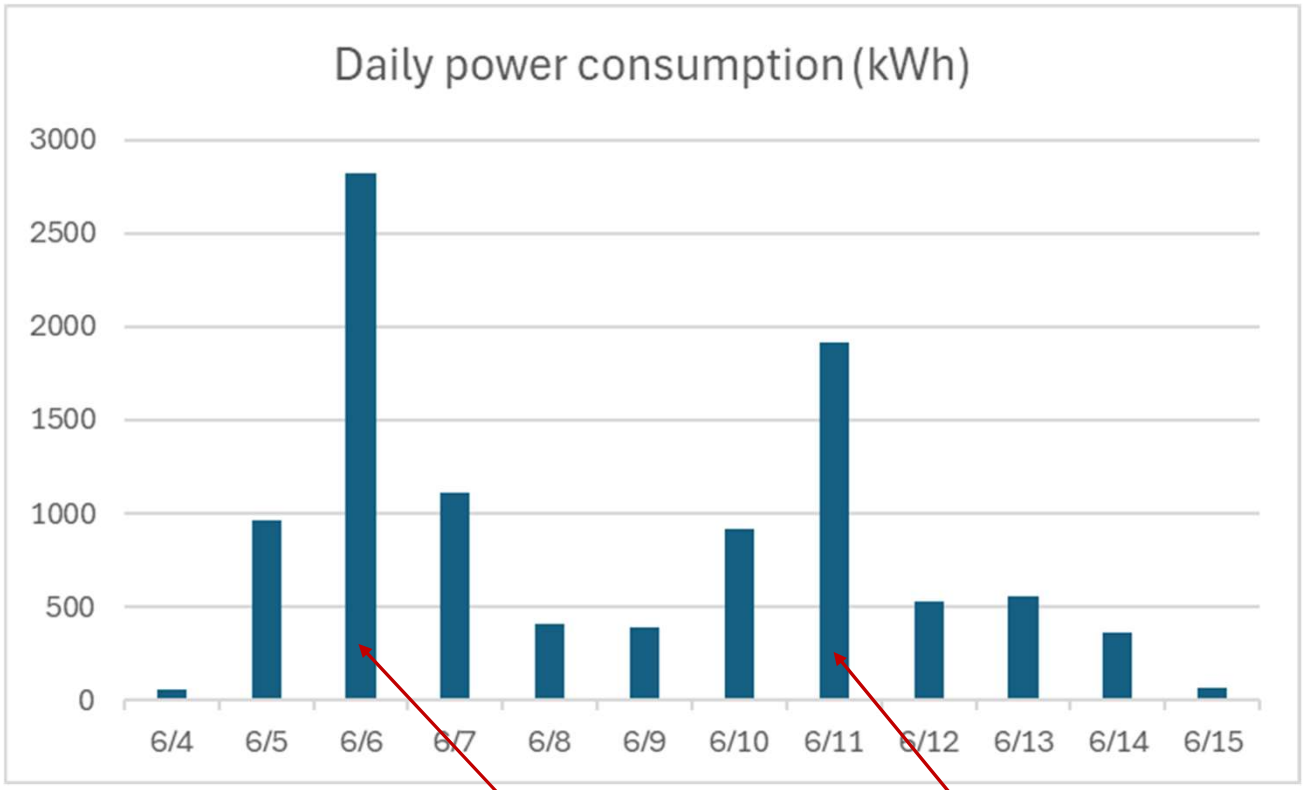






STARxpress Field Implementation

STARxpress Energy Consumption

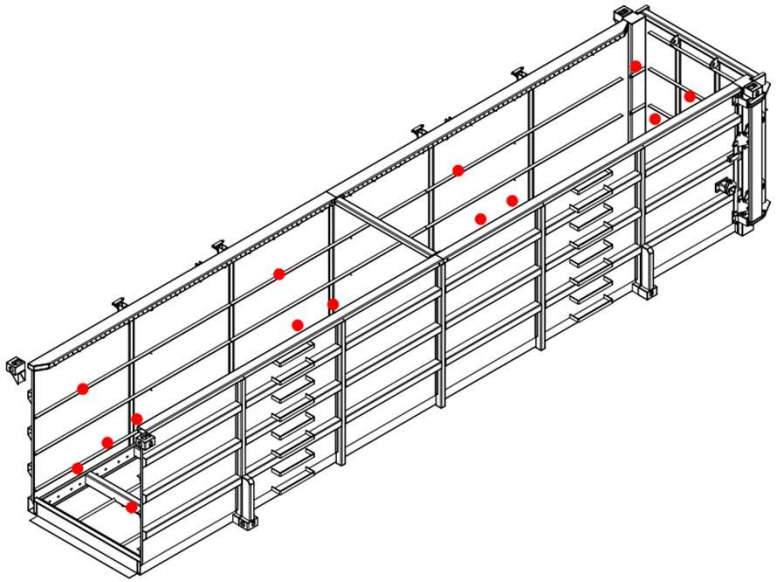


Average = 115 kWh/yd^3

Heaters ON: Batch 1

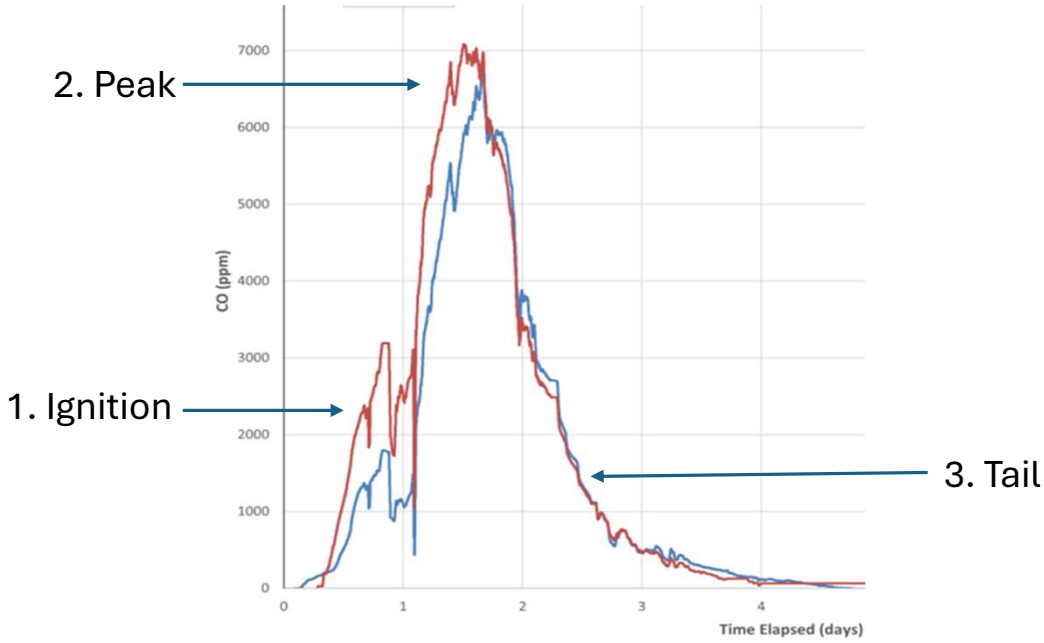
Heaters ON: Batch 2

STARxpress Soil Sampling



- 2x 10-part composite samples (eqv. to 1 sample per 2.25 yd^3):
  - PFAS (EPA 1633)
  - VOCs (EPA 8260D)
  - SVOCs (EPA 8270E)
  - DRO (AK 102)
  - TOC (EPA 9060A)
  - Anions (EPA 9056A)
  - Metals (EPA 6010D)
- 1x 10-part composite sample:
  - EOF (by CIC)
  - TOP Assay (EPA 537, Modified)
  - PIGE

STARxpress Vapor Sampling



- 3x emissions sampling events
- OTM-45 with sequential extraction for OTM-50, OTM-55, HF (EPA Method 26A), and Total Particulate Matter

STARxpress Treatment Results

- 45 days of operations
- >95% uptime
- Average 6-day batch cycle time
- 440 cubic yards of soil treated in 10 batches
- All batches treated to below the success criteria of ADEC MTG levels for PFOS and PFOA (and several batches <MDL)
- OTM-50 volatile fluorinated compounds <MDL
  - OTM-45/55 results pending
- Additional data validation and reporting in progress

STARxpress Plant Study

	Unamended	Compost	Fertilizer
July 1 2024			
Aug 21 2024			

PFAS Technology Development

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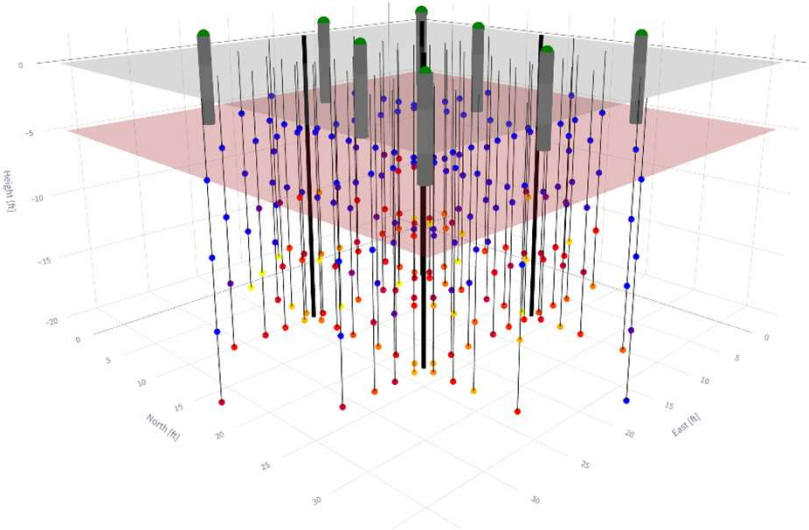
ESTCP (ER22-7470) - STAR

- STAR PFAS source zone destruction
- Carbon and CaO amendments applied via soil mixing
- 4 ignition points, 650 yd^3 soil volume
- 72 thermocouples
- OTM-45/50/55 emissions sampling
- Operations June 2025

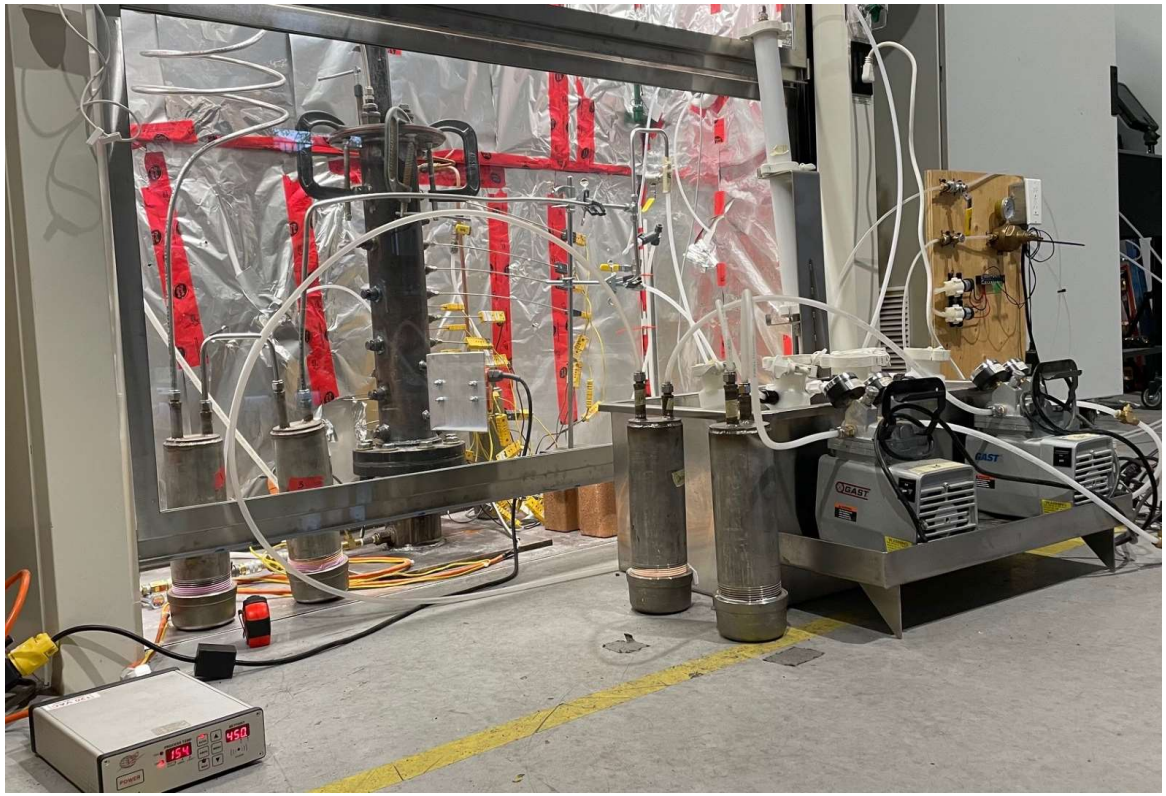


ESTCP (ER23-8372) - STARx

- Demonstrate destruction of PFAS impacted pond sediments
- 2x 1.3 yd^3 batches using Savron's redesigned Rapid Scaling Tool (RST)
- OTM-45/50/55 emissions sampling
- Operations May 2025

PFAS-Impacted Waste GAC - STARx

- Evaluate engineering scale up criteria
- 7x column tests conducted with varying feedstock and process conditions
- PFOS-spiked GAC (~100 ug/kg)
- Non-detect (EPA 1633) in ash and condensate
- Emissions (EPA 1633) below LOQ
- Volumetric reduction ~97%



Summary

- **Smoldering combustion successfully destroys PFAS in soils to regulatory requirements**
- **Laboratory results validated at full-scale with STARxpress Plant**
  - Surrogate fuel is used to achieve high temperatures required for PFAS destruction
  - <1% of total fluorine emitted as PFAS
  - Fluorine primarily sequestered in soil as CaF_2
  - CaO enhances PFAS destruction at lower temperatures and simplifies vapor treatment requirements
- **Additional ex situ and in situ field demonstrations in progress**

Acknowledgements

Questions?

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