SOIL WASHING: SUSTAINABLE COST-EFFECTIVE TREATMENT FOR PER AND POLYFLUOROALKYL SUBSTANCES

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Ex situ soil washing to remove PFAS adsorbed to soils from source zones

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Agenda

- Challenges for PFAS Soil Remediation
- PFAS Soil Treatment Options
- Soil Washing 1.0
- Soil Washing 2.0
- Sustainability and Cost

Regulatory Drivers for PFAS Soil Remediation

Challenges for PFAS Soil Remediation

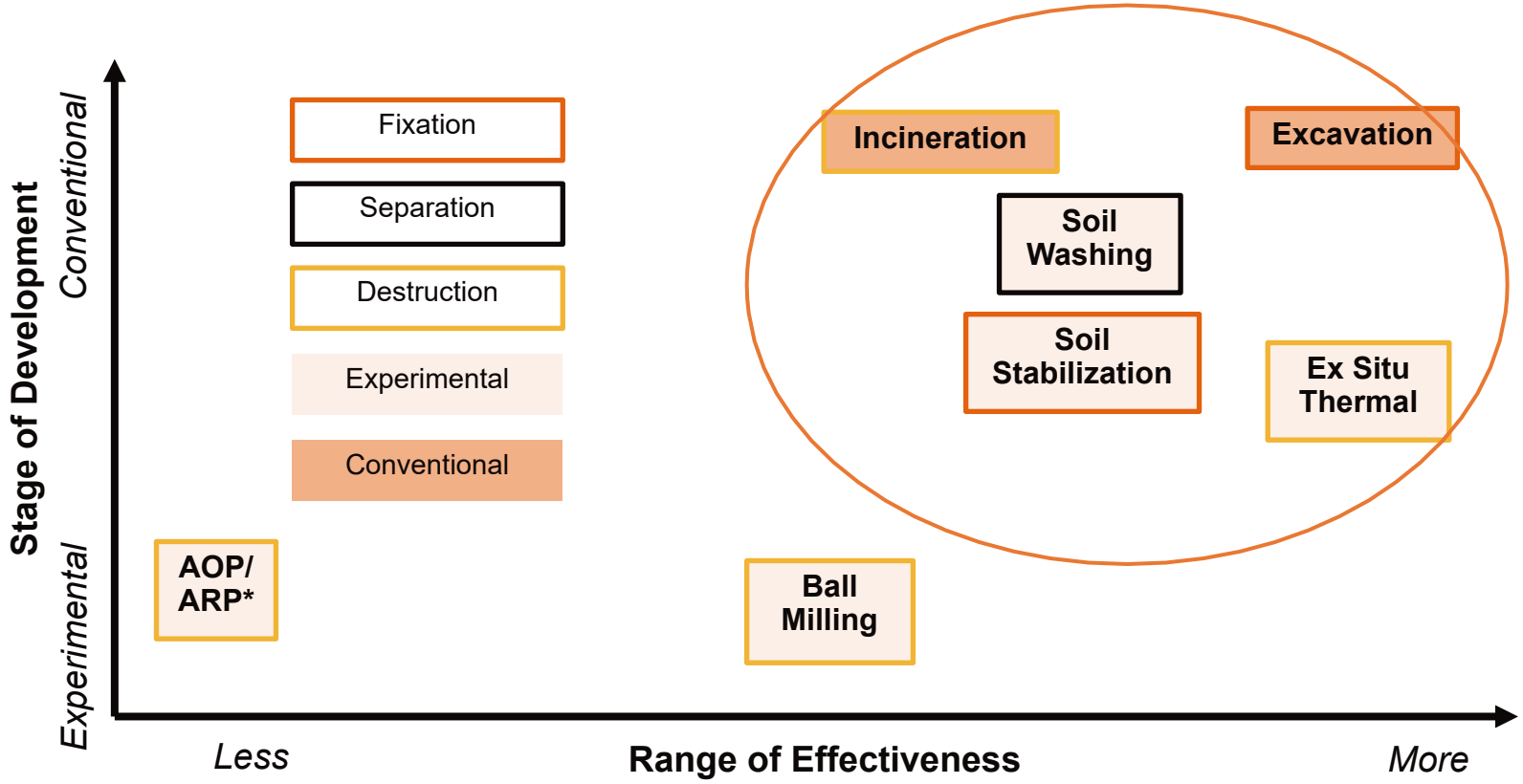
- Evolving regulations and hazardous substance designation will increase the need for cost-effective methods to remediate PFAS contaminated soil.
  - Some USEPA RSLs are below analytical detection limits
- Large volumes of source soil (AFFF hotspots) and non-source soil generated from construction projects require ongoing management to prevent PFAS leaching into the vadose zone.
- Fewer landfills accept PFAS-impacted wastes and acceptance criteria is decreasing
- Ultimately this soil will require cost effective treatment to reduce ongoing liabilities.

Focus of interim actions has been to protect drinking water, but treating source areas can reduce source loading, plume expansion and reduce overall lifecycle treatment costs

PFAS Soil Treatment Options

PFAS Treatment Technologies for Solids

- Not many cost-effective reliable options for PFAS soil treatment
- Key considerations for evaluation:
  - Site specific soil characteristics
  - Cost
  - Sustainability
  - Regulatory Drivers
  - Location



PFAS Treatment Technologies for Soil

Landfilling and Incineration

- RCRA sub-title C with leachate treatment
- Specialized landfill with composite liner and gas/leachate collection and treatment
- Incineration – at licensed facilities, expensive
- Emerging thermal desorption methods are expensive but reliable treatment method
- Questions remain about off gas emissions

Hazardous substance listing will increase costs which would favor on-site treatment

Soil washing is a sustainable volume reduction technology

- **Version 1.0** Treat sand and gravel, separate fines/organics for alternative treatment via thermal desorption, stabilization and/or landfilling
- **Version 2.0** Enhanced physical and chemical process to overcome kinetic limitations - Reduce/eliminate fines volumes requiring alternative treatment

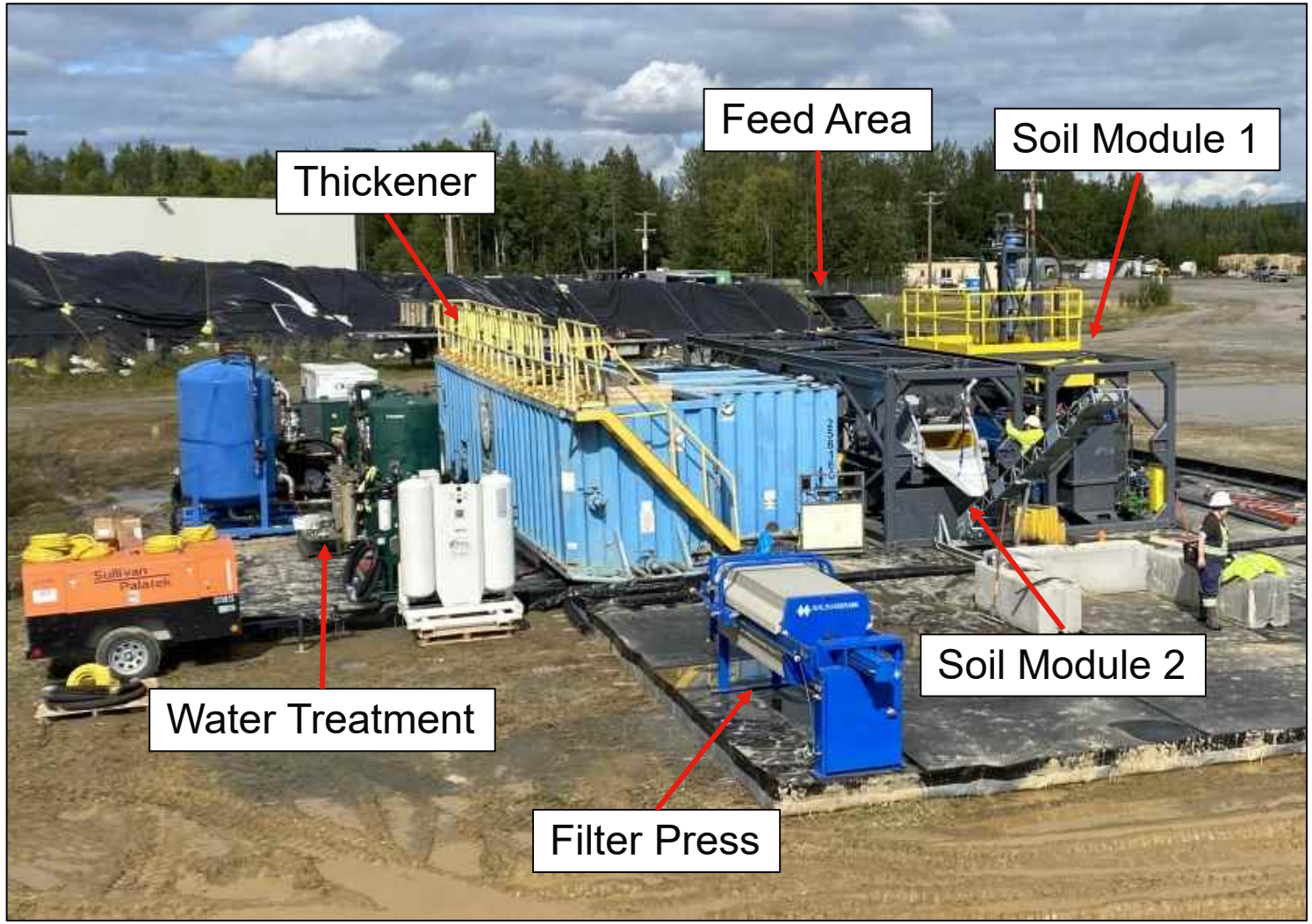
On-site soil treatment is a sustainable & cost-effective solution

Soil Washing

PFAS Soil Washing

Volume Reduction Technology

- Physical separation and desorption to remove contaminants from soil to the process water
- Process water treated using GAC and IXR and recycled
- Cost effectively treat coarse-grained soil (gravel and sand)
- Separate fines for secondary treatment:
  - Landfill
  - Stabilization
  - Incineration
  - Thermal Desorption
- Maximizes volume of soil beneficially reused onsite
- Minimizes waste requiring off-site disposal/treatment



Soil Washing 1.0 – Source Soil Results

ARCADIS

- Arcadis' Eielson AFB demonstration (2021) showed cost-effective sustainable treatment:
  - PFAS sources – up to 3 ppm PFOS treated to meet single digit ppb goals for PFOA and PFOS and leachate < 40 ppt PFOA and PFOS
    - Fines/organics separated for treatment by other means - landfill, incineration, or stabilization

Treatment Round	Stockpile EIE393-1 Soil Fraction	PFBS		PFOA		PFOS		Sum PFAS	
		Soil µg/kg	Leachate ng/L	Soil µg/kg	Leachate ng/L	Soil µg/kg	Leachate ng/L	Soil µg/kg	Leachate ng/L
	Untreated	6.6 J	230	<4.2	350	2,700	32,000	3,155	39,795
Round 1	Rock	<0.2	<10	<0.2	<10	**88**	**200**	97	270
	Gravel	<0.2	<10	<0.2	<10	**27**	**620**	32	803
	Sand	0.26	<10	0.55 J	26 J	**150**	**900**	170	1,005
	Fines	3.1 J	22 J	<3	**53**	**2,400**	**530**	2,822	1,123
Round 2	Rock/Gravel	<0.23	<10	<0.22	<10	**8.8**	**120**	9.4	194
	Sand	<0.19	<10	<0.19	<10	**12**	**75**	14	181
Round 3	Rock/Gravel/Sand	<0.24	<20	<0.24	<20	0.34 J	36 J	0.34 J	36 J
Performance Goals		**1,900**	**40**	**1.7**	**40**	**3**	**40**	--	--

Soil Washing 1.0 Results – Non Source Soil

- Treatment performance in line with source soil results
- Performance goals achieved for coarse soil using simplest treatment approach
- A portion of fines/organics met concentration standards

Non Source Soil Results

Stockpile	Soil Fraction	PFOS		Sum PFAS	
		Soil µg/kg	RE%	Soil µg/kg	RE%
EIE382-5	Untreated	4.5	--	6	--
	Gravel	<0.23	<DL	0.3	<DL
	Sand	0.2	96.1%	0.2	84.3%
	Fines	1.7	61.8%	2	65.6%
EIE385-4	Untreated	8		16	
	Gravel	0.2	98.1%	0.2	97.9%
	Sand	0.9	88.6%	1.3	92.1%
	Fines	**9**	-7.7%	12	58.8%
Performance Goal		3	--	--	--

Soil Washing 2.0 – Non-Source Soil

- Arcadis' partner applying next generation techniques for PFAS soil washing at a Canadian Site
- Advanced physical and chemical processes to overcome kinetic limitations
- Capable of achieving evolving regulatory standards:
  - Non-detect to sub-ppb concentrations in sand and gravel fraction
  - Non-detect (single-digit ppt) concentrations in leachate
  - Eliminate/reduce volume of fines/organics
- Pilot-scale treatability testing
  - Reduce performance uncertainty without cost of pilot

Location	Soil Fraction	PFOS		Sum PFAS	
		Soil µg/kg	Leachate ng/L	Soil µg/kg	Leachate ng/L
Area 3	Untreated	26.9	766	77.7	1,047.2
	Gravel	<0.20	<1	<DL	<DL
	Sand	0.3	<1	0.3	<DL
	Fines	0.5	<1	0.5	<DL
Performance Goal	**Total Leachate**	10 ug/kg		--	30 ng/L

Treated Gravel

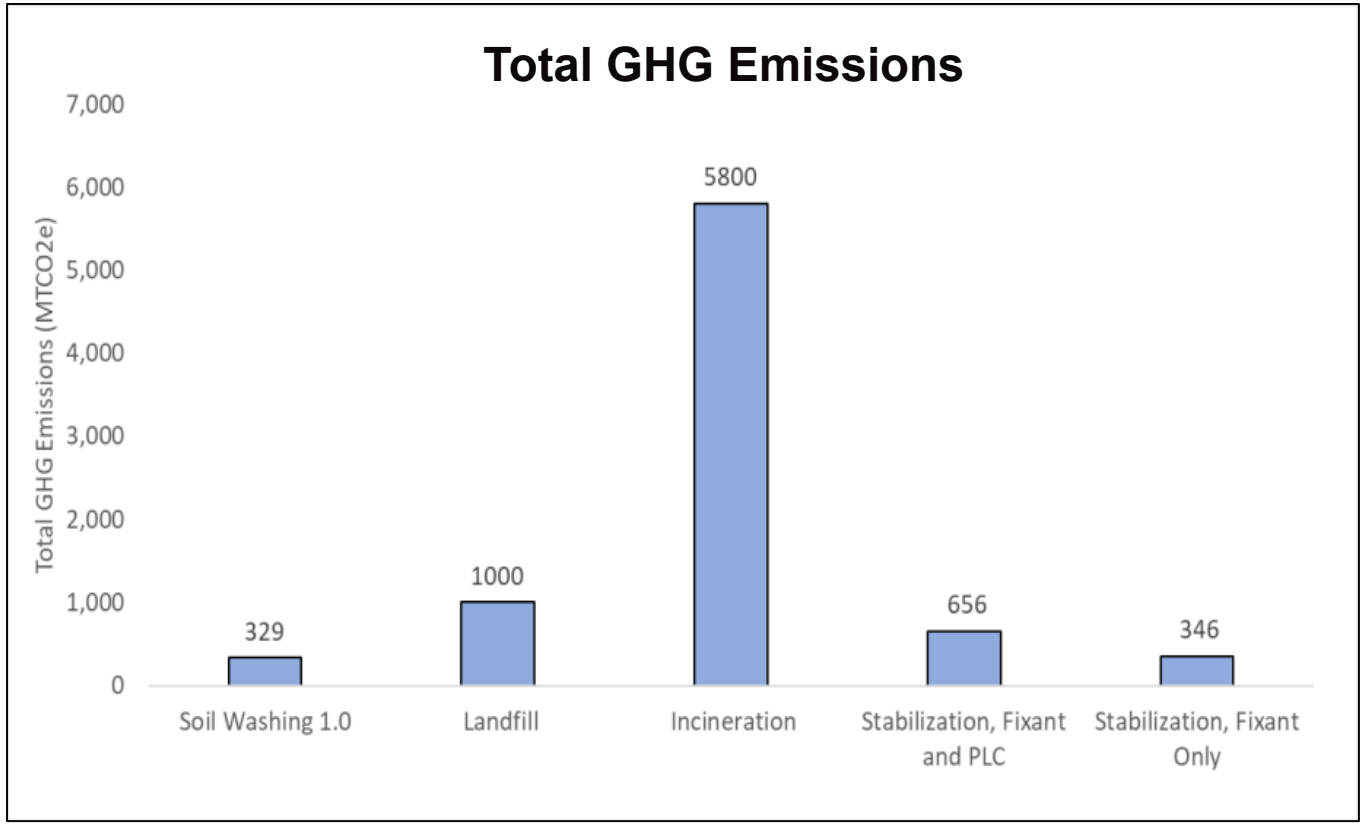
Treated Sand

Treated Fines

Sustainability Comparison - SiteWise

Soil washing 1.0 applied to 10,000 tons of soil

- 20% fines/organics landfilled
- Transport to hazardous waste landfill/incinerator – 250 miles
- Sand and gravel beneficially reused



Results

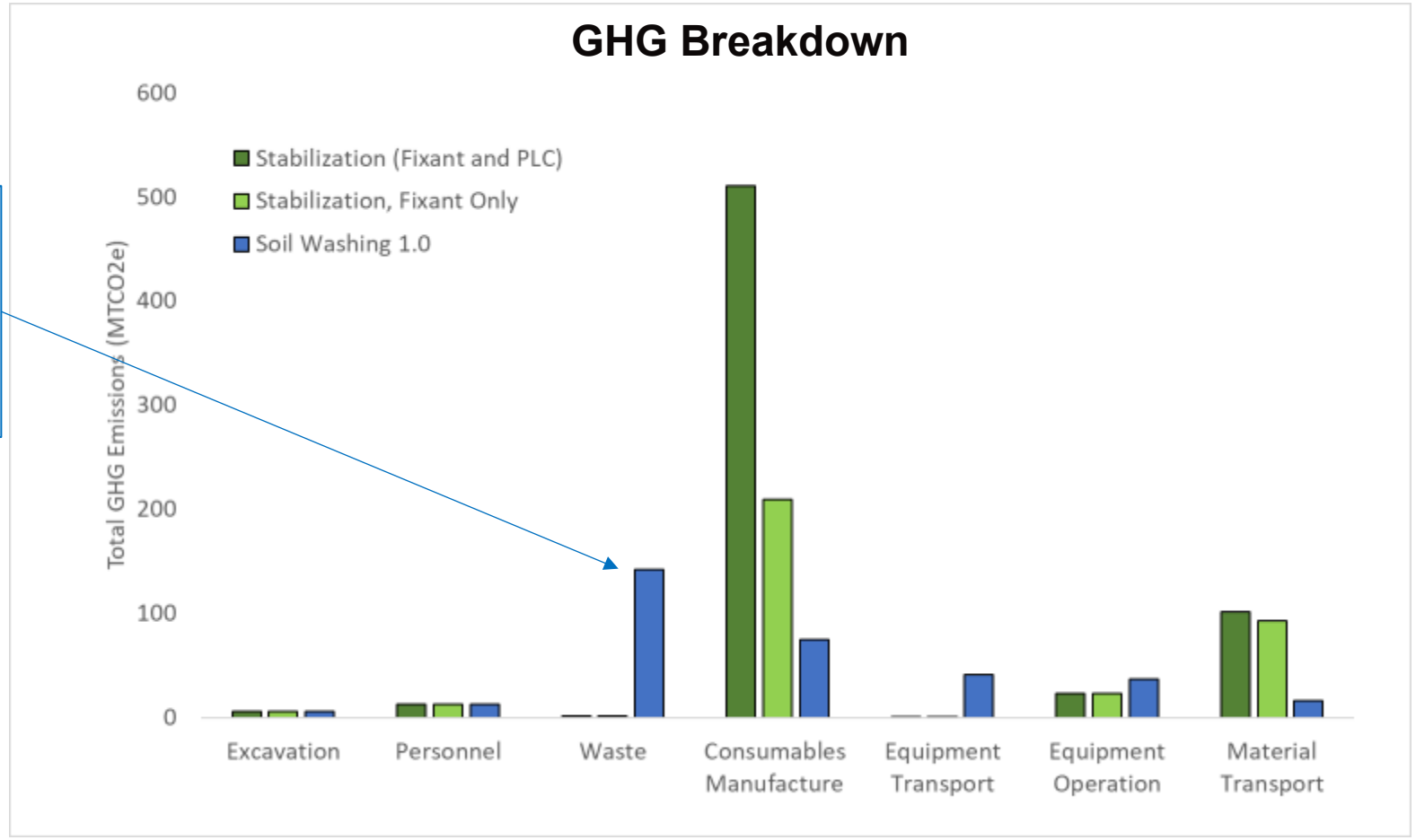
- 67% lower GHG footprint than landfilling
- 94% lower GHG footprint than incineration

MTCO2e: metric ton carbon dioxide equivalents

Sustainability Analysis – Key Drivers

Fines management represents 43% of emissions.

Soil Washing 2.0 will reduce/eliminate this component.



Fines management drives the soil washing GHG footprint.
Fixant composition, manufacture, and dosage are key drivers for stabilization.

Q&A

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