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smoldering solutions

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safe, and
better for the
environment

Smouldering Combustion for the Management of PFAS-Impacted Soils at Brownfields Redevelopment Sites in Canada

Presented by: Grant Scholes, M.E.Sc, P.Eng.

Overview

- PFAS
  - What, where, how
  - Current remediation strategies
- Smouldering Combustion
  - Technology basics
  - Brownfield case studies
  - Applicability to PFAS
- PFAS Smouldering Studies
- PFAS Smouldering: Field Application
- Conclusions/Questions

PFAS and PFAS Remediation
(The Simplified Version)

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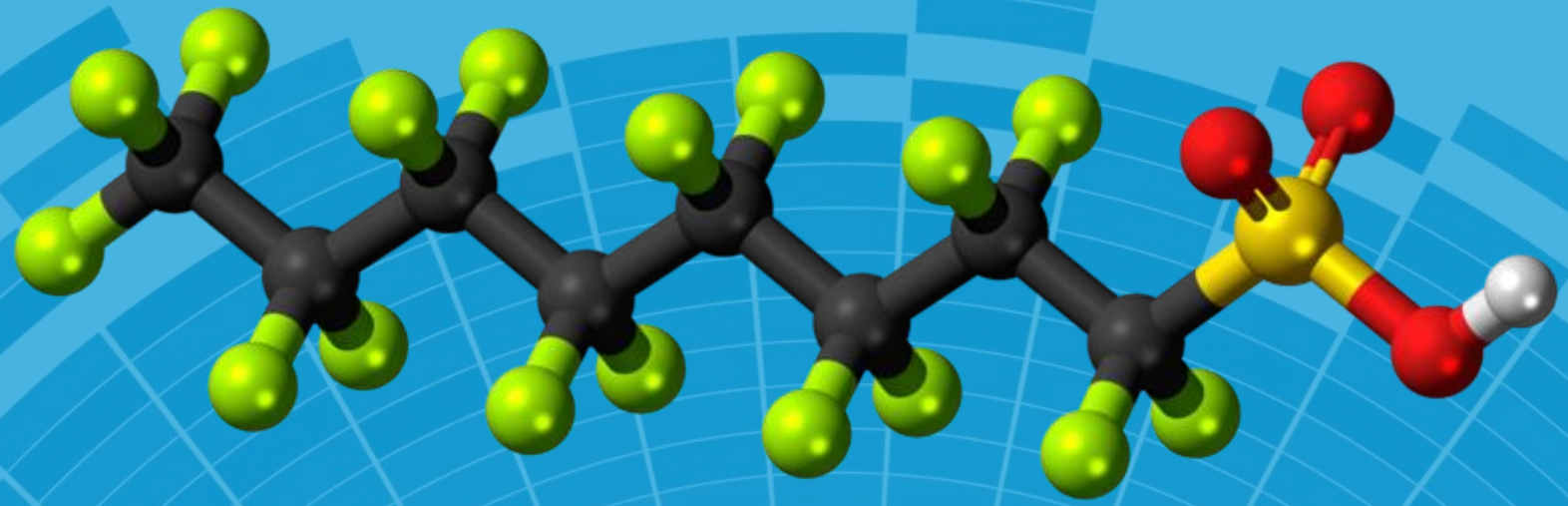
Polyfluoroalkyl Substances (PFAS)



Perfluorooctane sulfonic acid (PFOS)

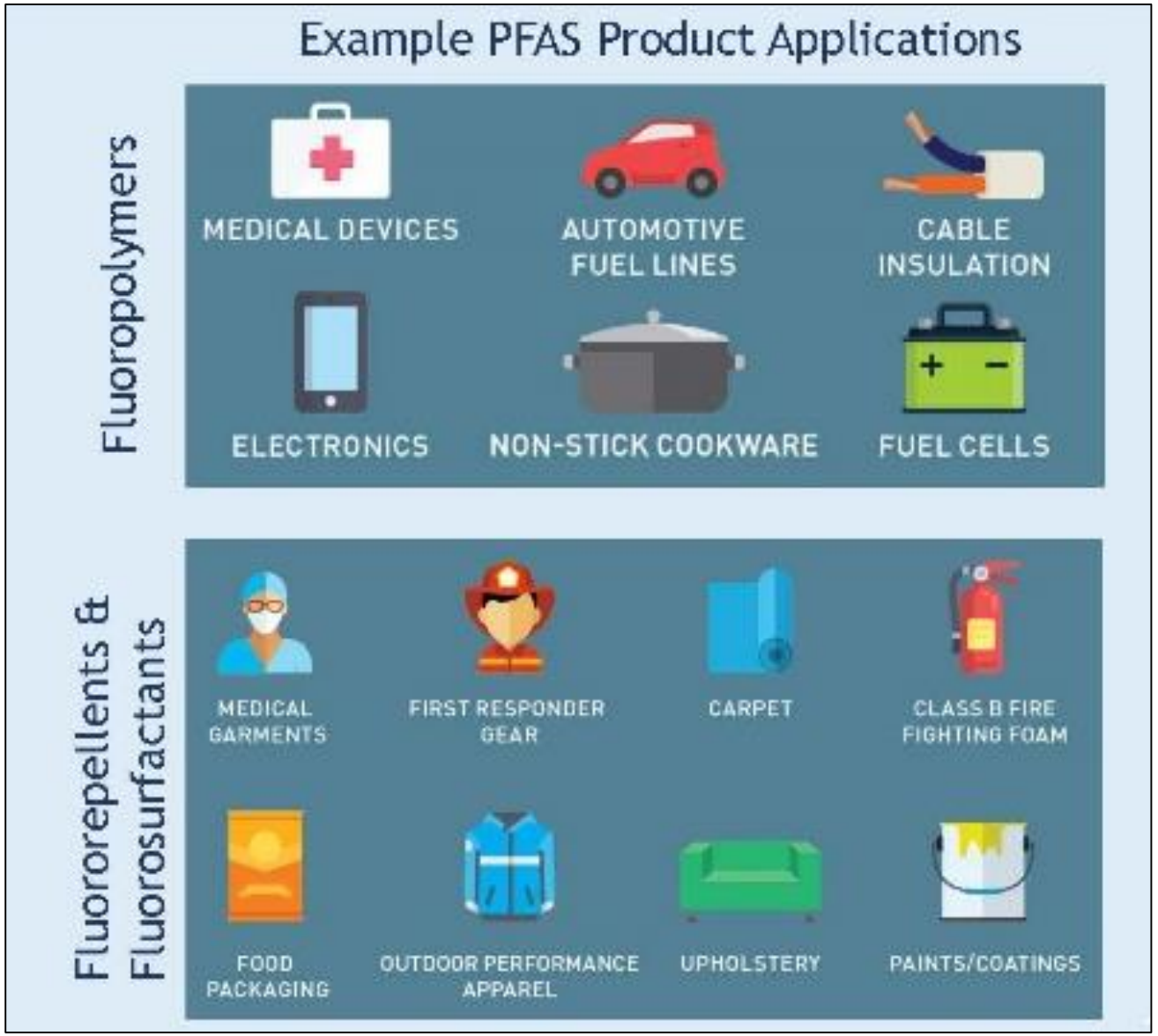
$C_8HF_{17}O_3S$

PFAS - Overview

No natural source

Thousands of chemicals

Thermally and chemically stable



Resist water, heat, and grease and reduce friction

Linked to cancer, immune and reproductive system toxicity

PFAS In the News

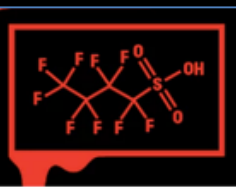
No end in sight for PFOS, PFOA investigation at Joint Base McGuire-Dix-Lakehurst

May 22, 2017

Date: May 22, 2017
0 Comments

JOINT BASE McGUIRE-DIX-LAKEHURST — More than a year has passed since a military investigation into chemical pollution from firefighting foam revealed that groundwater and soil at dozens of sites on the base were contaminated.

The Intercept_



PFOA AND PFOS ARE ONLY THE BEST-KNOWN MEMBERS OF A VERY DANGEROUS CLASS OF CHEMICALS

Feb 10, 2018

ENVIRONMENTAL Science & Technology LETTERS

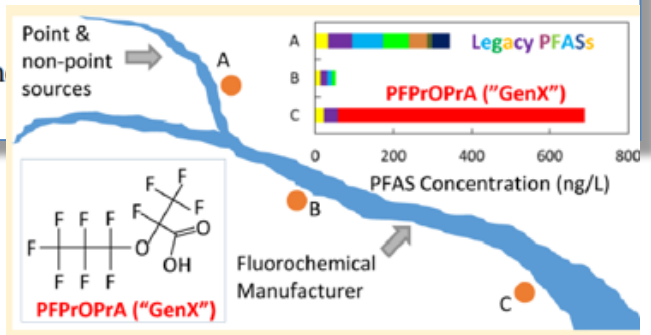
November 10, 2016

Letter

pubs.acs.org/journal/estlcu

Legacy and Emerging Perfluoroalkyl Substances Are Important Drinking Water Contaminants in the Cape Fear River Watershed of North Carolina

Mei Sun,[*,†,‡] Elisa Arevalo,[‡] Mark Strynar,[§] Andrew Lin
Adam Pickett,[⊥] Chris Smith,[#] and Detlef R. U. Knappe[‡]



The Intelligencer

CDC: Some in Horsham, Warrington, Warminster exposed to PFCs several times the safe level

May 24, 2017

PFAS - Overview

Aqueous film forming foams (AFFF)
Aerospace
Alternative energy
Automotive
Building and construction – weather resistant coatings
Biosolids
Building fir
Chemical r
Cosmetics
Electronics
Fire fightin
First responders
Healthcare
Industrial surfactants
Landfills – leachate, odor and dust control
Leather
Medical – implants, patches and grafts
Metal plating and etching
Mining – odor and dust control, enhanced recovery, biosolids for reclamation
Military
Oil and gas – enhanced recovery
Paints, varnishes, sealants, waxes and polishes
Paper products – food surfaces, Rite-in-the-Rain®, Post-It®
Personal care products
Resins
Semiconductors
Stain repellants
Textiles
Wastewater treatment plants
Weather resistant apparel and equipment
Wire manufacturing and coating

“The only places we’re not finding PFAS are places we’re not looking”

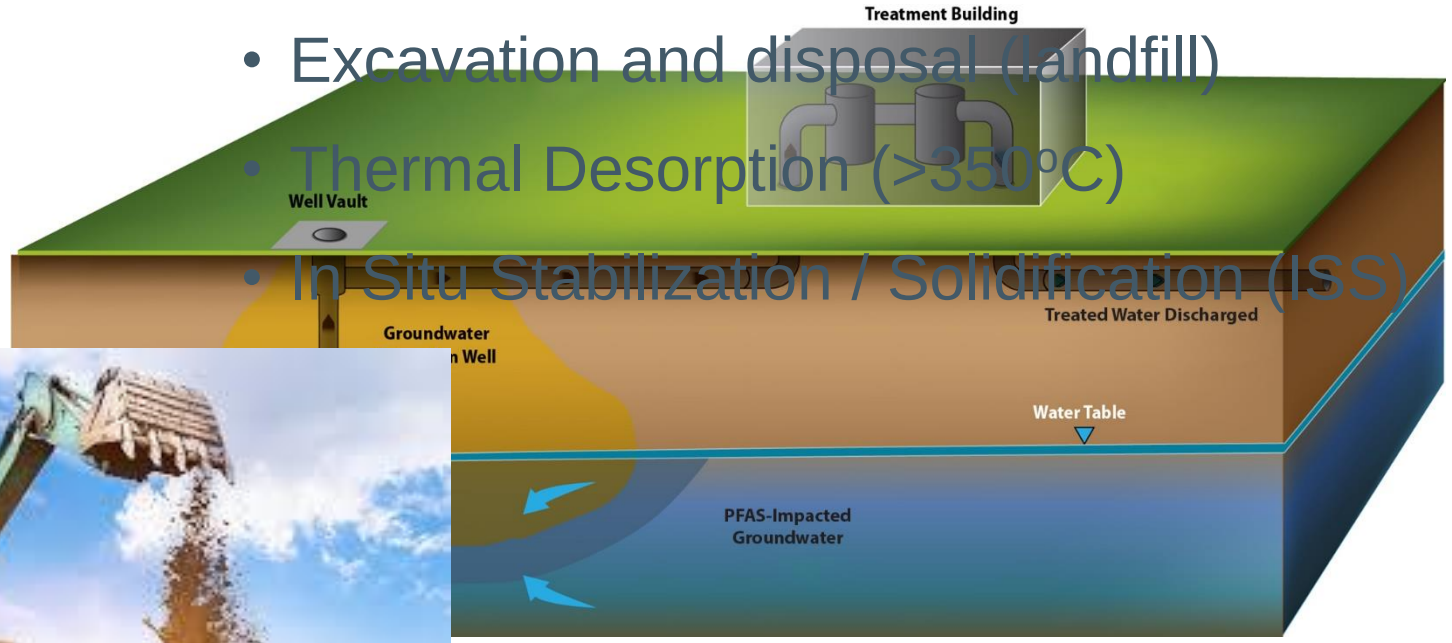
Heather Greither, Director, Michigan Department of Environmental Quality

PFAS Remediation

Soil / Source Areas

- Pri eatment)
  - G
  - S tion, p
  - Advanced oxidation
  - Gamma radiation

- Primarily ‘Transfer’ Technologies
  - Excavation and disposal (landfill)
  - Thermal Desorption (>350°C)
  - In Situ Stabilization / Solidification (ISS)



tem (modified from NMED)

Smouldering Combustion

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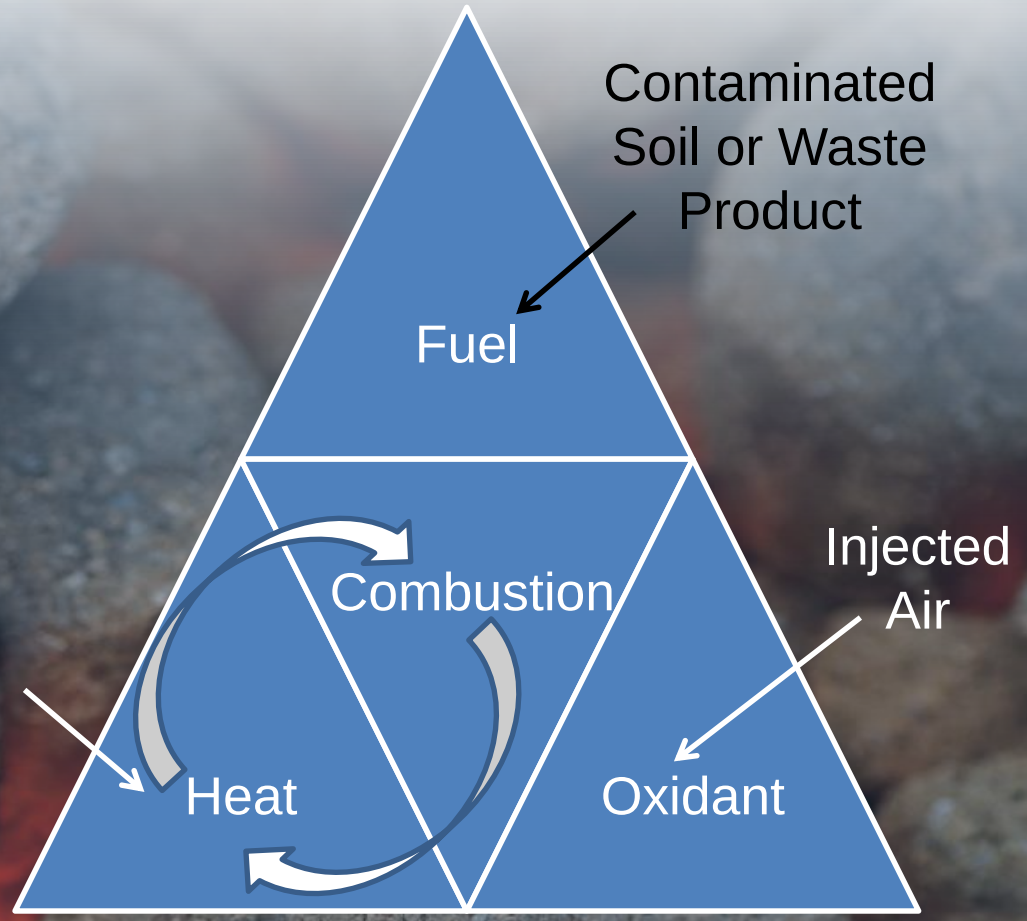
Smouldering Combustion

STAR and STARx are based on the process of smouldering combustion:

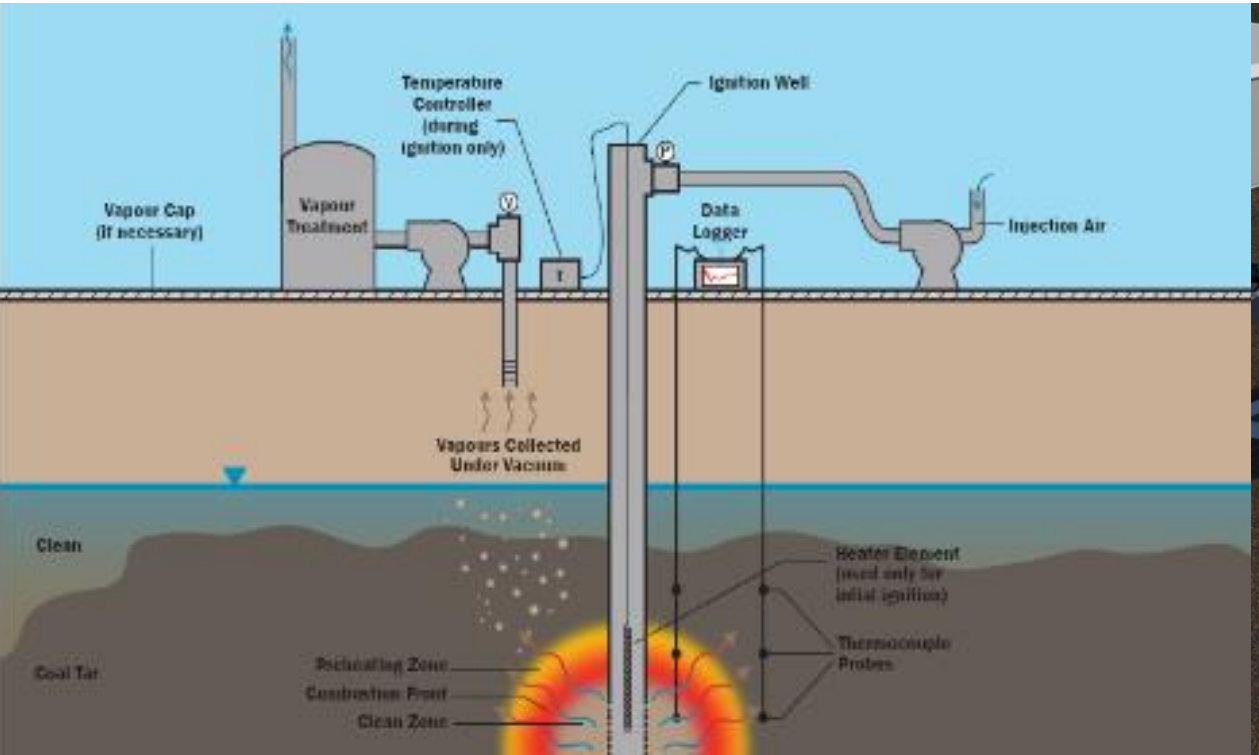
Exothermic reaction converting carbon compounds to $CO_2 + H_2O$



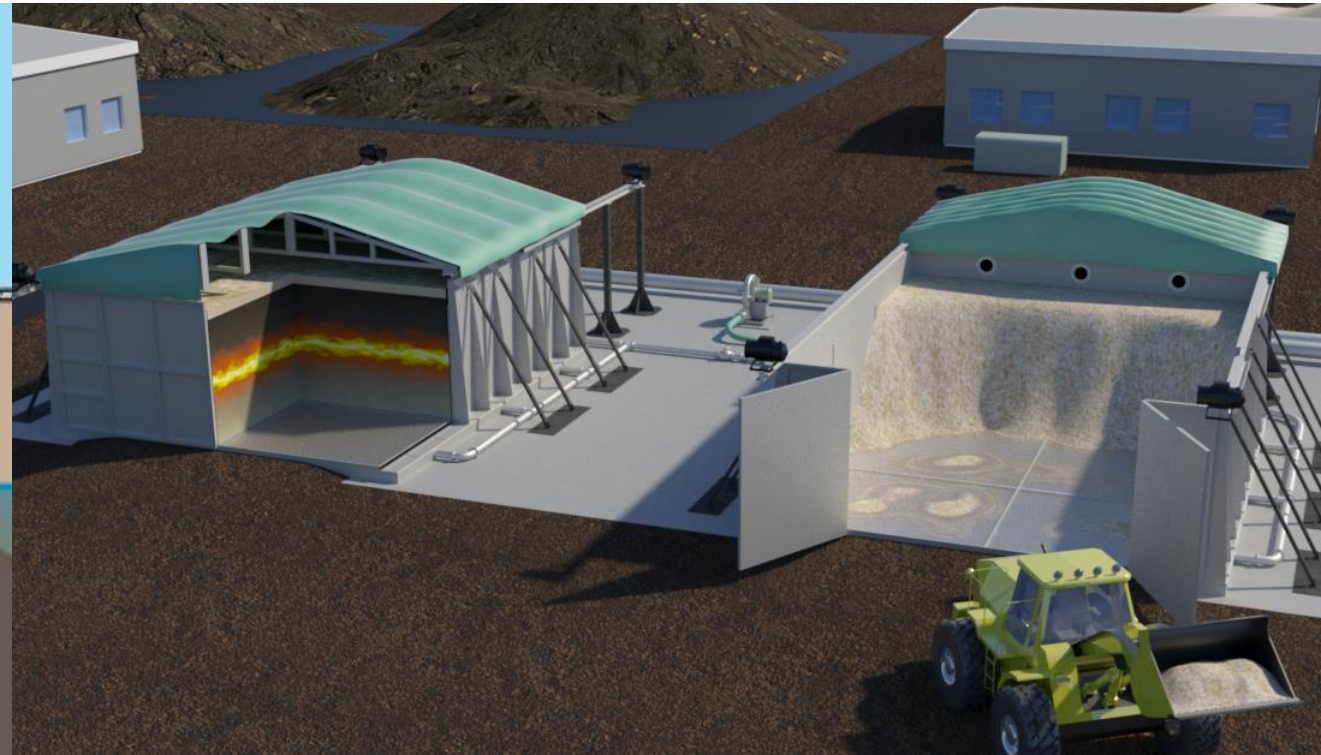
Smouldering possible due to large surface area of organic liquids (e.g., NAPL) within the presence of a porous matrix (e.g., aquifer)

Modes of Application

- **In situ (below water table)**
  - Applied via wells in portable in-well heaters



- **Ex situ (above ground)**
  - Soil piles placed on “Hottpad” system



Smouldering at Brownfields Sites

- **Full Scale STAR in New Jersey**
  - 40 acre former creosote plant
  - Over 2000 ignition points over 5 year period
  - Redevelopment underway following regulatory certification of site closure September 2019
- **STAR and STARx Pilot Testing at Waterfront Toronto**
  - Demonstrated technology applicable for soils management of Portlands redevelopment
- **STARx Pilot Testing at Former Lube Oil Plant, Taiwan**
- **STARx at Former Chemical Plant in Brazil, etc.,etc.,etc…**

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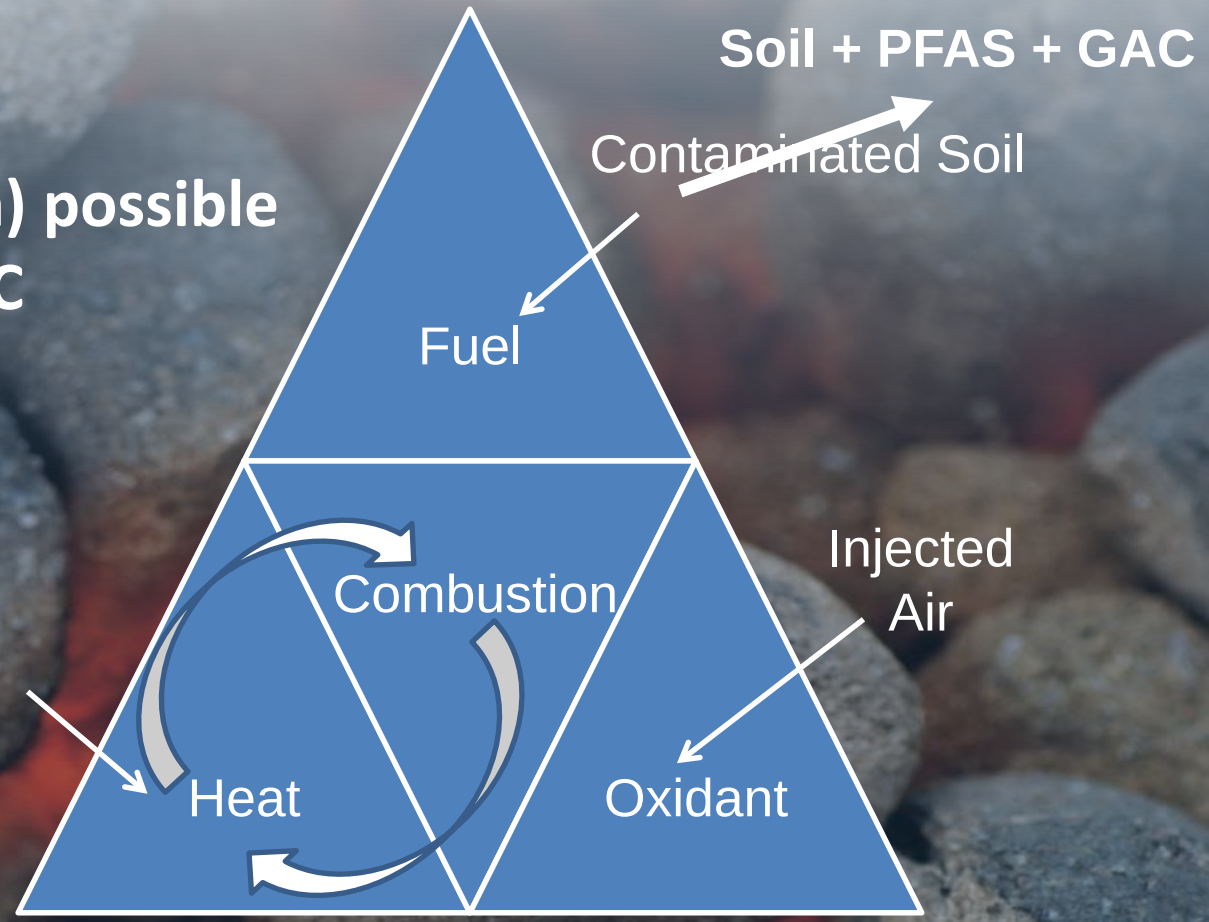
Smouldering PFAS?

- PFAS not a smoulderable fuel
  - Requires fuel surrogate
- Complete destruction (i.e., mineralization) possible
- PFAS mineralization to HF at Temp > 900°C



PFAS Smouldering Studies

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GAC PFAS SMOULDERING STUDIES

- **Smoulder PFAS-impacted Soil**
  - Add GAC as surrogate fuel
- **Smoulder PFAS-impacted GAC**
  - Add Sand as Inert Porous Matrix
- **Co-Treat PFAS-impacted Soil and PFAS-Impacted GAC**

Study Scope

Test 1 – PFAS-impacted GAC in Clean Sand (no PFAS)

GAC

Sand

Test 2&3 – PFAS-impacted GAC

PFOA

VWR (95%)

PFOS (salt)

Sigma (≥ 98%)

PFHxS (salt)

Sigma(≥ 98%)

Focus on PFAS concentration before and after smouldering

PFNA

Sigma (97%)

PFHpA

Sigma (99%)

PFBS

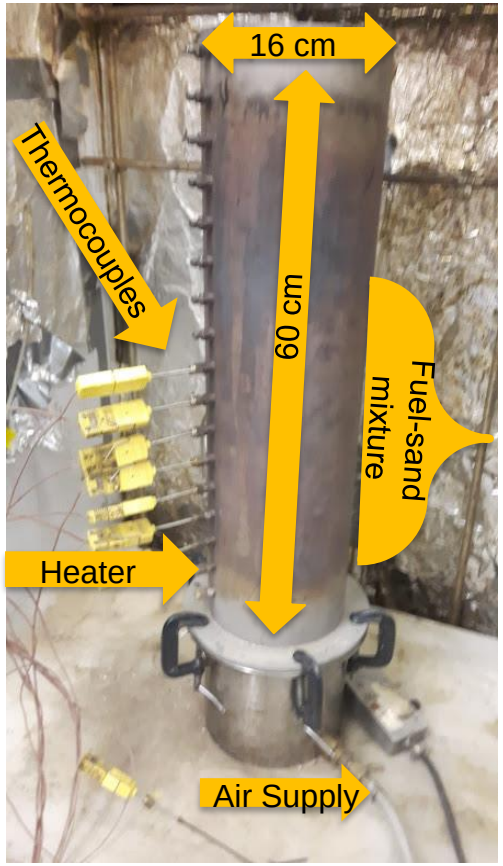
Sigma (99%)

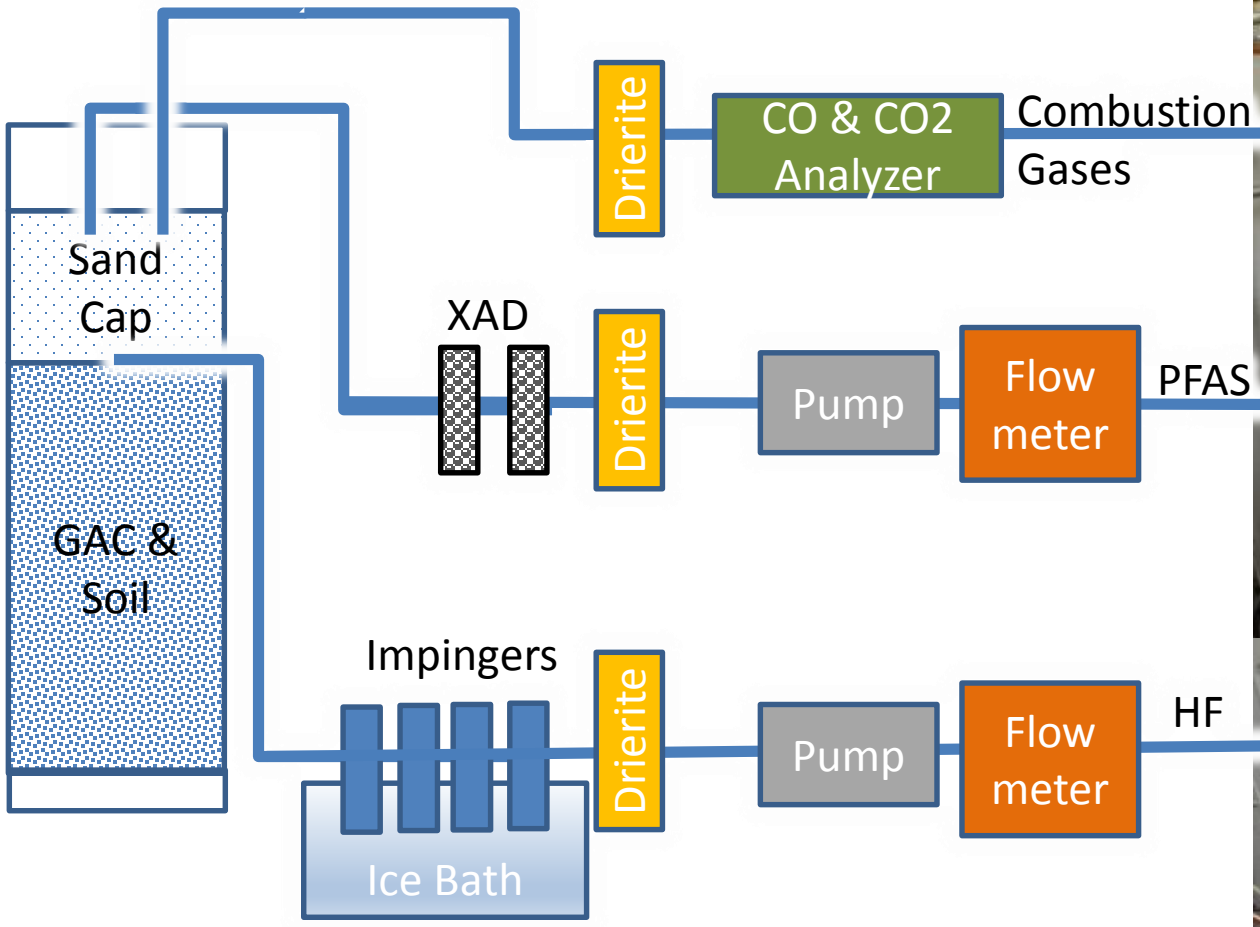
PFAS in Soil plus HF and PFAS in emissions

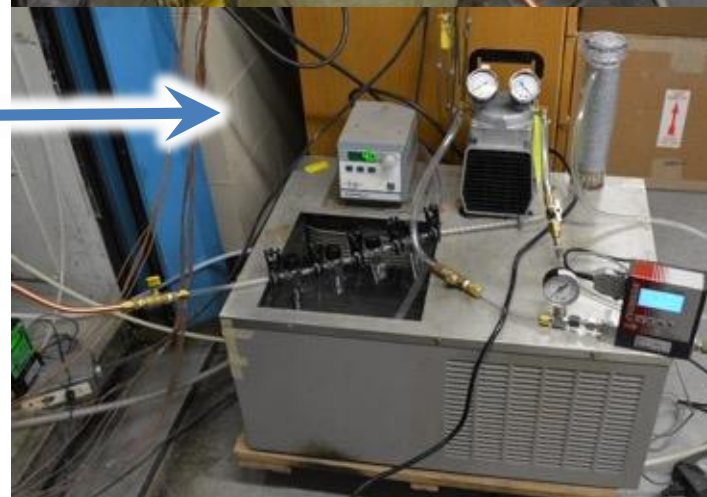
Test 4 – PFAS-impacted Soil (8 compounds)

Top soil (foc 1%) medium (0.6 mm) and course (1.18 mm) coarse sand mixture

Experimental Setup

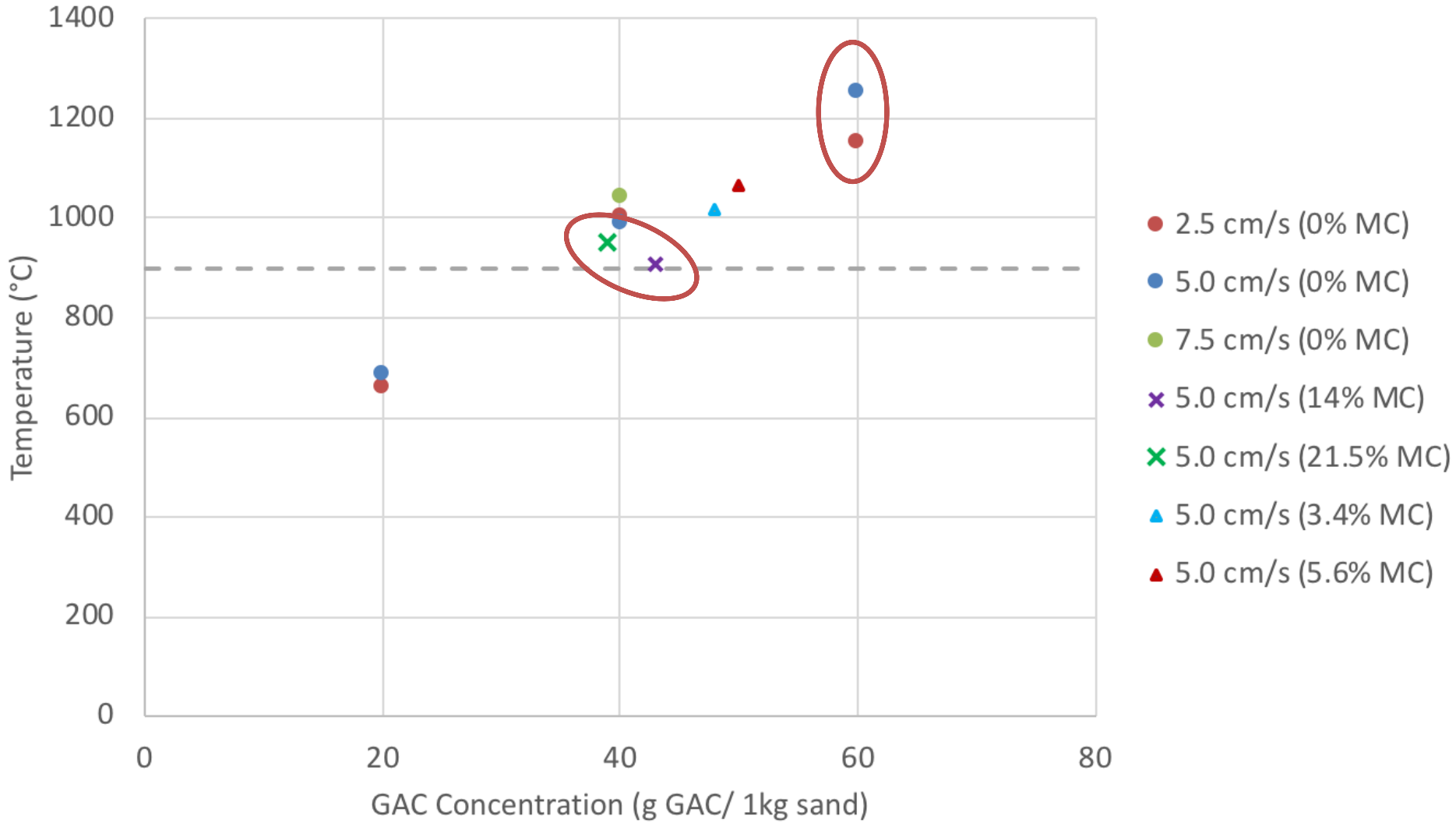






Study Results

Test 1– Temperature v. GAC Content in Clean Sand (no PFAS)



Study Results

Test 2&3 – PFAS-impacted GAC

Test	% GAC (w/w)	MC (%)	Peak Temperature (°C)	Compound	Initial Concentration[1]	Post Treatment Concentration[2]
2	4.3	14	908	PFOA	591	<0.0004
				PFOS	142	<0.0004
				PFHxS	240	<0.0004
3	3.9	21	950	PFOA	507	<0.0004
				PFOS	122	<0.0004
				PFHxS	221	<0.0004

[1]mg PFAS / kg GAC & Sand
[2]mg PFAS / kg Ash & Sand

Study Results

Test 4 – PFAS-impacted Soil (3 compounds)

Test	Compound	Initial Concentration[1]	Post Treatment Concentration[2]
4	PFOA	6.14	<0.00005[a]
	PFOS	9.54	<0.00005
	PFHxS	7.06	<0.00005

[1]mg PFAS / kg Soil; average of triplicate sample
[2]mg PFAS / kg Soil
[a]PFOA concentration of 0.0005 mg/kg in one (of three) samples
Average temperature > 1000 ^{o}C

Total Fluorine Captured as HF in Emission ~ 30-50%

Study Results

Test 5 – PFAS-impacted Soil (6 compounds)

Test	Compound	Initial Concentration[1]	Post Treatment Concentration[2]
5	PFOA	11.49	<0.00005
	PFOS	6.67	<0.00005
	PFHxS	7.21	<0.00005
	PFBS	1.3	<0.00005
	PFHpA	9.75	<0.00005
	PFNA	25.58	<0.00005

[1]mg PFAS / kg Soil; average of triplicate sample
[2]mg PFAS / kg Soil
Average temperature > 1000 ^{o}C

- Trace carboxylate PFAS detected in vapors (no sulfonates)
- PFAS could be captured in off gas by GAC that is recycled for treatment

Study Takeaways

- **Peak temperature is ~ linear with GAC concentration**
- **GAC ~40 g/kg soil achieved combustion at temperatures that destroy PFAS**
- **PFAS treated to non-detectable levels in soils, sand, and ash**
- **Detection of HF indicates PFAS decomposition**
- **Some PFAS may be present in emissions**
  - Capture and re-treat is a viable solution

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Field Application

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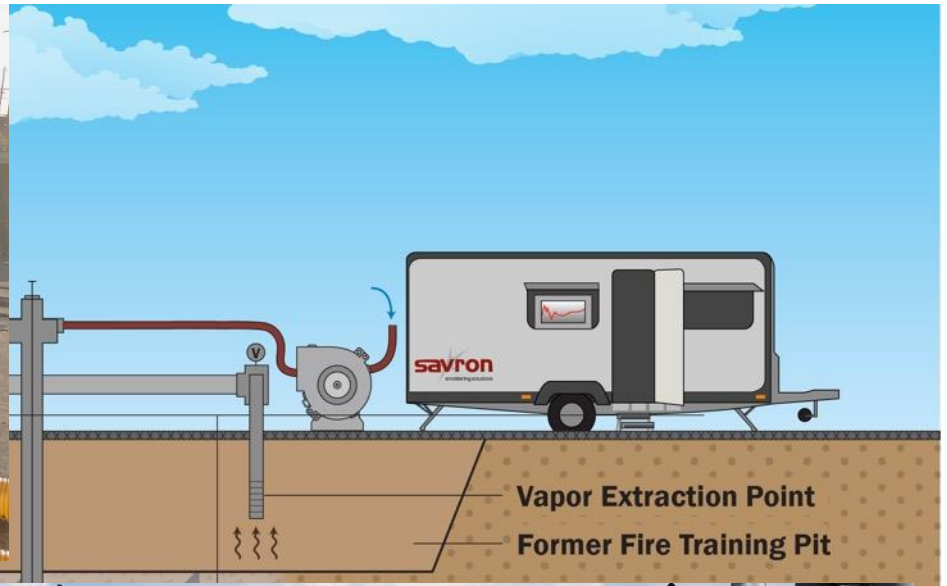
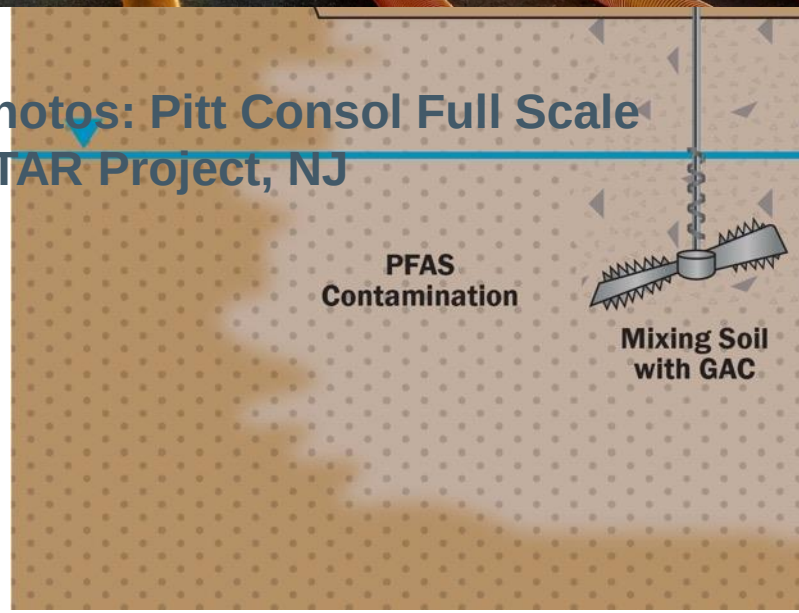
STARx: Soil and/or Waste GAC Treatment

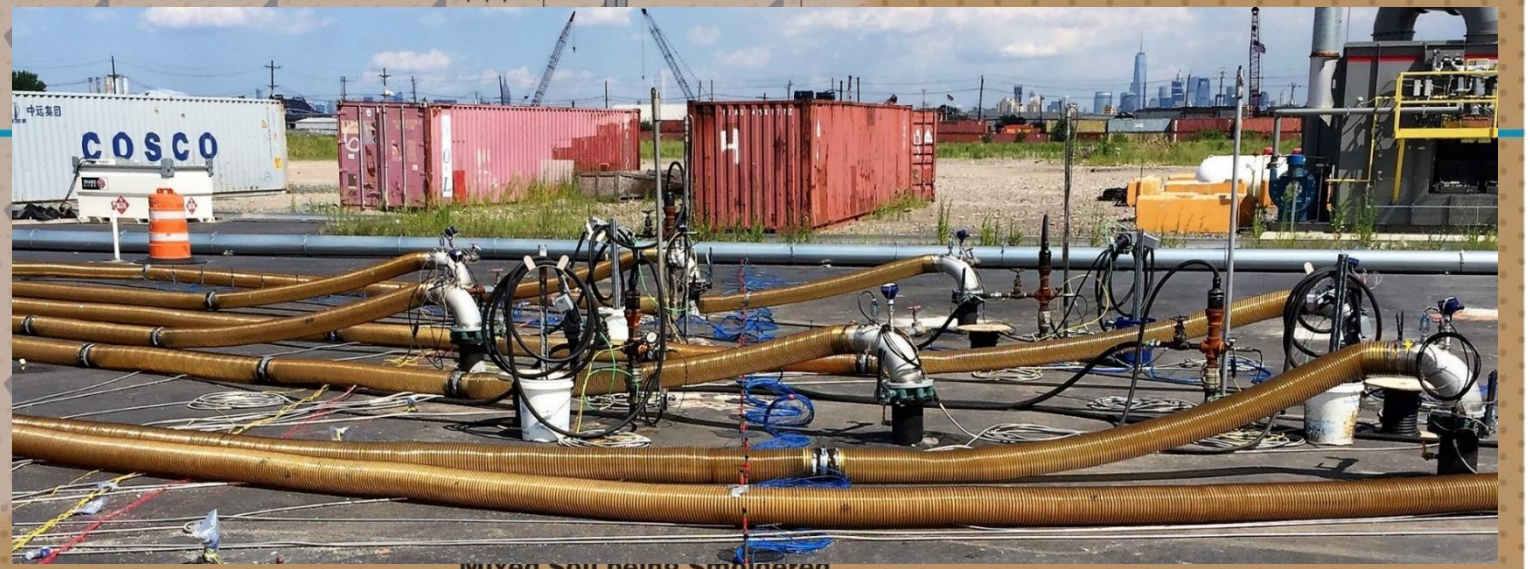
Photo: Full Scale STARx Hotpad System, SE Asia

STAR: Source or PRB Treatment



Photos: Pitt Consol Full Scale STAR Project, NJ





Mixed Soil being Smoldered

Summary

- **PFAS Compounds Widely Used in Industry**
  - Emerging concern for Brownfield redevelopment
- **Smouldering Proven Technology for Brownfield Remediation**
  - Systems currently available for traditional contaminants and PFAS
- **PFAS Destruction Demonstrated via Smouldering**
  - Surrogate fuel required (GAC)
  - Ongoing work to understand and optimize process

Acknowledgements

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Royal Military College of Canada

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Questions?

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gscholes@savronsolutions.com