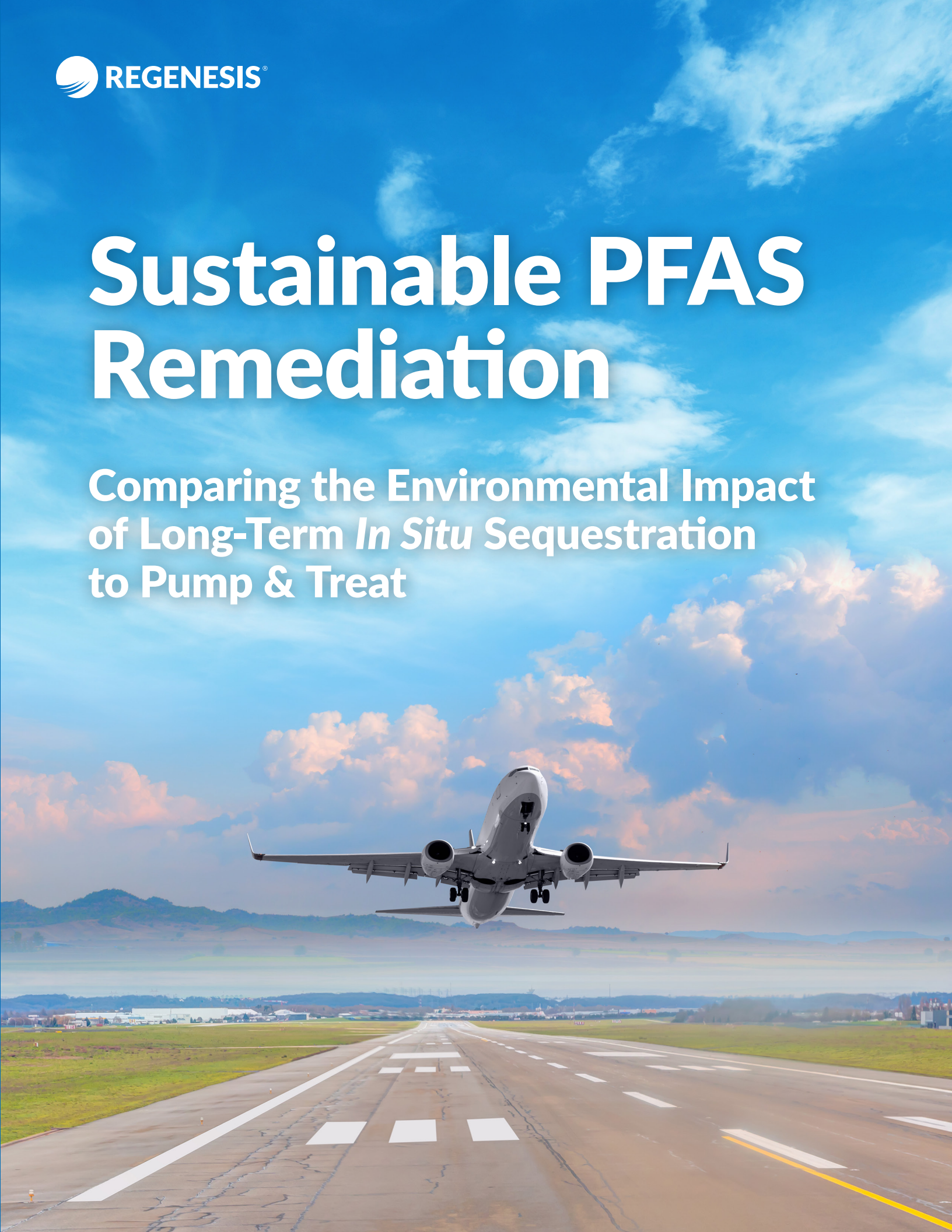
REGENESIS®

Sustainable PFAS Remediation

Comparing the Environmental Impact of Long-Term *In Situ* Sequestration to Pump & Treat



Why Consider Sustainability for the Remediation of PFAS?

Per- and polyfluoroalkyl substances (PFAS) contamination is a widespread global issue due to its extensive use, mobility, and recalcitrance. The challenge facing remediation practitioners is how to treat such widespread pollution while avoiding the production of extra greenhouse gas emissions, exacerbating climate change.

By using sustainability assessments on each PFAS project, the wider impact of the remediation activities on the environment, society, and economy can be considered.

PFAS are Everywhere!

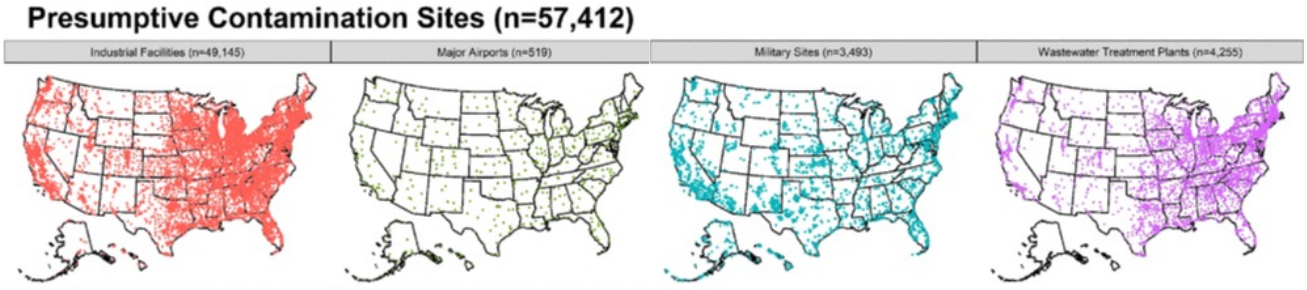
PFAS soil and groundwater contamination is widespread in the U.S. and globally. These compounds are highly versatile and have been widely used in commercial and domestic products and coatings for decades.

Additionally, for decades PFAS have been discharged onto the ground via aqueous film-forming foam (AFFF) used during firefighting, including routine training and testing exercises at airports and military bases.

In the environment, PFAS exhibit qualities that increase the exposure risk to people and communities:

- Retained in soils for decades.
- Very mobile in groundwater.
- Recalcitrant to degradation.
- Toxic at low concentrations.
- Creates large, very dilute plumes, impacting extensive areas.

Figure 1 **Presumed PFAS Contamination Sites in the U.S.**



Source: Northeastern University, Social Science Environmental Health Research Institute, published in Environmental Science and Technology Letters (2022).

In Situ Sorption and Enhanced Attenuation Using PlumeStop

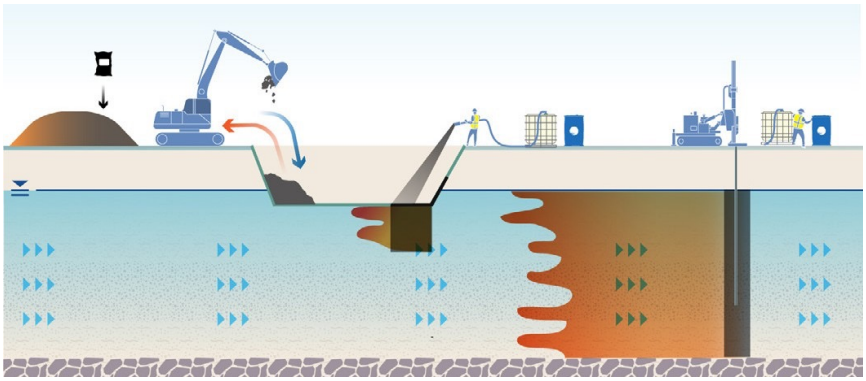
A Passive Approach

Remediation often focuses on extraction, disposal, or destruction, however, these approaches create a substantial carbon footprint.

Enhanced Attenuation (EA) using PlumeStop® Colloidal Activated Carbon (CAC) is an alternative approach that works by reducing PFAS leachability and migration *in situ*. Already used on over 40 sites worldwide, this passive approach requires no operational energy, maintenance, or PFAS-saturated waste products.

Figure 2

Source and plume treatment using colloidal activated carbon



Verification Using Life Cycle Analysis

Logic dictates that the passive, *in situ* approach should be significantly more sustainable than *ex situ*, pump & treat methods that require the continuous pumping of water. To verify this assumption, a Life Cycle Analysis (LCA) was conducted on the CAC material, with boundaries extending from 'cradle to grave', including upstream material sourcing, core manufacturing processes, and the downstream processes of transport and injection.

The LCA was undertaken by Ramboll according to the International Organization for Standardization ISO14044/ISO14025, using *GaBi* Professional software, meeting international standards (e.g., EN15804) to create an Environmental Product Declaration (EPD).

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Sustainability Comparison of a Site

Sustainability analysis was completed on a real-world PlumeStop application, located downgradient of a PFAS source at a commercial airport. A comparison was made by designing two alternative 'pump & treat' (P&T) systems, with filtration either by granular activated carbon (GAC) or foam fractionation (FF). The carbon footprint of each approach was completed using Life Cycle Inventory Analysis, using GaBi Professional software.

SURE by Ramboll

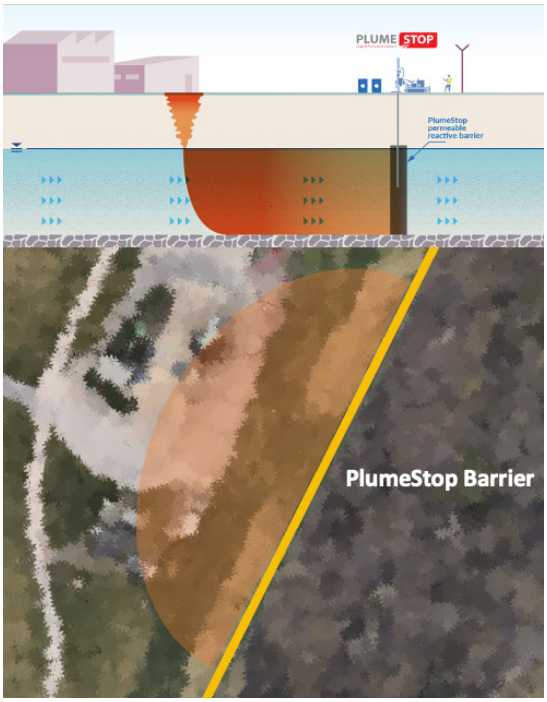
Additionally, a Life Cycle Cost Analysis (LCCA) was completed using net present value. Finally, a Tier 2 sustainability assessment using Ramboll's SURE model, considering 15 sustainability indicators, was completed for each remedial approach.

A	B1	B2
		
Immobilization with PlumeStop Colloidal Activated Carbon	VS **Pump & Treat** Pumping with GAC Filtration	VS **Pump & Treat** Pumping with Foam Fractionation



Site Designs

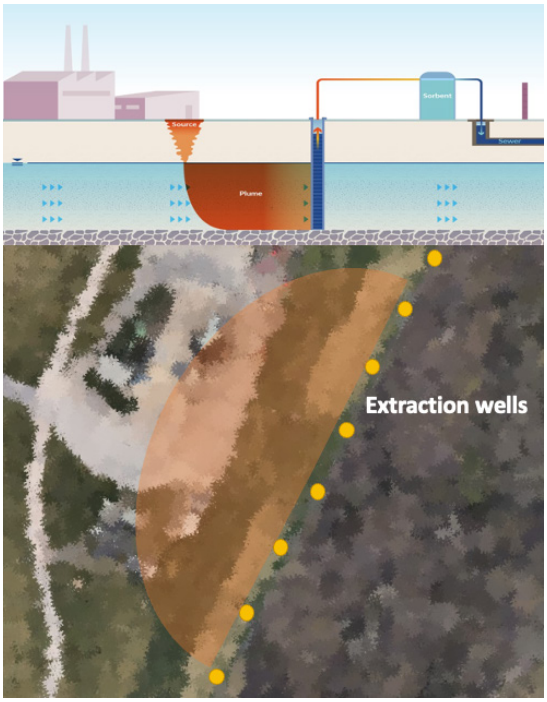
Immobilization with PlumeStop (A)



Section and plan view of actual *in situ* remediation project

- Single injection round
- Designed for minimum 15 years of efficacy
- 102 injection points
- 360 ft long
- 74,100 lbs PlumeStop
- 423 gallons fuel used for injection
- 3 monitoring wells, ~30 ft deep
- 2 times/yr environmental monitoring

Pump & Treat with GAC Filtration (B1) or Foam Fractionation (B2)



Section and plan view of alternative P&T systems

- Based on consensus from 3 P&T designers
- Fixed equipment installation
- Continuous operation 15 years, 95% uptime
- 8 extraction wells, 8 m deep to avoid excess draw-down = vertical spread/smear
- 100 gal/min pumping rate
- 52,900 lb/yr GAC usage rate (B1)
- 100 mg/kg adsorption capacity (B1)
- 960 MWh/yr electricity consumption (B1)
- 4 times/yr O&M inspection from office
- 608 gallons fuel used for installation
- 3 monitoring wells, 30 ft deep
- 2 times/yr environmental monitoring

Results

Total Carbon Footprint

97.5-98.5% Lower
Total Carbon Footprint of a PlumeStop Immobilization Approach

The PlumeStop carbon footprint is 97.5 to 98.5% (i.e. 40-70 times) lower than the alternatives.

Regarding the pump & treat approaches:

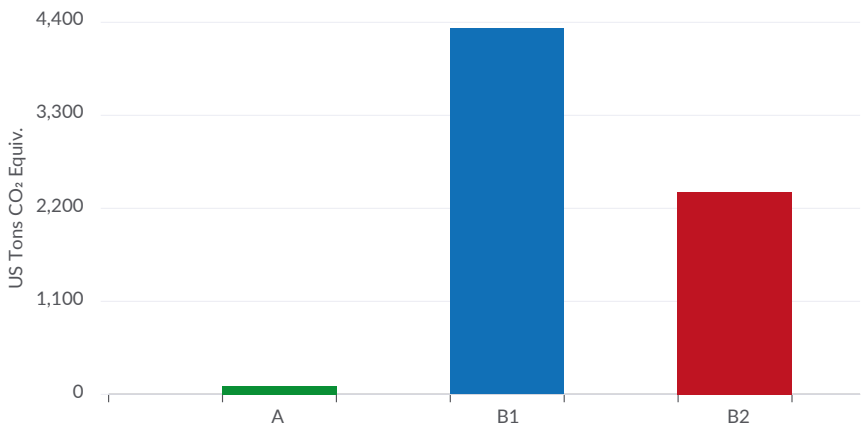
- The water extraction part of the process alone has a carbon footprint 1-2 orders of magnitude higher than Immobilization with PlumeStop.
- Either filtration method increased the carbon footprint further, i.e., changing the treatment approach did not provide a significant reduction in carbon footprint.

'Operation' and 'waste management' were the life cycle stages that had the greatest impact on the difference in carbon footprint between the *in situ* and *ex situ* methods.

Figure 5

Total carbon footprint for different remediation approaches

- Immobilization with PlumeStop
- Pump & Treat with GAC
- Pump & Treat with FF





Life Cycle Cost Analysis

Pricing analysis carried out by Ramboll has been based on a 15-year treatment duration with costs calculated at different times throughout.

61-65% Lower

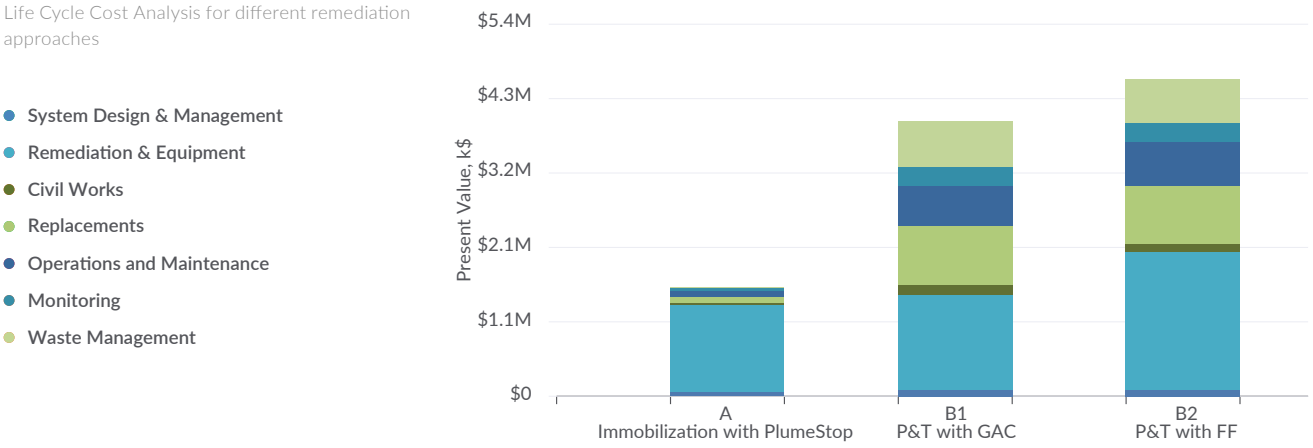
Immobilization with PlumeStop offers significant cost savings over *ex situ* treatment approaches

2023 Net Present Value:

- PlumeStop = $1.57M
- P&T with GAC = $4.02M
- P&T with FF = $4.54M

Figure 6

Life Cycle Cost Analysis for different remediation approaches





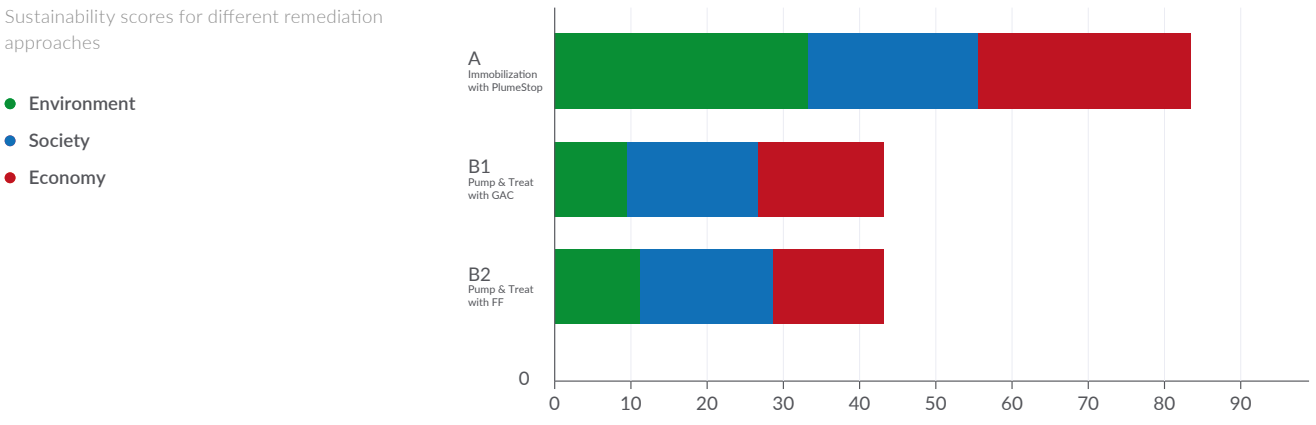
Sustainability Score

A 'Tier 2' sustainability assessment was completed using SURE by Ramboll, a sustainability assessment program based on standards from ISO and ASTM (i.e., American Society of Testing and Materials.)

- Linear-additive multi-criteria analysis (MCA) method is designed to incorporate both qualitative and quantitative information.
- 15 sustainability indicators encompassing each sustainability domain weighted and scored.
- In comparing remedial options, PlumeStop has a 100% higher Sustainability Assessment Score than the *ex situ* alternatives

Figure 7

Sustainability scores for different remediation approaches



Conclusion

Remediation Options Appraisals for PFAS impacted sites should include sustainability assessments to ensure that the site is not managed in isolation.

PlumeStop has a carbon footprint that is 97.5 to 98.5% (i.e. 40-70 times) lower than pump & treat.

'Pump & treat' has a carbon footprint for both components of the approach:

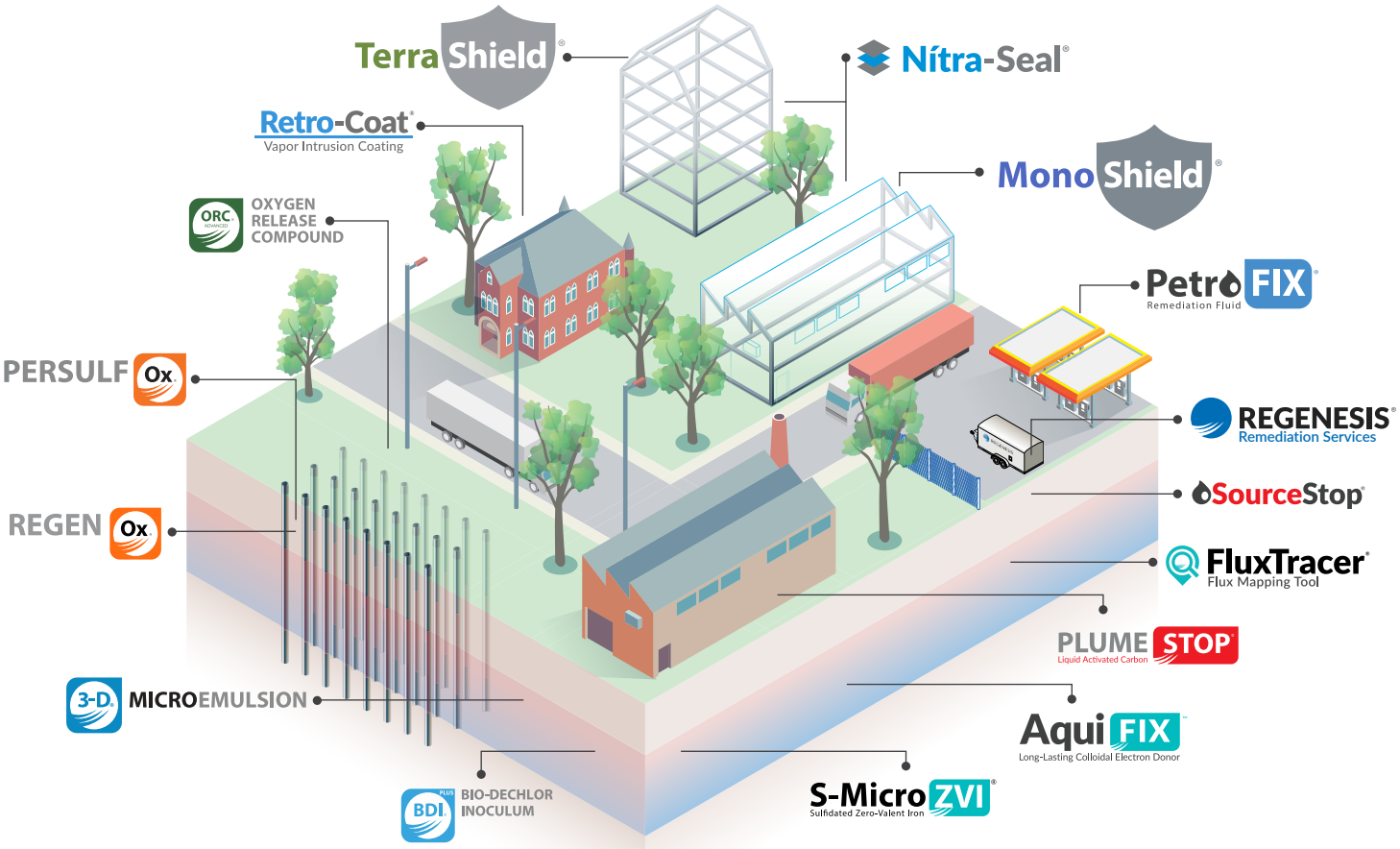
- Water extraction, on its own, has a much higher carbon footprint than *in situ* treatment.
- Either filtration method increased the carbon footprint (as would any nascent destructive technique).

The PlumeStop barrier has a much lower Total Cost of Ownership compared to pump and treat

The overall Sustainability Assessment Score for PlumeStop was 100% higher than the *ex situ*, pump & treat alternatives. PlumeStop also exceeded pump & treat in each of the sustainability categories, 'Environment', 'Society' and 'Economy'.

Enhanced attenuation, through the *in situ* retention of PFAS using PlumeStop CAC injection is an effective and sustainable approach to address a global pollution issue.





About REGENESIS

At REGENESIS we value innovation, technology, expertise and people which together form the unique framework we operate in as an organization. We see innovation and technology as inseparably linked with one being born out of the other.

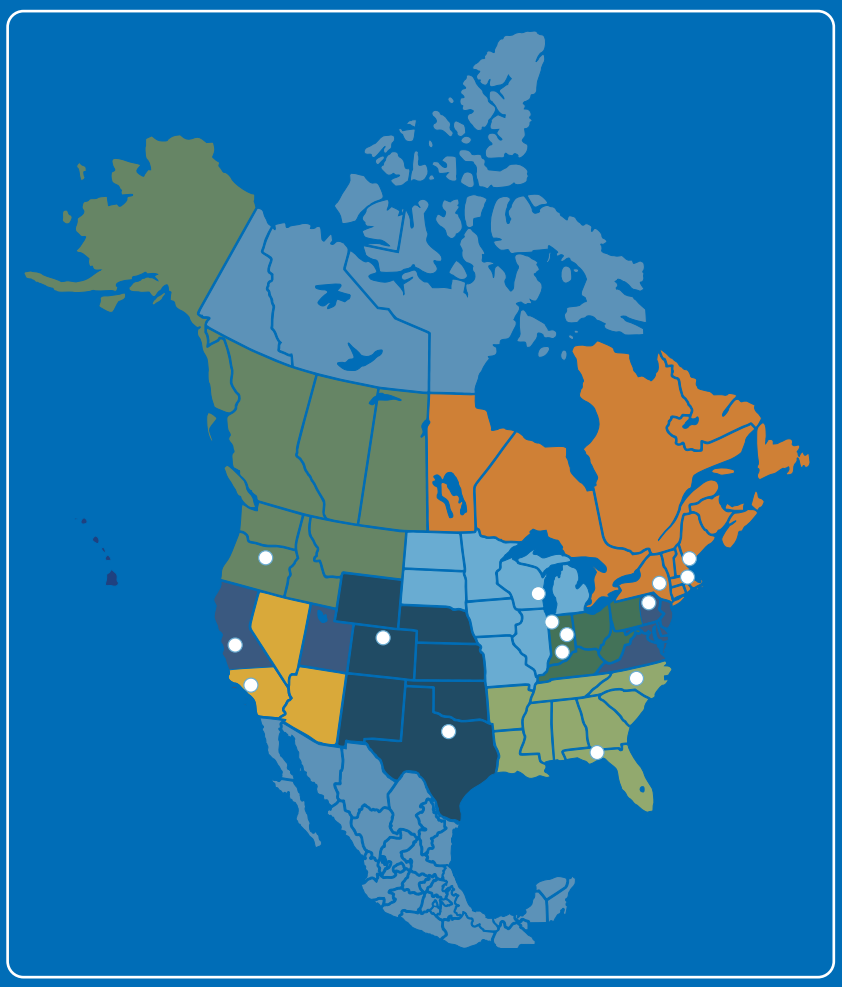
Inherently, innovation imparts new and better ways of thinking and doing. For us, this means delivering expert environmental solutions in the form of the most advanced and effective technologies and services available today.

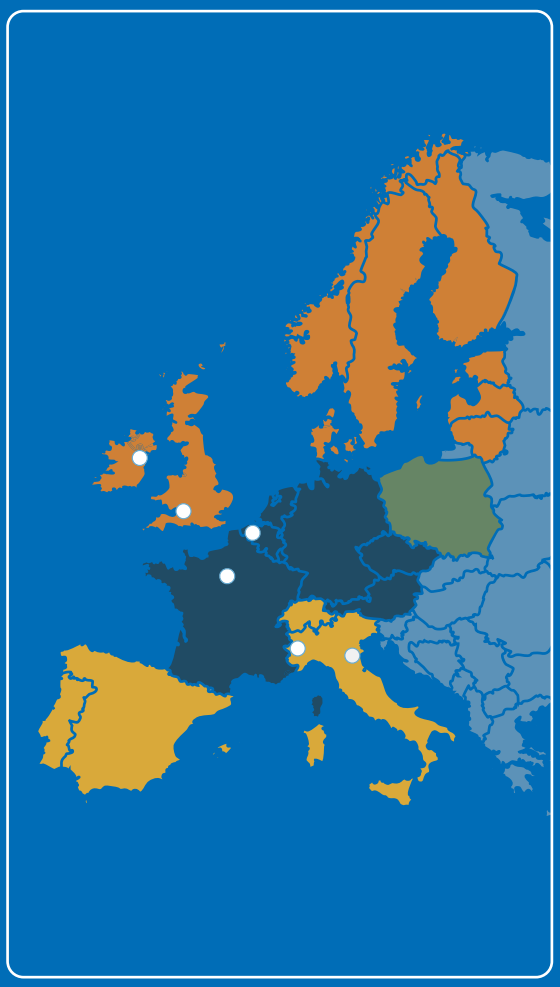
We value expertise, both our customers' and our own. We find that when our experienced staff collaborates directly with customers on complex problems, there is a high potential for success including savings in time, resources and cost.

At REGENESIS we are driven by a strong sense of responsibility to the people charged with managing the complex environmental problems we encounter and to the people involved in developing and implementing our technology-based solutions. We are committed to investing in lasting relationships by taking time to understand the people we work with and their circumstances. We believe this is a key factor in achieving successful project outcomes.

We believe that by acting under this set of values, we can work with our customers to achieve a cleaner, healthier, and more prosperous world.

We're Ready to Help You Find the Right Solution for Your Site





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