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Miljö & teknik

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Stabilization of PFAS contaminated soils

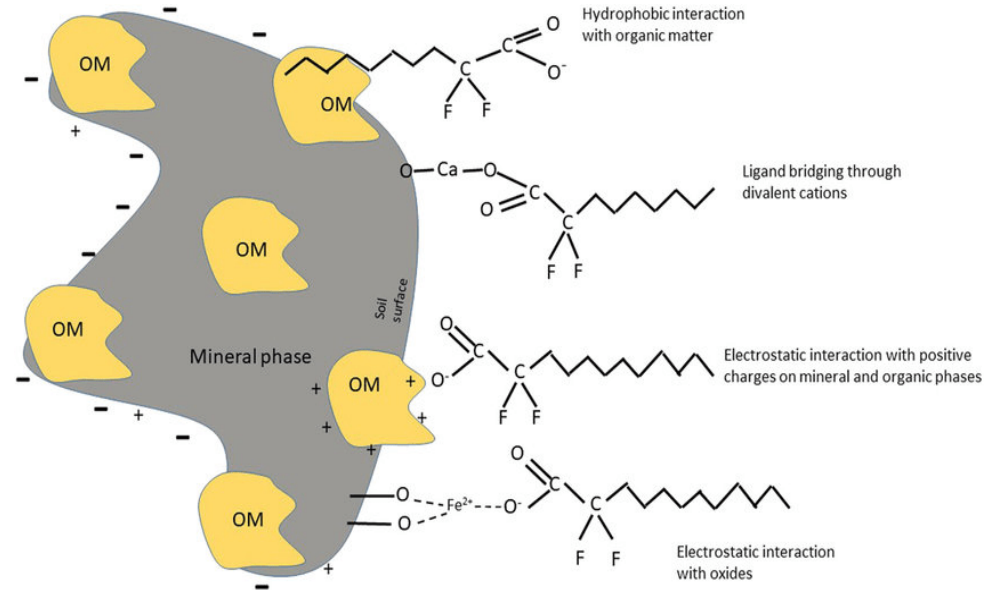
PFAS in soil

Short chain PFAS – more mobile and are prevalently found in water

Long chain PFAS – less mobile and are prevalently found in soils



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PFAS in soil

- Supra molecule, sticks to surfaces (creating layers)
- Total concentration vs **Leachability**
- Leaches for a long time



Example PFAS contaminated soil from an airport

Description	Unit	Sample 1	Sample 2	Sample 3	Sample 4
		Gravel sand	Gravel sand	Gravel sand, rocks	Sand with 30% ash from burnt
Sum PFAS28 - total concentration	ug/kg	48	155	231	331
Sum PFAS28 - leachability	ng/l	11 000	18 000	68 000	9 200

PFAS in soil

- >C6 PFAS are prevalantly found in soils.
- <C6 PFAS are prevalantly found in water



Carbon chain length ↑

Compound	Unit	Sample 3 L/S 2	Sampl 3 L/S 8
PFDA (Perfluordekansyra)	ng/l	120	23
PFNA (Perfluornonansyra)	ng/l	140	12
PFOA (Perfluoroktansyra)	ng/l	910	42
PFOS (Perfluoroktansulfonsyra)	ng/l	60000	11000
PFOSA (Perfluoroktansulfonamid)	ng/l	2600	720
6:2 FTS (Fluortelomer sulfonat)	ng/l	1900	97
PFHxS (Perfluorhexansulfonsyra)	ng/l	930	41
PFHpA (Perfluorheptansyra)	ng/l	140	<10
PFHxA (Perfluorhexansyra)	ng/l	240	12
PFPeA (Perfluorpentansyra)	ng/l	400	<20
PFBA (Perfluorbutansyra)	ng/l	57	<20
PFBS (Perfluorbutansulfonsyra)	ng/l	33	<10
Summa PFAS SLV 11	ng/l	65000	11000
Summa PFAS 28	ng/l	68000	12000

Stabilization of PFAS contaminated soils

Rembind® – Stabilization agent

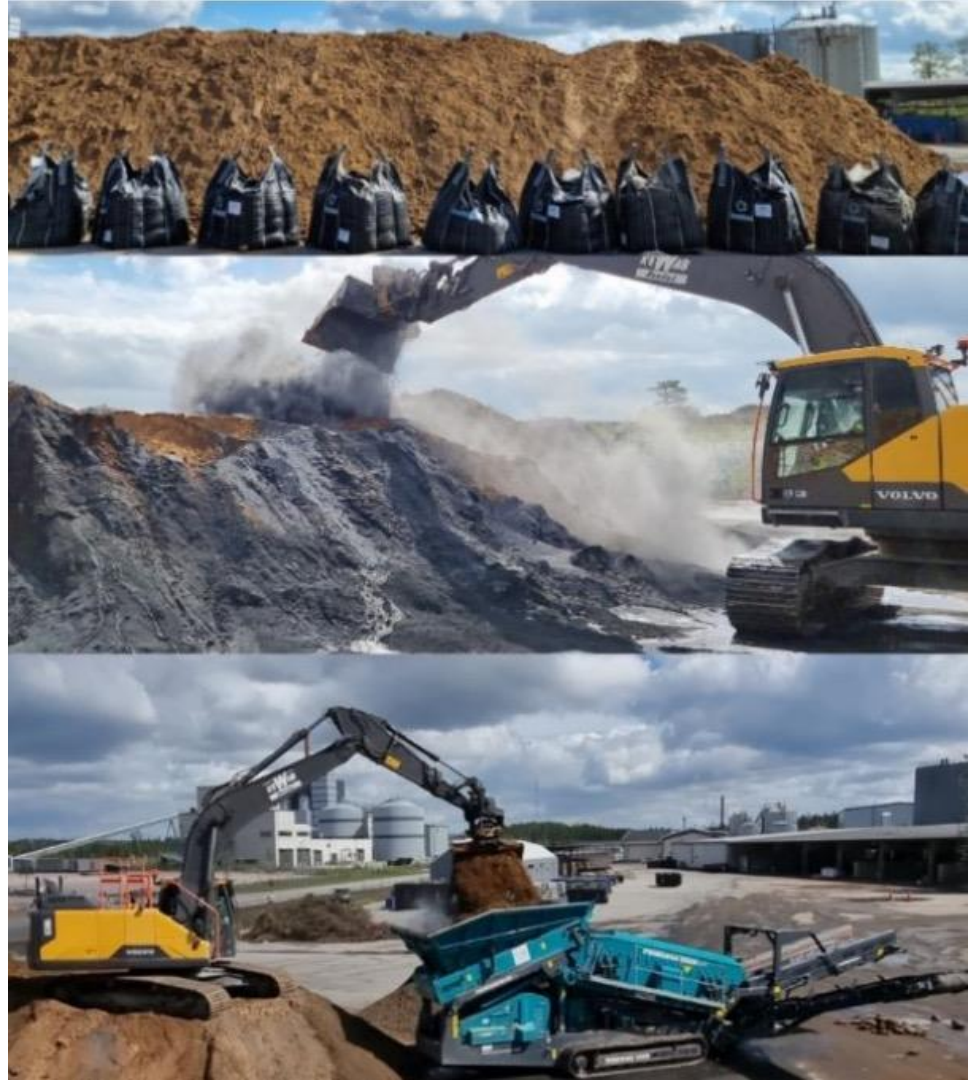
Rembind Distribution Rights



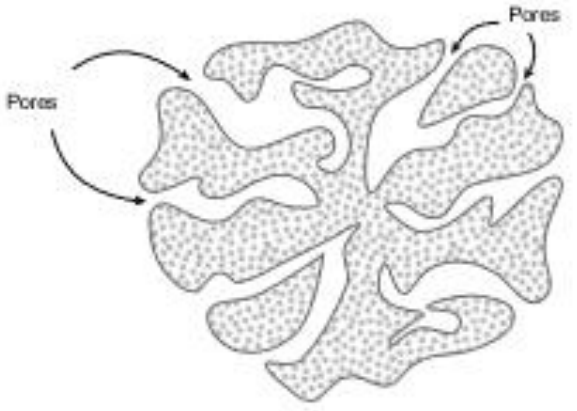
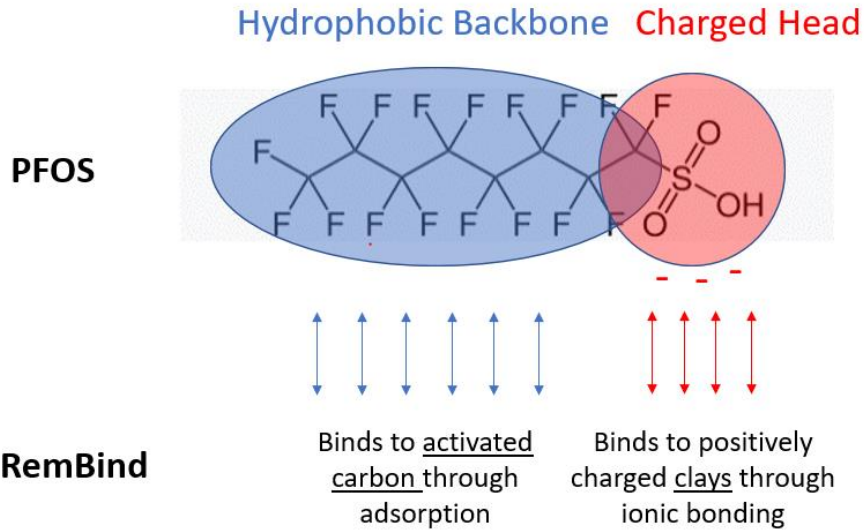
What is Rembind and how does it work?

Activated carbon product for stabilization of PFAS contaminated soils

- Made in Australia
- Patented material containing activated carbon, aluminium hydroxide and other adsorbents. The product is a fine powder, 200-400 μm (PAC <100 μm).
- A product specifically made for stabilization of contaminants in soil.



Rembind – Stabilization of PFAS in Soil



Rembind – Stabilization of contaminants in Soil

Not only PFAS!

- Metals (Cu, Zn, Pb, Ar...)
- PAH:er
- TBT, DBT, MBT
- and others...

- Report SweBoat

https://www.atgardsportalen.se/bibliotek/Sweboat-atgardstest_batuppstallningsplats_v1,01ink_bilagor.pdf



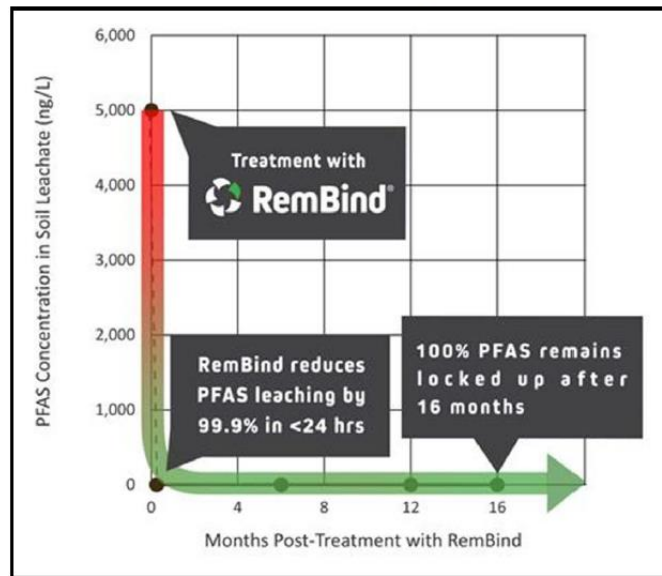
Analyzing methods to verify effect and evaluate long time durability

About 5 years of verified field data, and counting...
Several studies have been carried out to evaluate the long-time stabilizing effects for Rembind on PFAS.

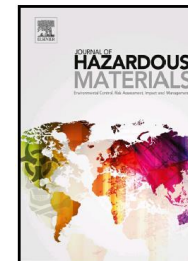
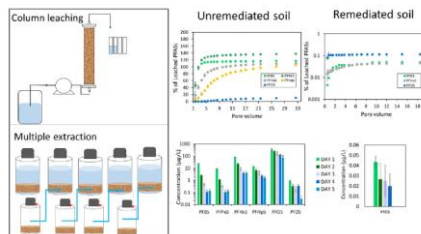
For evaluation, these analytical methods are used

- EN12457-1 European Standard test
- LEAF method – U.S. EPA Leaching Environmental Assessment Framework (USA)
- MEP-1230 - the U.S. EPA Multiple Extraction Procedures (USA)
- Simulating the worst possible conditions that can occur in nature and repetitive treatment cycles of leaching to simulate decades of rainfall under different extreme conditions (extreme variations in pH, temperature, ionic strength conditions etc.)

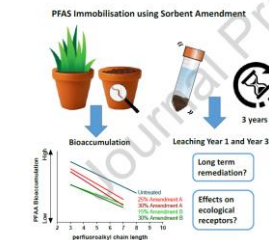
Reduction in PFAS Leachability over 16 Months











Peer review articles



Graphical Abstract:



Reduction in leachability and bioavailability			Long term durability and stability			Product comparisons (bio char/GAC/Rembind)	
<p><i>Application of soil amendments for reducing PFAS leachability and bioavailability (2022)</i></p> 	<p><i>Changing bioavailability of per- and polyfluoroalkyl substances (PFAS) to plant in biosolids amended soil through stabilization or mobilization (2022)</i></p> 	<p><i>Assessing the impact of immobilisation on the bioavailability of PFAS to plants in contaminated Australian soils (2024)</i></p> 	<p><i>Sorptive remediation of perfluorooctanoic acid (PFOA) using mixed mineral and graphene/carbon-based materials (2018)</i></p> 	<p><i>Sorbent assisted immobilisation of perfluoroalkyl acids in soils – effect on leaching and bioavailability (2021)</i></p> 	<p><i>LEAF method - Durability of sorption of per- and polyfluorinated alkyl substances in soils immobilized using common adsorbents: 2. Effects of repeated leach[...] (2021)</i></p> 	<p><i>Performance of different sorbents toward stabilizing per- and polyfluoroalkyl substances (PFAS) in soil (2022)</i></p> 	<p><i>Durability of sorption of per- and polyfluorinated alkyl substances in soils immobilised using common adsorbents (2021)</i></p> 

The optimal Dosage of Rembind

Eurofins Sweden  eurofins

1. Representative sample of the soil
2. Analyzing for PFAS
3. Envyytech will recommend about 3 different dosage rates of Rembind (experience from previous projects)
4. Bench-scale stabilization test, carried out at Eurofins lab

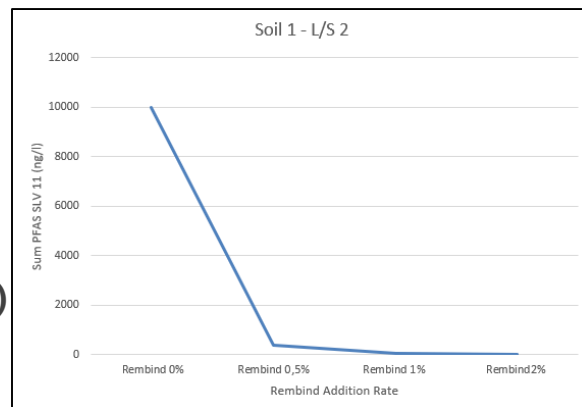


Screen soil, dose reagents (0% to 5%)



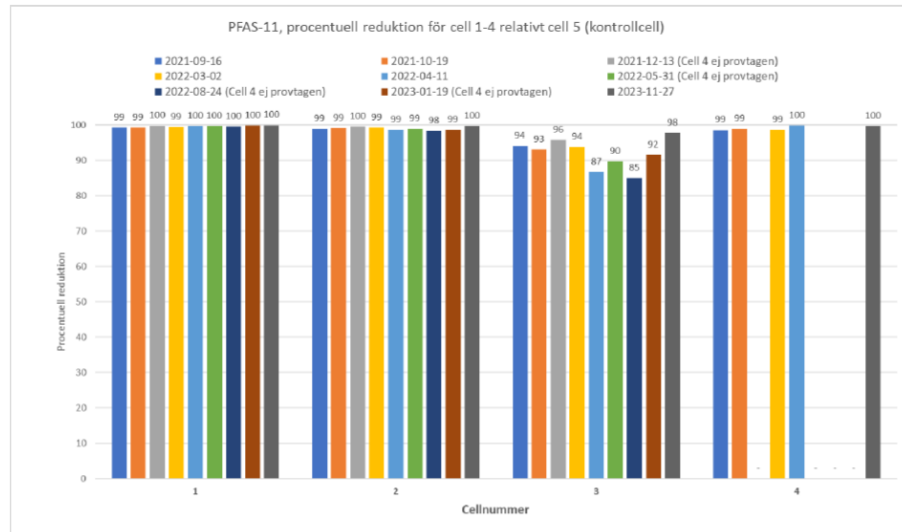
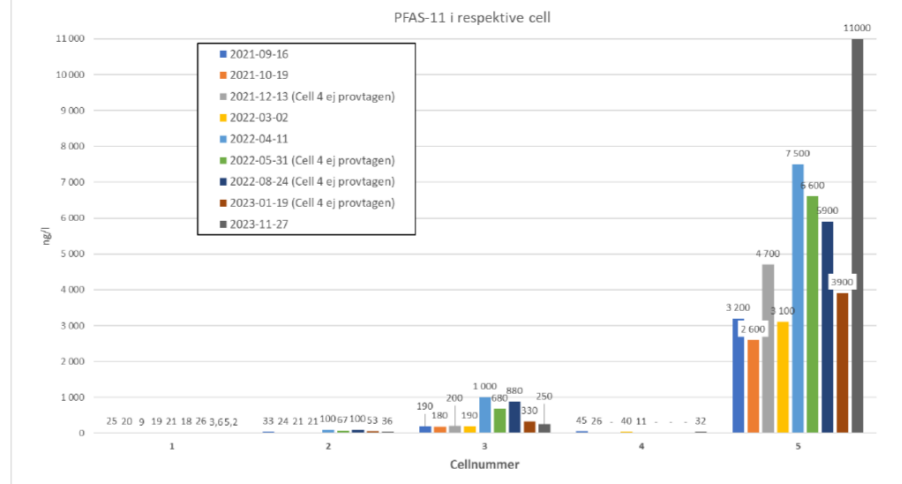
Add water and fix for 24 hours

5. Leachability test
6. Results will show the optimal dosage of Rembind (dosage curve)



NEW - Full scale pilot!

- Swedavia (Arlanda airport Stockholm)
- 2,5 years of measurements – comparing four different stabilizations products
- Adding 3 % Rembind
- >99% reduction of leachability



Stabilization Lab Trial for silty sandy soil from Fire Station Area

Lab trial on silty sandy soils

Total conc PFAS11: 17 ug/kg

Stabilization using Rembind percentages of 0%, 0,5%, 1% and 2%

Analyzing of soil using the European standard method for PFAS sum 11

Result reduction of leachability >99 %

Dosage 0,5 % Rembind



Ämne	Enhet	Koncentration
TOC % TS	% TS	0,91
6:2 FTS (Fluortelomer sulfonat)	ug/kg	0,098
PFHxS (Perfluorhexansulfonsyra)	ug/kg	0,35
PFOA (Perfluoroktansyra)	ug/kg	0,15
PFOS (Perfluoroktansulfonsyra)	ug/kg	16
PFPeA (Perfluorpentansyra)	ug/kg	0,26
Summa PFAS SLV 11	ug/kg	17

	Brandstation	Brandstation	Brandstation	Brandstation
	2023-04-27	2023-04-27	2023-04-27	2023-04-27
Ämne	Rembind 0%	Rembind 0,5%	Rembind 1%	Rembind 2%
	LS = 2	LS = 2	LS = 2	LS = 2
6:2 FTS (Fluortelomer sulfonat)	69	0	0	0
PFBA (Perfluorbutansyra)	33	0	0	0
PFBS (Perfluorbutansulfonsyra)	10	0	0	0
PFHpA (Perfluorheptansyra)	29	0	0	0
PFHxA (Perfluorhexansyra)	74	0	0	0
PFHxS (Perfluorhexansulfonsyra)	92	0	0	0
PFNA (Perfluorononansyra)	18	0	0	0
PFOA (Perfluoroktansyra)	53	0	0	0
PFOS (Perfluoroktansulfonsyra)	1800	2,9	0	0
PFOSA (Perfluoroktansulfonamid)	20	0	0	0
PFPeA (Perfluorpentansyra)	97	1,1	0	0
Summa PFAS SLV 11	2300	4	0	0
L/S = 8	430	1,9	0	0

Stabilization Lab Trial for sandy soil from Luleå airport

Lab trial on sandy soils



DÅVA D·A·C

Total conc PFAS11: 140 ug/kg

Stabilization using Rembind
percentage of 0%, 1,5%, 2% and 2,5%

Analyzing of soil using the European
standard method for PFAS sum 11

Result reduction of leachability >96
%

Dosage 1,5 % Rembind



	DÅVA Flygplats	DÅVA Flygplats	DÅVA Flygplats	DÅVA Flygplats
	2022-11-04	2022-11-04	2022-11-04	2022-11-04
Ämne	Rembind 0%	Rembind 1,5%	Rembind 2%	Rembind 2,5%
	LS = 2	LS = 2	LS = 2	LS = 2
6:2 FTS (Fluortelomer sulfonat)	910	22	37	<1,0
PFBA (Perfluorbutansyra)	35	<20	<20	<3,0
PFBS (Perfluorbutansulfonsyra)	39	<10	<10	<1,0
PFHpA (Perfluorheptansyra)	140	<10	<10	<1,0
PFHxA (Perfluorhexansyra)	380	<10	<10	<1,0
PFHxS (Perfluorhexansulfonsyra)	3600	57	81	1.0
PFNA (Perfluorononansyra)	75	<10	<10	<1,0
PFOA (Perfluoroktansyra)	1400	18	33	<1,0
PFOS (Perfluoroktansulfonsyra)	150000	4800	6400	67
PFOSA (Perfluoroktansulfonamid)	300	56	86	1.0
PFPeA (Perfluorpentansyra)	170	<20	<20	<1,0
Summa PFAS SLV 11	160000	5000	6700	69
L/S = 8	13000	38	130	87

	DÅVA Flygplats	DÅVA Flygplats	DÅVA Flygplats	
	2022-11-04	2022-11-04	2022-11-04	
Ämne	Rembind 1,5%	Rembind 2%	Rembind 2,5%	
Summa PFAS SLV 11	50	7,4	4,9	L/S= 0,1
Summa PFAS SLV 11	250	120	180	L/S= 2
Summa PFAS SLV 11	180	110	180	L/S= 9,9

Full-Scale stabilization

Rembind® – Stabilization agent

Rembind Reference Projects Sweden

Over 180 projects, World Wide
Treatment of >500 000 tons of
PFAS contaminated soil

- Stabilization of 500 tons of soil from construction works at a fire fighting station. Treatment at landfill before soil was put in landfill cells.
- Stabilization of 4000 tons of soil from metal surface treatment industry. Treatment at landfill before soil was put in landfill cells.
- Stabilization of 1000 tons of soil from Fire Fighting Practice area. Treatment at landfill before soil was put in landfill cells.
- Stabilization of 1000 tons of soil from Fire Fighting Practice area – **On site and Reused**
- Stabilization of 5000 tons of soil from Umeå Airport, Treatment at landfill before soil was put in landfill cells.



How to carry out full scale stabilization – "Contact sport"

- Two step mixing procedure

1. Pre-mix (rough mixing)

- Excavator
- Loader
- Add water (dust control and activating the product).



2. Fine mixing

- Trommel screen
- Soil recycler
- ALU Bucket



- Mixing in Rembind as a slurry



How to carry out full scale stabilization





Galaxy S22 Ultra

Results for stabilization of different type of soils with different sources of PFAS



Rembind 100

Soil type	Pollution source	Concentration PFAS 11/PFAS 28 (ug/kg TS)	Concentration leachate L/S2 (ng/l)	Mixture percentage Rembind 100 (%)	Concentration leachate L/S2, after stabilisation with Rembind 100 (ng/l)	Reduction of leachability
Gravel sand	Surface treatment industry	1000	230 000	3	8500	96%
Gravel sand	Surface treatment industry	1000	230 000	5	4600	98%
Gravel sand	Surface treatment industry	30	4 300	3	590	86%
Gravel sand	Airport area	231	54 000	2	23	99,9%
Gravel silty sand	Airport area	155	18 000	1	43	99,9%
Gravel sand	Airport area	48	11 000	1	1,7	99,9%
Gravel sand	Airport area	410	170 000	2	680	99,9%
Sand	Fire drill site	420	138 000	2	50	99,9%
Sand	Fire drill site	420	138 000	5	<10	99,9%
Sand	Airport area	140	160 000	1,5	4900	97%
Sand	Airport area	140	160 000	2,5	68	99,9%

Stabilization of PFAS contaminated soil at an active firefighting training site

**Swedish Defence Estate site
(army base)**

Active site in need of an installation of a new petroleum tank



Stabilization of PFAS contaminated soil at an active fire fighting training site

- Swedish Defence Estate site (army base)
- Active site in need of an installation of a new petroleum tank
- Active as in fire fighting is carried out weekly
- Area widely contaminated with PFAS
- A total of 1000 ton in need of treatment
 - 500 ton: 140-540 ug/kg
 - 500 ton: 500 -1100 ug/kg

Stabilization of PFAS contaminated soil at an active fire fighting training site

How construction and installation projects used to be carried out by Defence Estate:

- Area sampled and classified
- Soil being excavated to make room for new installations – soil labelled as waste by law, as you are NOT allowed to re deposit contaminated soil with levels above target criterias for the site
- Soil is loaded on trucks
- Trucks drive long distanses to find a place where PFAS contaminated soil is accepted (creating a new piont source as no landfills have treatment systems for PFAS leachate)
- Clean soil has to be bought and transported to site
- Clean soil is used as fill in contaminated and active area.
- Clean soil is now PFAS contaminated.



Stabilization of PFAS contaminated soil at an active fire fighting training site

How construction and installation projects are carried out NOW by Defence Estate:

- Area sampled and classified
 - Soil being excavated to make room for new installations – soil labelled as waste by law, as you are NOT allowed to re deposit contaminated soil with levels above target criteria for the site
 - Soil is mixed with Rembind on site – minimizing the leaching ability of the PFAS from the soil. Soil is now treated and is NOT a waste and can be re deposited
 - Soil is used as fill material (a resource!)
-
- ➔ No long transports needed
 - ➔ No creation of a new point source
 - ➔ No need to buy new soil or to transport it

Results

Leachability in soils after stabilization

Substance	Suffix	Untreated (average concentration in leachate)	Treated soil Column test	Reduction in leaching abilities
		L/S=2.0	L/S=2.0	
6:2 FTS	ng/l	1300	<10,0	99,9%
PFBA	ng/l	220	<10,0	99,9%
PFBS	ng/l	120	<10,0	99,9%
PFDA	ng/l	<100	<10,0	99,9%
PFHpA	ng/l	270	<10,0	99,9%
PFHxA	ng/l	1200	23 ±7	91,4%
PFHxS	ng/l	500	<10,0	99,9%
PFNA	ng/l	<100	<10,0	99,9%
PFOA	ng/l	830	<10,0	99,9%
PFOS	ng/l	400 000	<10,0	99,9%
PFPeA	ng/l	480	<10,0	99,9%

Cost?

Ex. Case:

- Site conditions:
 - Sand / silty sand
 - Concentrations, Sum PFAS: 50 – 150 ug/kg
 - **1000 ton** of contaminated soil
 - Reuse of stabilized soil, **on-site**

- Optimal dosage rate Rembind: 1 %



	% Rembind	Cost / ton treated soil
Rembind + freight	1 %	50 Euro
Mixing equipment on-site		
Total cost (treating 1000 ton)		50 000 Euro

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