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smoldering solutions

fast, simple,
safe, and
better for the
environment

Innovations in Smouldering: Management of PFAS, Biosolids, Acid Mine Drainage, and Other Environmental Applications

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Overview

- **Smouldering Combustion Basics**
- **STAR (in situ) and STARx (ex situ) Applications for Hydrocarbons**
- **Innovations:**
  - PFAS and other Recalcitrant Compounds
  - Biosolids
  - Acid Mine Drainage (AMD)
- **Summary**

Smouldering Combustion

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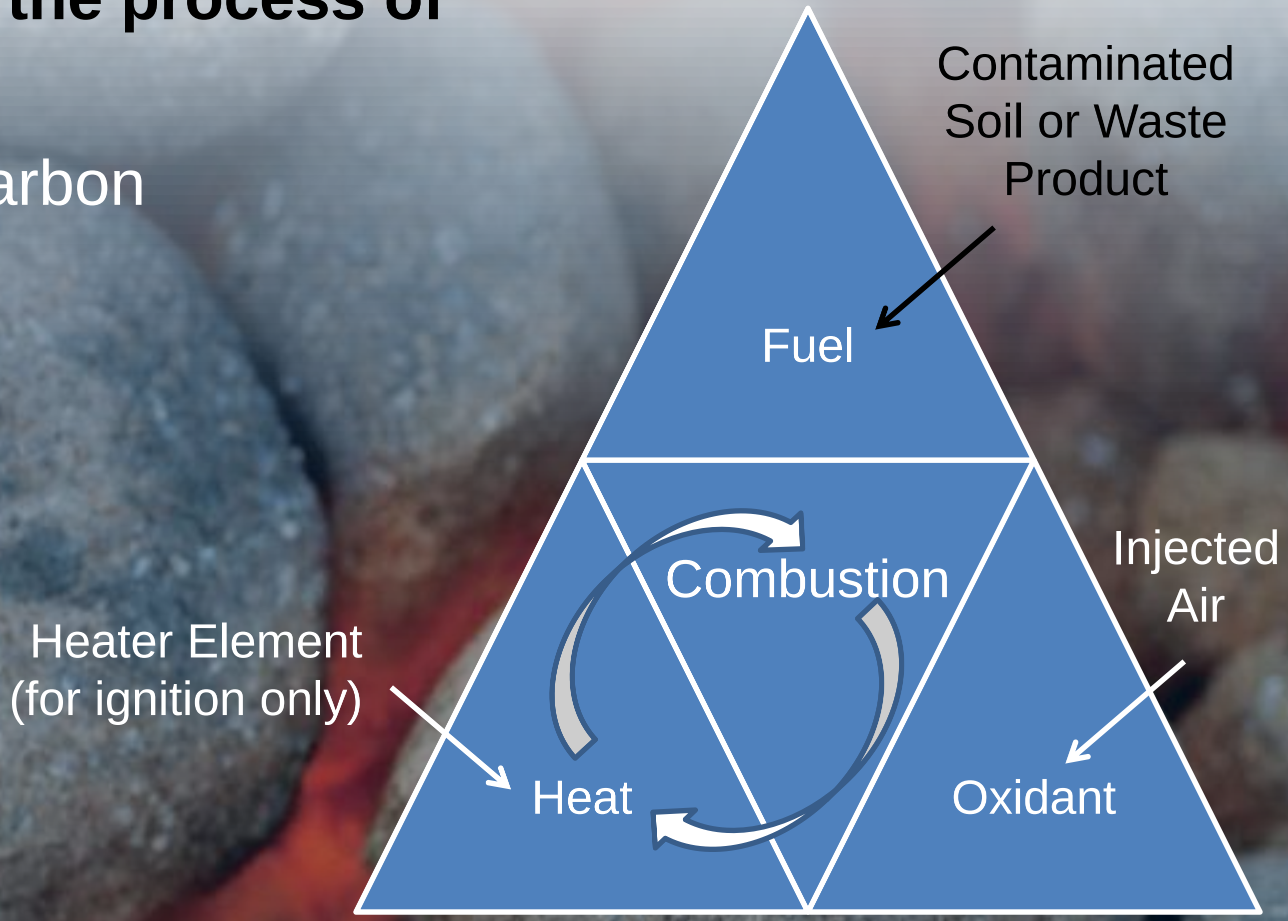
Smouldering Combustion

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

Exothermic reaction converting carbon compounds to CO_2 + H_2O

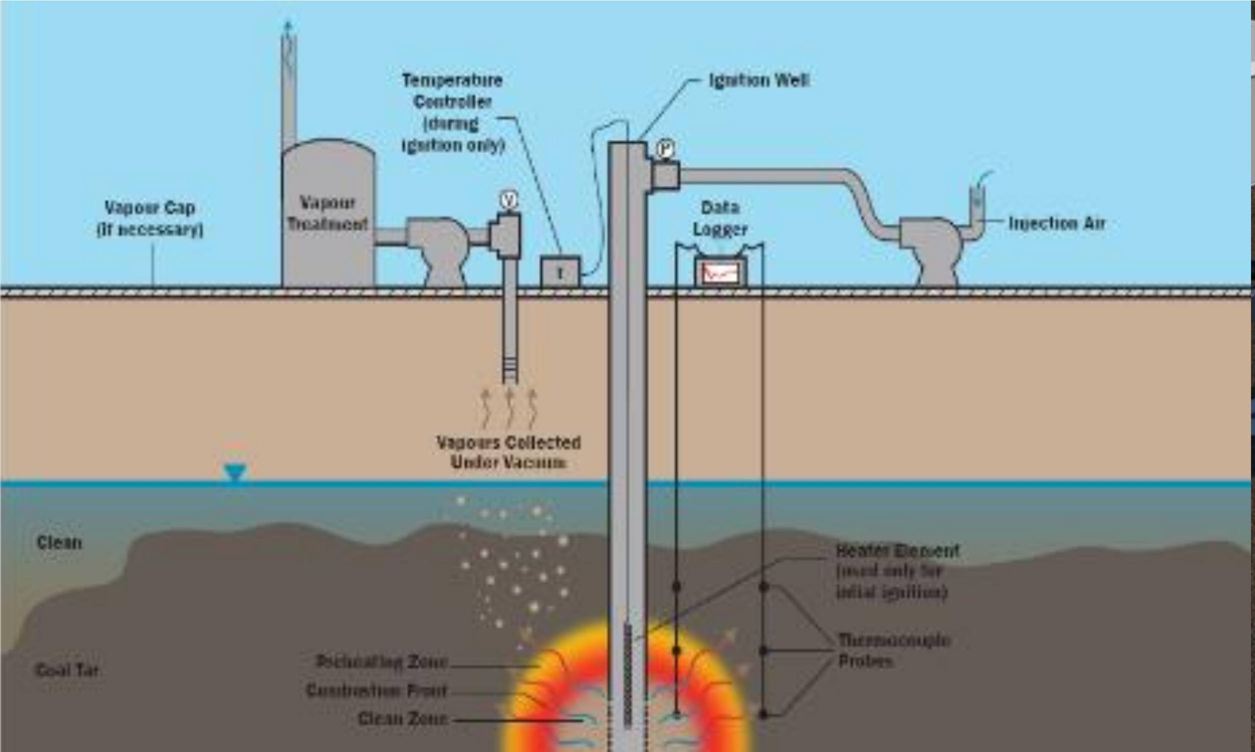


Smouldering possible due to large surface area of organic liquids (e.g., NAPL) within the presence of a porous matrix (e.g., aquifer)

Modes of Application

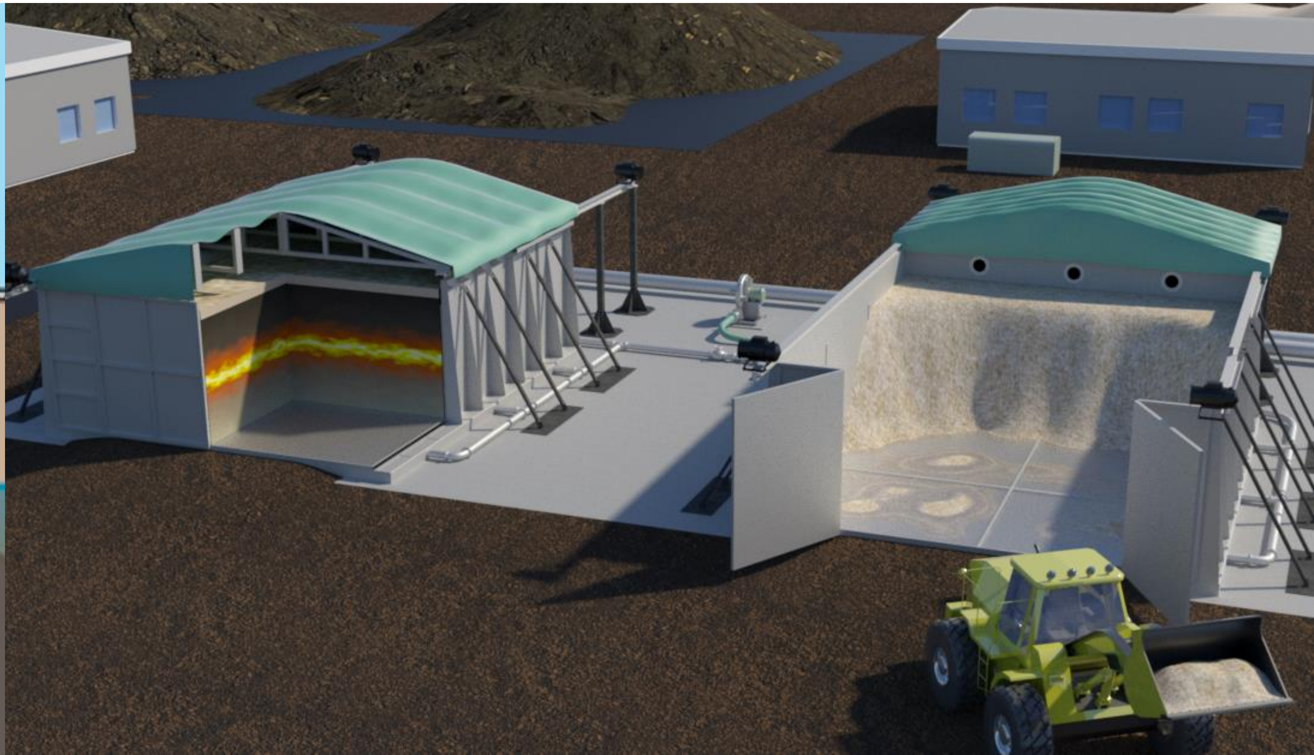
STAR

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



STARx

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



Applicability

- **Silts and coarser**
- **Coal tar, creosote, hydrocarbons**
- **Threshold concentration for self-sustained smouldering = 3,000 mg/kg**
  - Note: Any concentration can be combusted, but 3,000 mg/kg or greater has enough energy for SS propagation

Example STAR Projects:

- Coal tar MGP – NJ, IL, MI,
- Coal tar coke plant, Belgium
- Navy Special Fuel Oil (NSFO) - VA
- Petroleum Hydrocarbons, Canada
- Petroleum Hydrocarbons, Taiwan
- Gasoline / Diesel (with fuel surrogate) - MI
- Creosote - WA

Example STARx Projects:

- Hydrocarbon-impacted soil, Canada
- Hydrocarbon-impacted soil, Taiwan
- Hydrocarbon-impacted soil, SE Asia
- API separator sludge, SE Asia
- Hydrocarbon-impacted soil, Africa
- Oily sludge, USA
- Tank bottom residuals, Australia
- Oily sludge, Middle East

STAR: In Situ Smouldering Combustion

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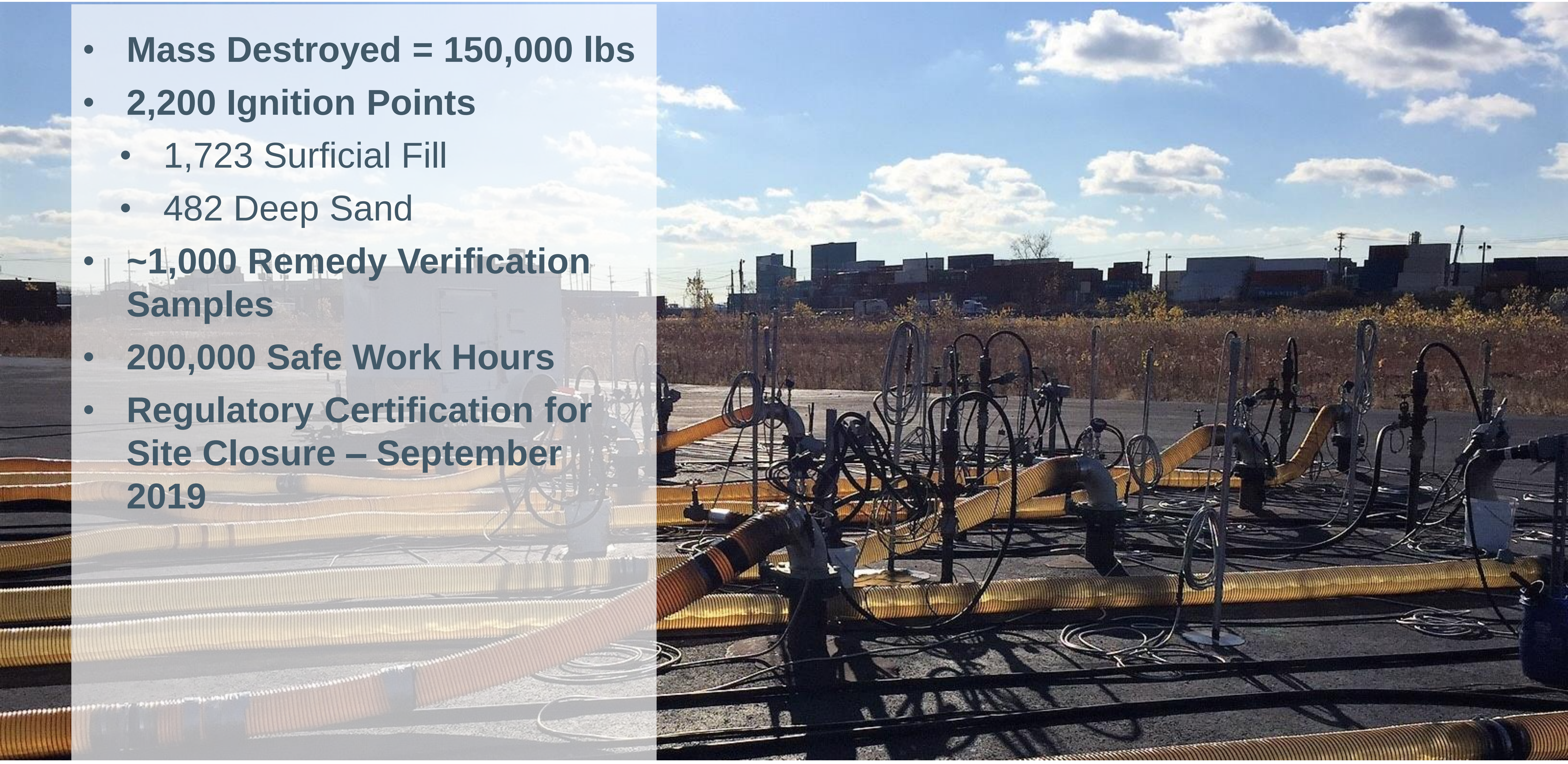
STAR Case Study – Coal Tar, NJ

- **15-Hectare former manufacturing facility in Newark, New Jersey**
- **Coal tar associated with former waste lagoons (now in-filled)**
- **40,000 m^3 impacted soils:**
  - Shallow fill (0-3 m bgs)
  - Deep Sand (~3-13 m bgs)

System Overview

Summary of Completion

- **Mass Destroyed = 150,000 lbs**
- **2,200 Ignition Points**
  - 1,723 Surficial Fill
  - 482 Deep Sand
- **~1,000 Remedy Verification Samples**
- **200,000 Safe Work Hours**
- **Regulatory Certification for Site Closure – September 2019**



STARx: Ex Situ Smouldering Combustion

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STARx Case Study – PHC, SE Asia

- **Active terminal facility in south east Asia**
- **Designed to treat 3,500 m^3 of stockpiled API separator sludge**
- **Co-treatment with oil-impacted site soils**

Hottpad Assembly

Unloading - Results

Before

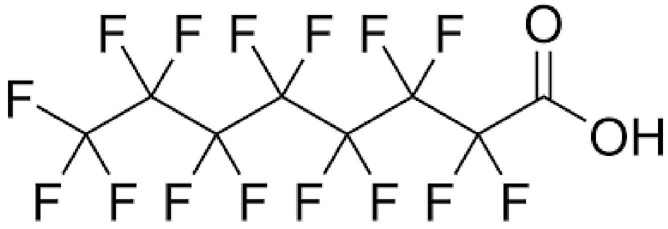
After

Summary

- **STAR/STARx is rapid, sustainable, and cost-effective**
- **Technology is robust and works both above and below the water table under fully saturated conditions**
- **Well suited for coal tar, creosote, and petroleum hydrocarbons**
- **Can be applied in situ or ex situ (Hottpad systems)**
- **Technology backed by more than a decade of world-class research**
  - New applications being developed

Innovations

- **PFAS, PCBs (and other recalcitrant compounds):**
  - Challenge: not typically smoulderable (due to volatility, low concentrations)
  - Solution: surrogate fuels
- **WWTP Biosolids:**
  - Challenge: high water content, low fuel content
  - Solution: co-treatment
  - Value added: see PFAS
- **Acid Mine Drainage:**
  - Challenge: inorganic issue
  - Solution: smouldering is a cost effective way to make heat



PFAS Remediation

- **Need for Destructive PFAS Remediation Technique**
  - Applicable to soil (source zones) and groundwater treatment media (GAC)
- **Mineralization to HF possible**
  - Requires temperatures >900^{o}C
- **PFAS not typically smoulderable**
  - Requires fuel surrogate
  - Tars, GAC, wood chips, etc. have potential as surrogate
  - PFAS-impacted GAC is an ideal surrogate

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

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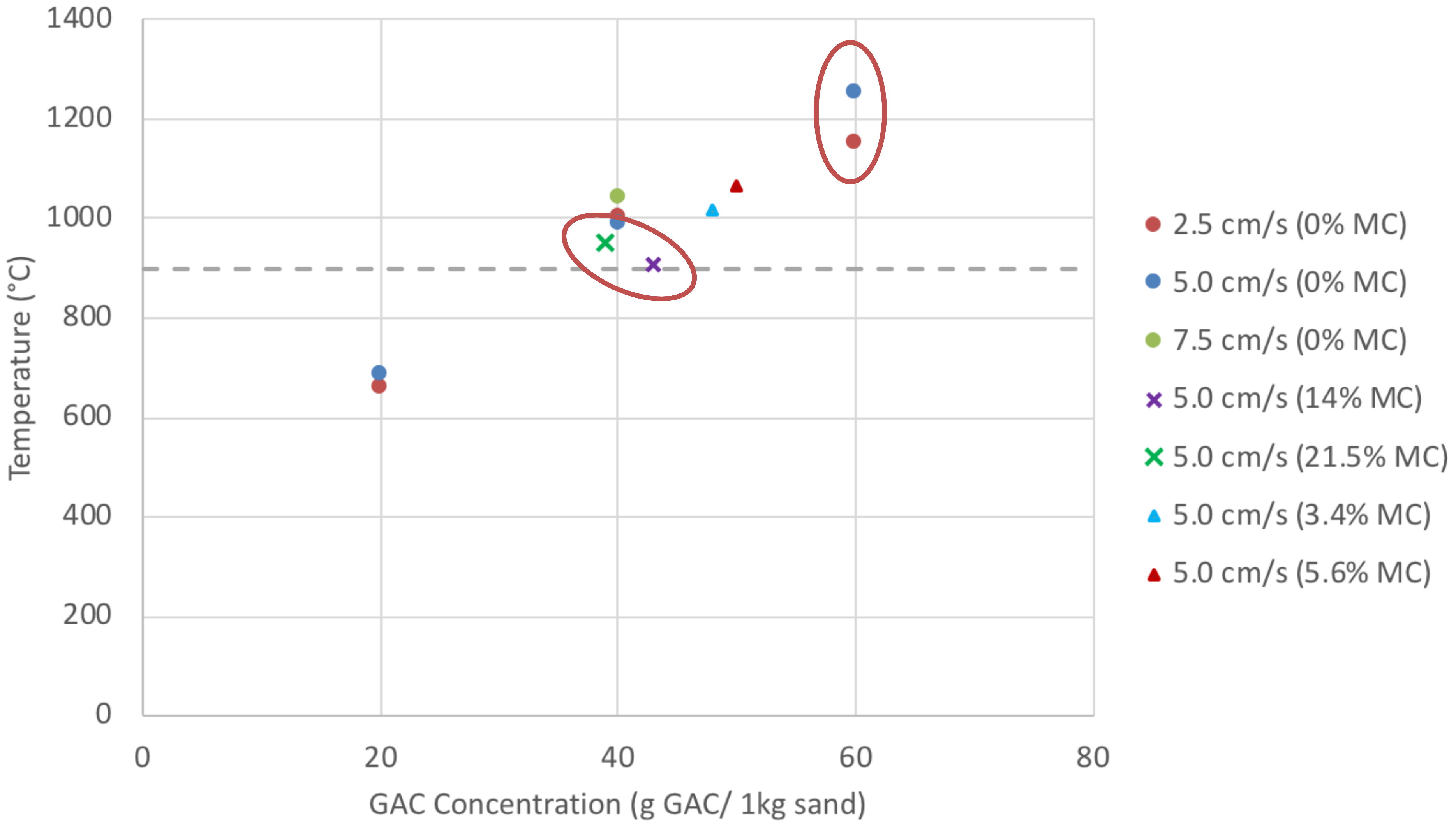
Phase I – Temperature v. GAC Content in Clean Sand (no PFAS)



Phase II Results

Phase II – PFAS-impacted soil and GAC

Test	Compound	Initial Concentration[1]	Post Treatment Concentration[2]
II-4	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

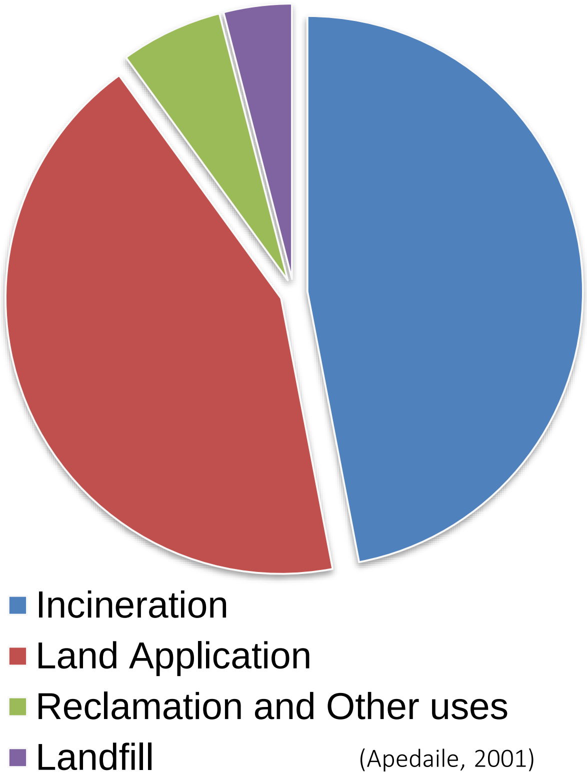
[1]mg PFAS / kg Soil; average of triplicate sample
[2]mg PFAS / kg Soil
Average temperature > 1000 ^{o}C

- HF detected in emissions
- Trace carboxylate PFAS detected in vapors (no sulfonates)
- PFAS could be captured in off gas by GAC used for treatment

WWTP Biosolids

- **Challenges with treatment / disposal of WWTP biosolids**
  - **High moisture content (~70-97%)**
  - **Low effective calorific values (~0-3 MJ/kg)**
  - **Significant fraction of operational costs (~50%)**

WWTP Biosolids End Use in Canada



(Apedaile, 2001)

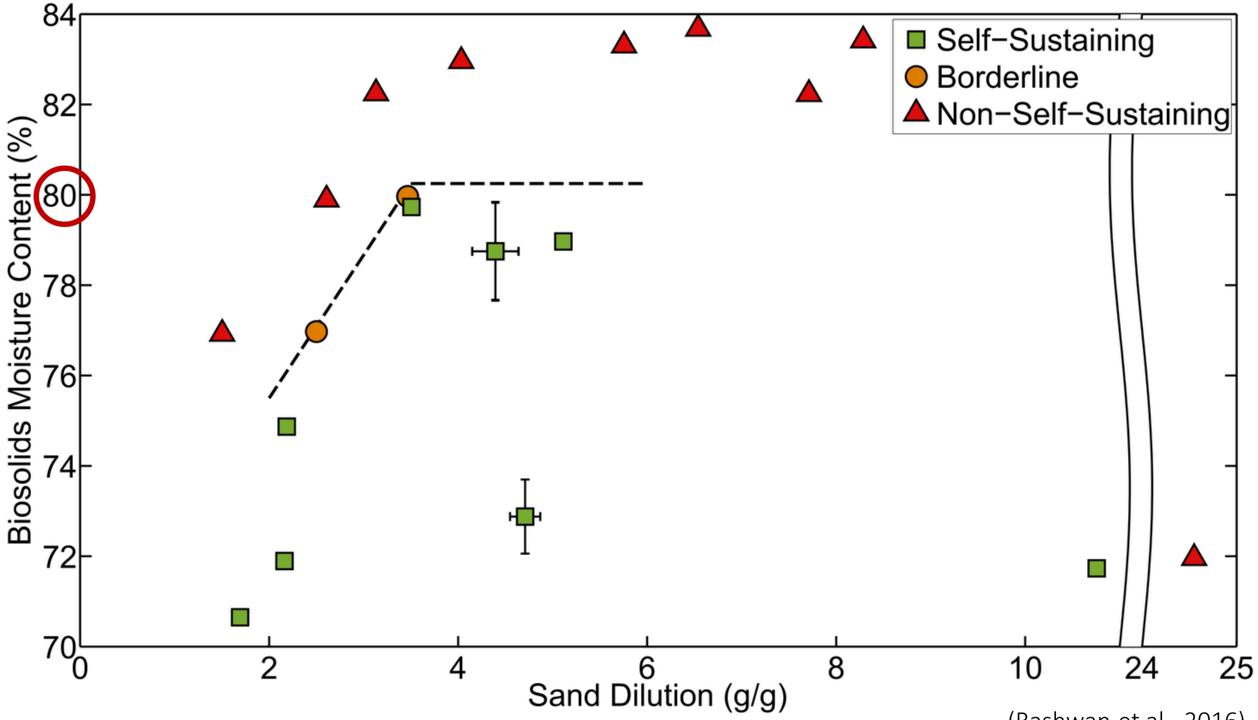
	Pros	Cons
Land application	• Beneficial reuse of nutrients	• Stabilization expensive • Contaminants of emerging concern
Incineration	• Small footprint • Waste volume reduction	• Dewatering expensive • High energy consumption

- **Smoldering is a low energy alternative**

PFAS!

Proof of Concept

- **Master's Thesis (UWO):**
  - **Treatment of combined primary / waste activated sludge**
  - **Varied moisture content, sand:sludge mixing ratio**
  - **Can smolder 80% MC**



(Rashwan et al., 2016)

Prototype Testing

$$Reactor\ Size \uparrow$$
$$Energy\ Efficiency \uparrow$$

However:

- **Compressibility of sludge leads to air channeling at large scale**

Solution:

- **Use of a smolderable porous matrix (e.g., wood chips)**

LSR 2.4 m^3

ISR
0.27 m^3

Lab
0.008 m^3

- **Successful treatment of WWTP sludge using a porous matrix that is also a fuel**

Wood Chips

Mushroom

Macadamia Nut Pulp

Only ash remains - potential for continuous smoldering

Smoldering AMD / ARD

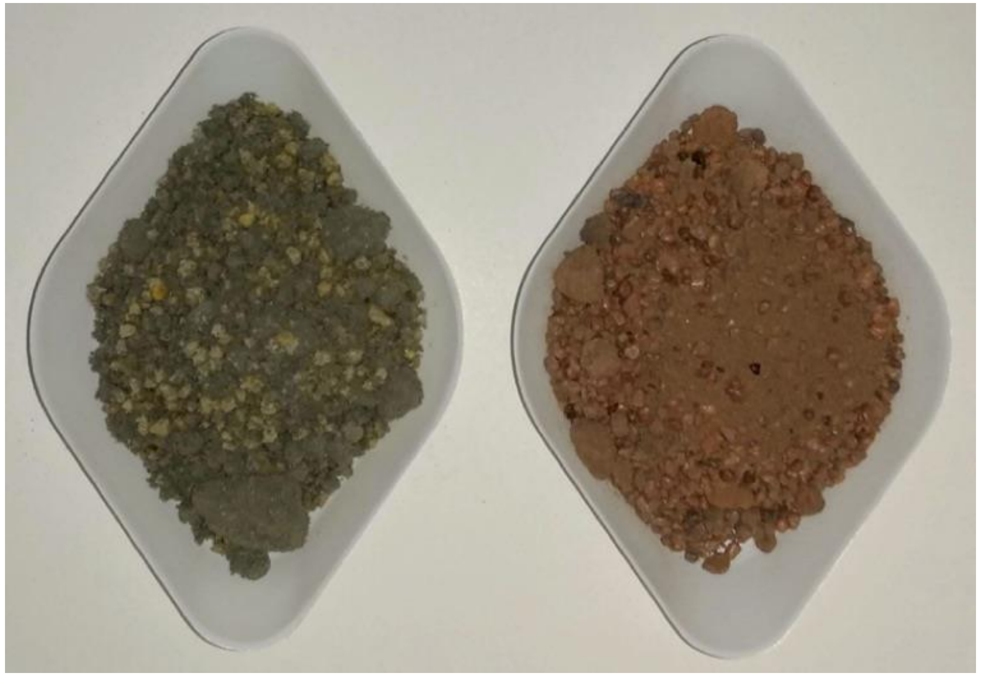
- **AMD / ARD significant environmental challenge**
  - Acid conditions generated through oxidation of metal sulfides (e.g., pyrite)
- **Removal of S can prevent generation of acidic conditions**
  - Eliminating S (from pyrite) requires temperatures ~600-1,000^{o}C
- **Traditional thermal techniques are expensive**
  - Smoldering combustion is a low energy / high temperature alternative

POC Testing

- **Vegetable oil added to tailings**
  - <u>Modest</u> smouldering temperatures achieved

Sample	Average Total S (mg/kg)
Untreated Tailings	71,600
Smoldered Tailings	16,300
% Reduction	**77%**

  - GAC a more predictable / higher T fuel



Untreated Tailings Smouldered Tailings

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Questions?

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