

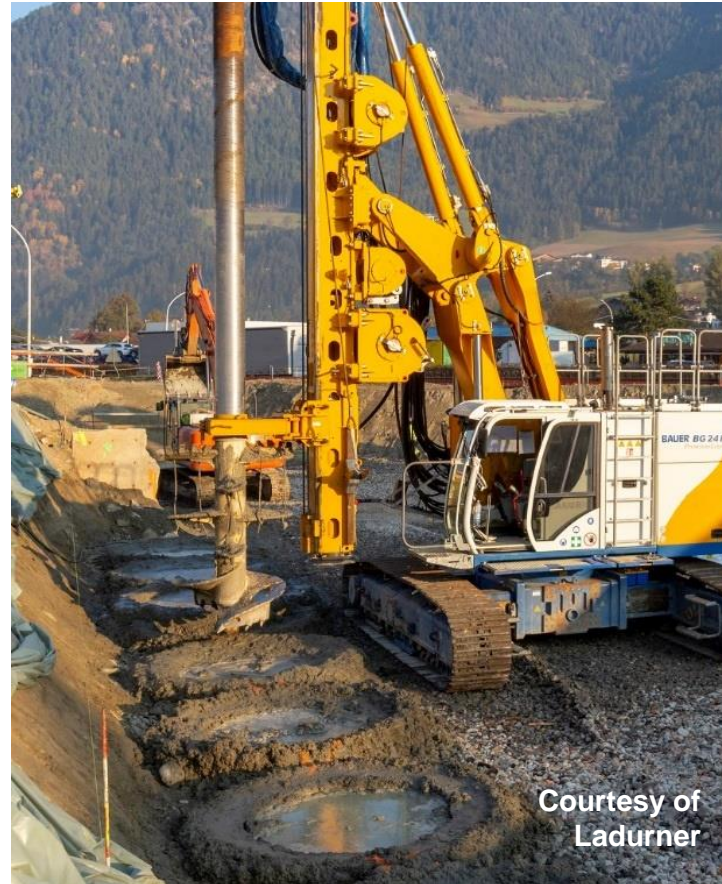
Contaminant Treatment with Sequestered Residuals: Combining In Situ Stabilization (ISS) with In Situ Chemical Oxidation (ISCO)

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Intersol 2025; Lyon, France
March 25, 2025

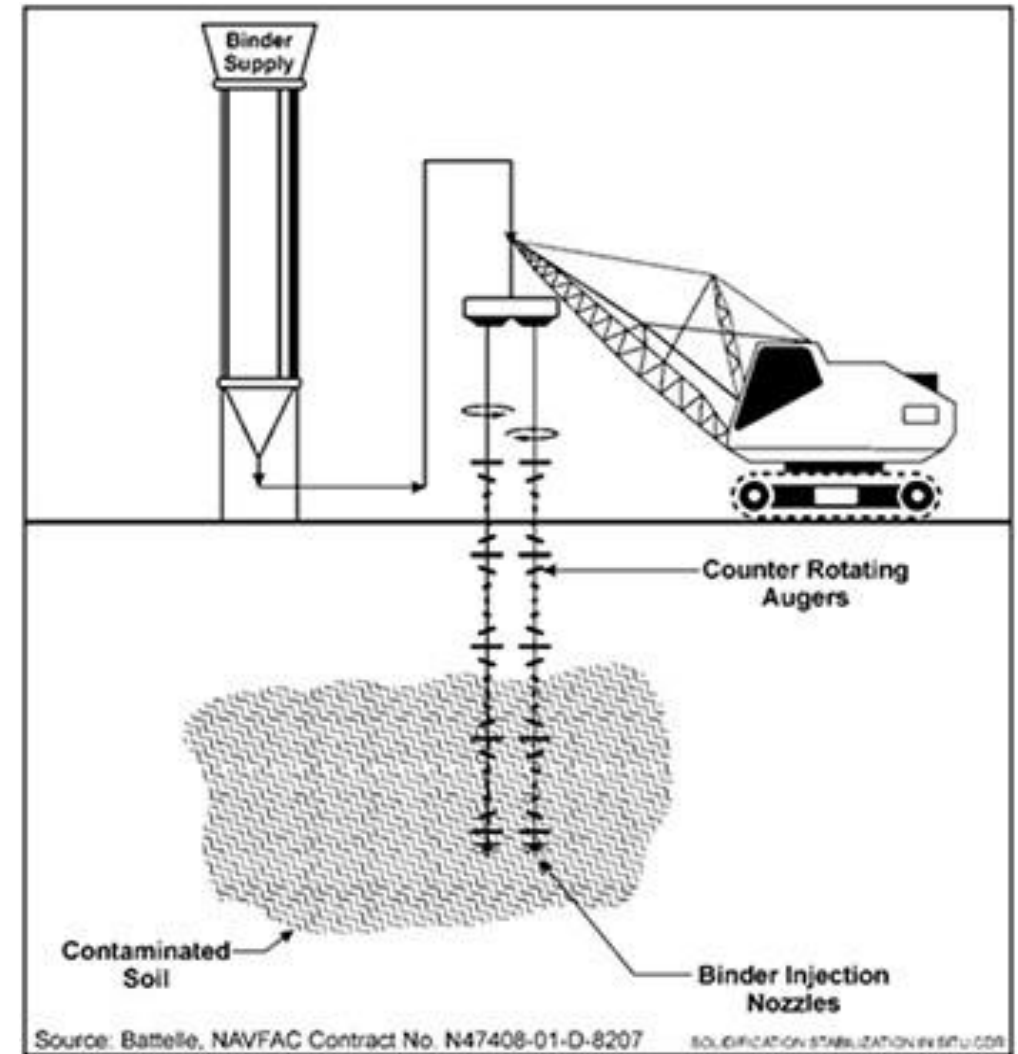
Presentation Outline

- Technology Overview
 - ISS
 - ISCO
 - Combined ISCO / ISS
- Why Combine?
 - Benefits & Synergies
- Case Studies



In Situ Solidification and Stabilization

- Use of soil mixing to blend binding agent(s) with contaminated soils:
 - Portland Cement
 - Blast Furnace Slag/Other Pozzolans
- Methods:
 - Stabilization:
 - Chemical processes that reduce leachability
 - Solidification:
 - Decreasing of surface area, hydraulic conductivity, effective porosity
 - Increasing compressive strength



Common Objectives of ISS

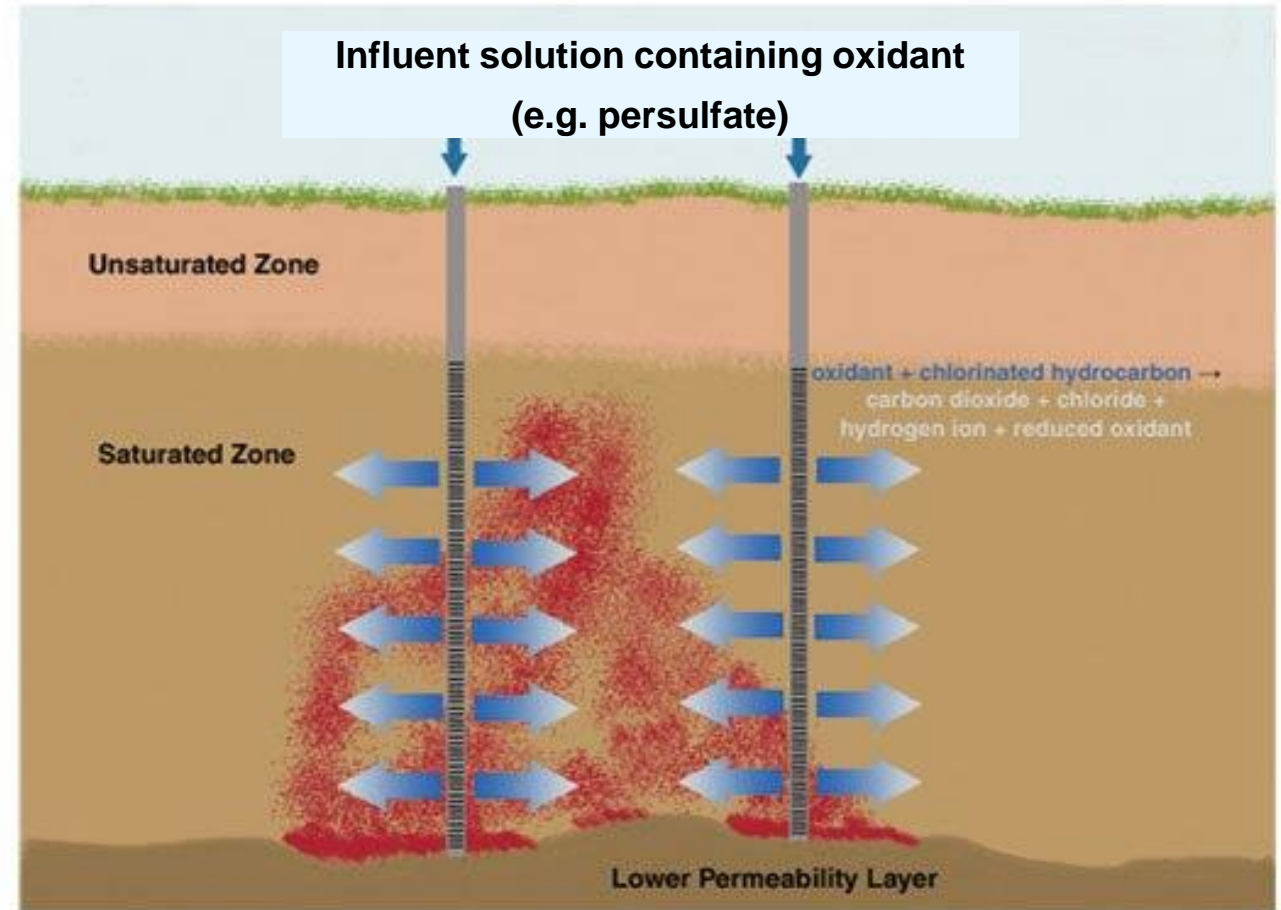
- 1. Reduced hydraulic conductivity
 - 2-3 orders of magnitude below native soils
 - 1×10^{-6} cm/sec
- 2. Unconfined Compressive Strength (UCS)
 - “Workable” ~20-60 psi
 - Hardened
 - ISS often targets 50 psi
- 3. Lower contaminant flux and leachate concentrations

General Relationship between Soil Consistency and Unconfined Compressive Strength				
Consistency	Unconfined Compressive Strength (UCS) Ranges			
	psi		kPa (KN/m ²)	
	Low	High	Low	High
Very soft	0	3	0	24
Soft	3	7	24	48
Medium	7	14	48	96
Stiff	14	28	96	192
Very Stiff	28	56	192	383
Hard	>56		>383	

Typical target range for “workable” soils ~20-60 psi

In Situ Chemical Oxidation

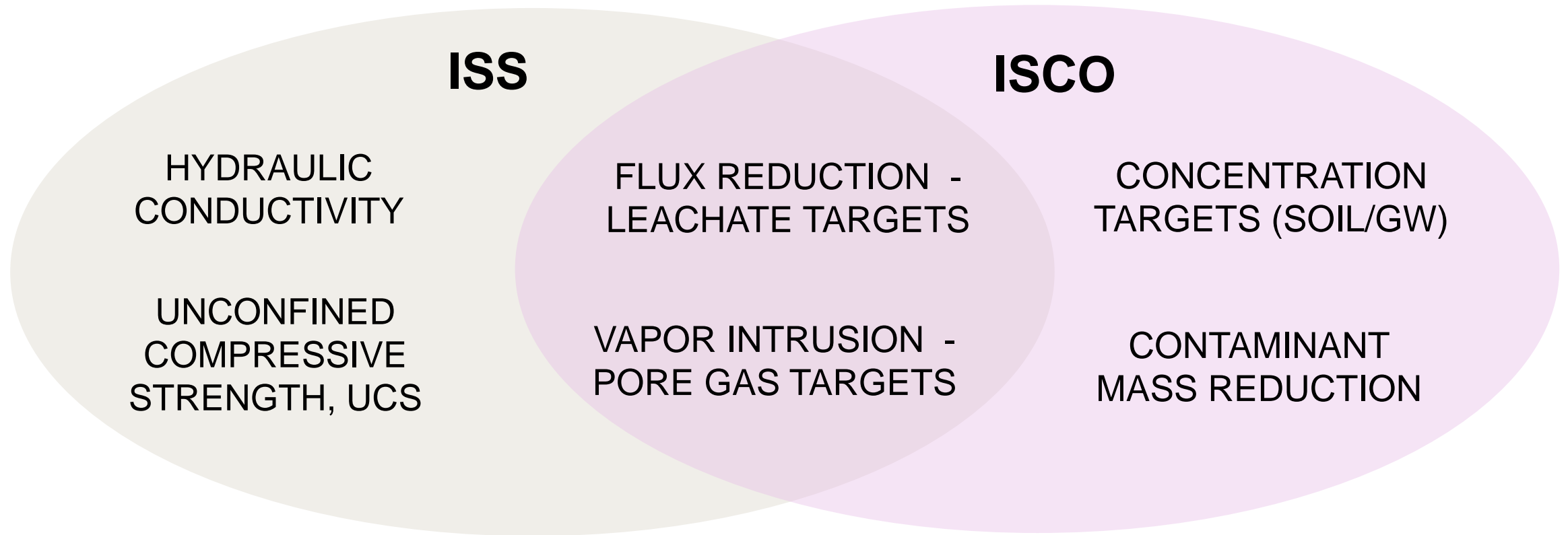
- What it is:
 - Oxidants are reagents that accept/take electrons from, or oxidize, contaminants of concern $\rightarrow \text{CO}_2$
 - Typically applied via injection or soil mixing
- Objectives:
 - Contaminant destruction / mass reduction
 - Reduced concentrations in soil, groundwater, leachate and vapors



Examples (persulfate reactions):



Common Remedial Goals



ISCO Can Help

Combined Remedy: Primary Benefit

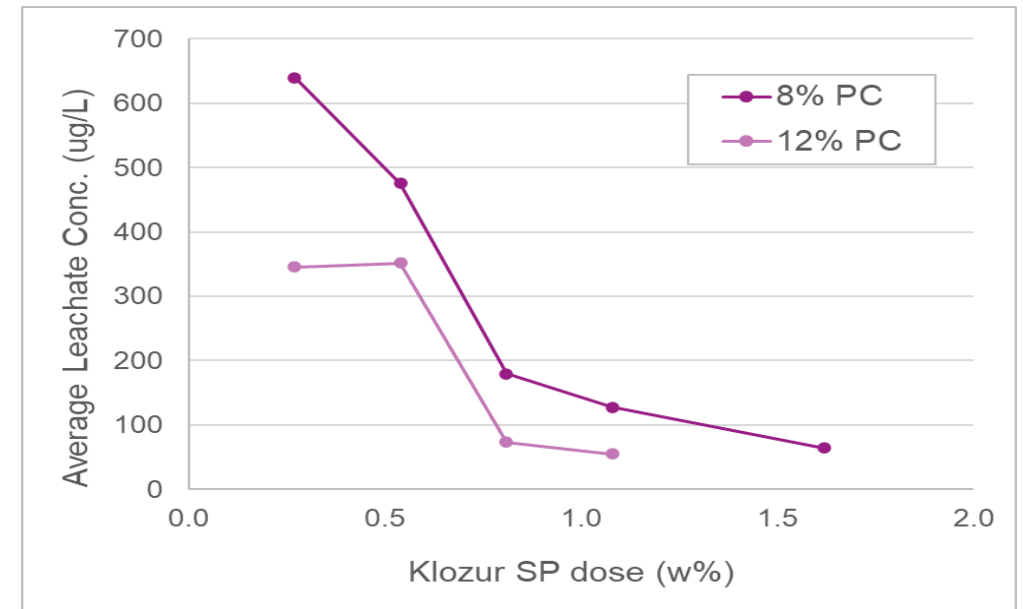
Whatever contamination that is not treated by ISCO

Is then solidified in a low permeable matrix by ISS

Ready for Redevelopment

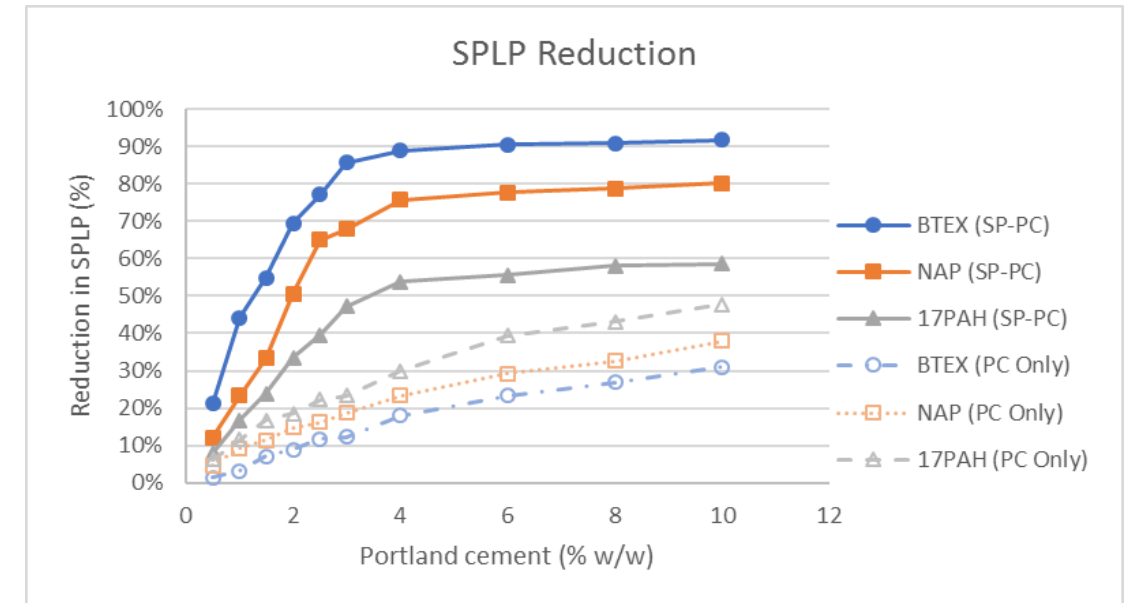
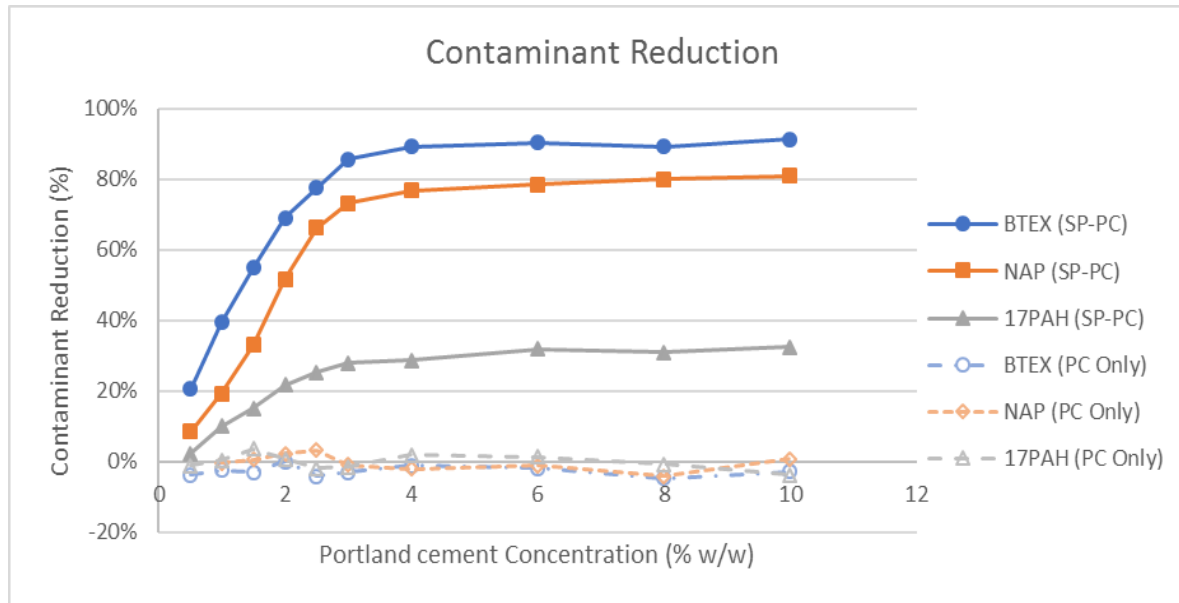
Combined Remedy: Synergies

- Synergies
 - Alkalinity from ISS creates alkaline activated persulfate
 - Compounding effect:
 - Both technologies reduce leachate and soil vapors
 - Oxidizing organic results in stronger solidification
 - Lower hydraulic conductivity
 - Can result in less bulking/swell
 - Decrease handling/disposal costs



Synergistic benefits with combined approach

Contaminant destruction can result in lower leachate concentration compared to ISS Only



2:1 Ratio of PC:SP

>37,000 mg/Kg MGP Residuals

Srivastava et al (2016) J. of Environ. Chem. Eng., (4), 2857-2864

Synergies: Improved UCS

- Persulfate addition can improve UCS to a certain point
- Lowering binder requirements to achieve remedial goals
- Less binder → soil bulking → Cost savings

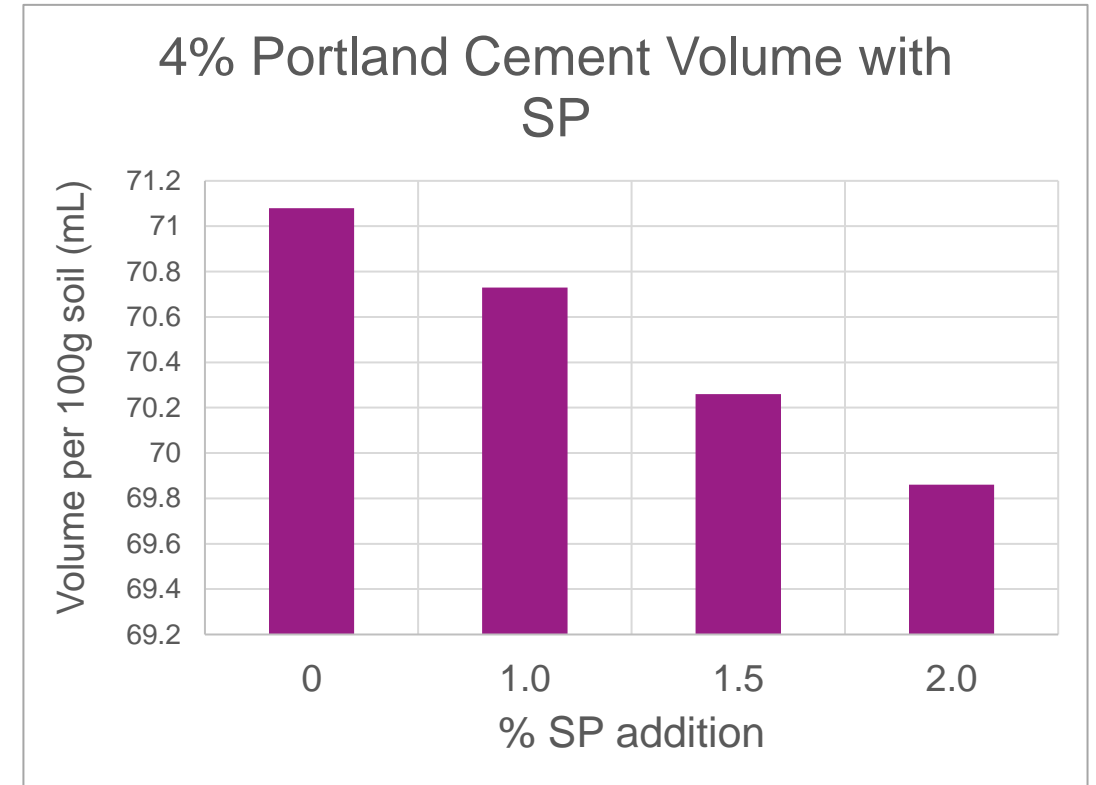
Klozur SP (% w/w soil)	8% PC		8% PC/BFS	
	Day 90 UCS (psi)	% of ISS only	Day 90 UCS (psi)	% of ISS only
0	90	100%	110	100%
1	105	117%	160	145%
2	110	122%	175	159%

Mechanism 1 to Less Bulking:
Can Require Less Binder

Synergies: Reduction in Swell/Fluff

- Second mechanism:
 - Soils tested had decreasing volumes with increasing SP addition for same amount mass of binder
 - Up to ~40% reduction in swell observed with 2% SP addition

Example: If you had 20% swell without SP, you may have 12% swell with 2% SP for the same PC addition



Case Studies

Former MGP Site in Stockholm being Redeveloped into Residential Area

Client: City of Stockholm

Contractor: PEAB / ARKIL

Treatment Volume: 50,000
m³ clay layer

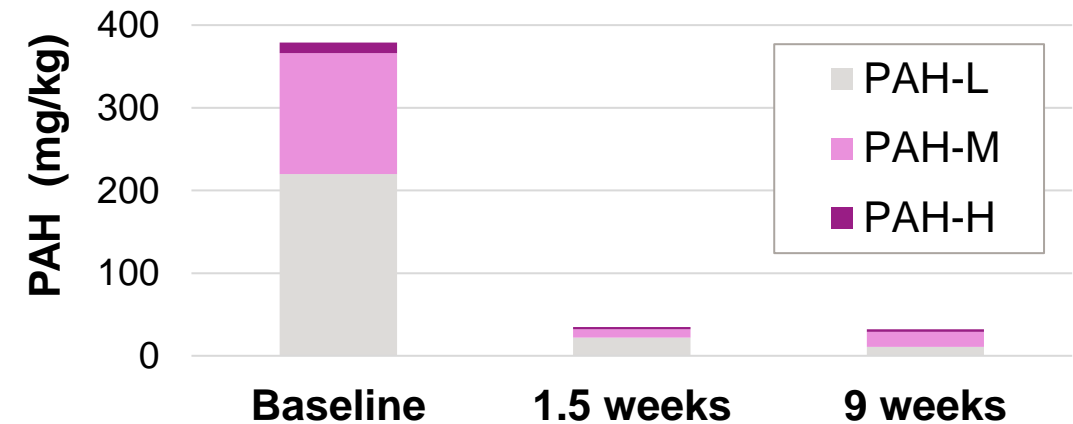
Remedial Goals: Prevent
vapor intrusion to planned
buildings via combination
of stabilization and
contaminant reduction

Reagent dose:

- 1.8wt% Klozur SP
- 4-8 wt% Slag cement



**Klozur SP, cement and
water applied using large
diameter auger**



- ~95% reduction in PAH-L
- ~90% reduction in PAH-M
- ~80% reduction in PAH-H
- Higher % reduction in lower molecular weight fractions.
- All samples below remedial goal of 250 mg/kg

Reference: Uppföljning av föroreningshalter i pelare efter stabilisering och kemisk oxidation av lera (ISS-ISCO), Golder, Jan 2022

ISCO-ISS for Remediation of Former Søllerød MGP site in Residential Neighborhood

Location: Copenhagen, Denmark

Lead Consultant: COWI / Geosyntec

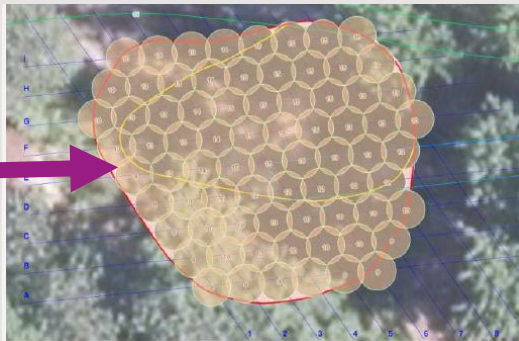
Contractor: ARKIL

Treatment Volume: 1,865 m³ soil, 10 to 15 m bgs

Remedial goals: Combination of stabilization and contaminant reduction

75 overlapping columns

Reagent dose:
•3 wt% Kloxur SP
•8 wt% Slag cement



Geotechnical Results Achieved

- UCS >20 psi (Day 80)
- $K \leq 1 \times 10^{-6}$ cm/sec

Compound	Baseline Concentration ¹ (mg/Kg)	Post Application Concentration (mg/Kg)	Reduction due to Treatment (%)
Benzene	13 to 27	ND	>99
Naphthalene	100 to 160	23	80-85
Phenols	3	0.04	99
TOC	500 to 800	23	85-90

1. Based on conversion of contaminant mass estimates

ISCO-ISS Successfully Remediates Petroleum Contaminated Soils for Site Redevelopment

Location: Bolzano, Italy

Lead Consultant: Ladurner Bonifiche S.r.l.

Contaminants: Petroleum Hydrocarbons

Goals: Combination of contaminant reduction, soil stability targets, limit soil bulking

Treatment volume: 3,500 m³, from 3-8 m bgs

Dose (w/w soil):

- Klozur SP: 0.7-1%
- Portland Cement: 4-8%

Installation: 556 columns w. large diameter auger



ISCO Results & Goals:

- Benzene: 100% samples < 2 mg/Kg
- TPH (C4-C12): 100% samples <250 mg/Kg
- TPH (C13-C40): Over 50% samples <750 mg/Kg

ISS / Geotechnical Goals Achieved:

- UCS: 30 to 70 psi
- Permeability: 2.8×10^{-6} to 7.3×10^{-7} cm/sec

Less than 15% soil bulking

What Data is Needed to Screen Sites

- Site Access
 - ISCO-ISS applied via soil mixing or potentially jet grouting. Need physical access
- Can soils be mixed?
- Can contaminants be treated?
 - Limits to ISCO (~10,000 mg/Kg)
- Remedial Goals
 - Do goals align with ISCO-ISS
 - Can goals be achieved with ISCO-ISS

Parameter	Baseline Monitoring
Contaminants (Soil & GW)	x
Soil Type	
Moisture Content	
Dry Bulk Density	
Boulders (size)	
Native UCS	
Fraction Organic Carbon on Soil	x
Sodium/Potassium/Sulfate Ions	x
Soil Oxidant Demand (SOD)	x
Electric Conductivity	x
Oxidation-Reduction Potential	x
pH	x
Dissolved Organic Carbon	x

Summary

- ISCO-ISS is combined remedy of two established technologies
 - Single application
 - Treat/degrade significant portions of contaminant mass
 - Residual is solidified in a monolith
 - Several synergistic benefits:
 - Higher UCS, lower leachate, lower hydraulic conductivity
 - Target UCS range, soils can be reworked, if needed
 - Less soil bulking can decrease project costs
 - Site ready for redevelopment/access shortly after application

Bench studies recommend:

- Determine dosage/ratio of Binder and SP
- Look at parameters:
 - UCS
 - HC
 - Contaminant destruction
 - Leachate (LEAF/Dunk Test)
 - Vapor intrusion

Thank you!

Questions?



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