REGENESIS®

eBook

In Situ PFAS Remediation: A Low-Cost Approach to Avoiding Long-Term Risk and Liability

What Readers Will Learn

This eBook examines and compares the available remediation technologies for addressing PFAS (per- and polyfluoroalkyl substances) in groundwater. It contains the following key learning points for stakeholders addressing PFAS contamination at their sites:

Only Two Treatment Approaches

Only two approaches are used for mitigating risk due to PFAS in groundwater: deploying *ex situ* pump-and-treat systems, or *in situ* remediation using colloidal activated carbon. Both approaches contain PFAS plumes to prevent exposure risk, achieving the definition of "remediation."

Pump-and-Treat is Expensive and Ineffective

Over the past 40+ years, pump-and-treat has proven expensive and ineffective for restoring chlorinated solvent-impacted aquifers. Considering the chemistry and low cleanup standards for PFAS compounds like PFOA (perfluorooctanoic acid) and PFOS (perfluorooctanesulfonic acid), restoring a PFAS contaminated aquifer using pump-and-treat would be expected to take >100 years. Pump-and-treat can only be considered as a method for plume containment.

Pump-and-Treat Increases PFAS Exposure Risk

Pump-and-treat systems bring PFAS chemicals to the surface, creating exposure risks for individuals and communities. The PFAS waste generated is costly to handle and results in long-term liabilities for site owners and responsible parties.

In Situ Approach Avoids PFAS Waste

In situ remediation treats PFAS in place and below the ground, avoiding waste generation and related exposure risks.

Cost-Effective, Rapid, Long-Term Results

In situ remediation using colloidal activated carbon commercially available as Plumestop® and or SourceStop® offers rapid long-term effectiveness, while producing zero waste streams, and is less than 1/3 the cost of pump-and-treat.

> ***The significant differences between** ex situ **and** in situ **remediation approaches should be carefully assessed when evaluating strategies to mitigate PFAS risk.***

Presumptive Contaminations Sites (n=57,412)

Industrial Facilities (n=49,145)

Major Airports (n=519)

Military Sites (n=3,493)

Wastewater Treatment Plants (n=4,255)

Map of presumptive contamination sites identified using presumptive contamination model. Figure from Presumptive Contamination: A New Approach to PFAS Contamination Based on Likely Sources (Salvatore et al., 2022).

Introduction

PFAS: A Global Environmental Concern Requires Effective, Economical Solutions

PFAS constitute a group of thousands of synthetic organic chemicals that contaminate all environmental media and impact communities globally.

More than 57,000 Contaminated Sites in the US Alone

In the US alone, an estimated 57,000-plus sites have released these chemicals into the environment over many decades.[1] These releases caused PFAS to leach into groundwater, which supplies almost half of the drinking water in the US.[2] Recent studies indicate that PFAS chemicals likely impact between 45% and 60% of Americans' tap water.[3 4] Ongoing sampling of public water systems mandated by the USEPA has already confirmed 89 million people have been exposed, with many more systems yet to be sampled.[5]

$200B in PFAS Remediation Costs Projected

Remediation to mitigate the potential PFAS exposure risk from these sites is projected to cost around $220 billion, according to one estimate.[6] Meanwhile, US Public Water Utility Sector costs to remove PFAS from already impacted systems could approach $50 billion.[7]

In Europe, PFAS chemicals have been detected on 23,000 sites, with more than 21,500 additional sites[8] presumed to be impacted, suggesting a comparable level of effort and cost for PFAS remediation.

Practical PFAS Solutions are Paramount

Effective remediation solutions are essential to prevent further environmental impacts and eliminate future exposure risks from PFAS migrating from these sites. Considering the scale of the PFAS issue, practical solutions that can be quickly implemented at a low cost, to achieve the site-specific PFAS risk reduction goals, become paramount.

Remediating PFAS Above Ground or Below Ground

When deciding on a PFAS remediation strategy, one critical decision involves determining whether the remediation will occur above ground (*ex situ*) or below ground (*in situ*). Relevant research and case studies provided present and contrast these *ex situ* and *in situ* PFAS remediation alternatives. Choosing between these approaches can have significant and lasting consequences for stakeholders addressing PFAS contamination on their sites.

---

1. Salvatore et al., 2022
2. NGWA, n.d.
3. Smalling et al., 2023
4. Andrews & Naidenko, 2020
5. EWG, 2024
6. Scaggs, 2024
7. AWWA, 2023
8. Dagorn, 2023

Understanding PFAS Remediation

The True Definition of Remediation

The Interstate Technology and Regulatory Council (ITRC) defines remediation as:

> *"A process used to reduce or eliminate the risk for humans and the environment that may result from exposure to harmful chemicals.[9]"*

In environmental remediation, the risk to be "reduced or eliminated" is tied directly to chemical exposure and is expressed in equation form as:

PFAS Risk = PFAS Hazard × Potential for Exposure

Remediation eliminates the potential for chemical exposure. This may involve eliminating the hazard or, in many cases, simply containing it – thereby eliminating any routes of exposure.

---

9. ITRC, 2020

How is PFAS Remediated in Groundwater Today?

PFAS cannot be destroyed except under high pressure and temperature conditions using energy-intensive technologies that are infeasible for groundwater remediation. As a result, remediating PFAS in groundwater involves techniques to contain the hazard. When the PFAS hazard is effectively contained, the exposure pathway is incomplete, the risk is removed, and the remediation of PFAS in groundwater is achieved.

~~PFAS Risk~~ = **PFAS Hazard** × ~~Potential for Exposure~~

Two PFAS Remediation Approaches: *Ex Situ* and *In Situ*

> ***By preventing the migration of these chemicals toward human or environmental receptors, both pump-and-treat** (ex situ) **and** in situ **remediation approaches operate under the same principle of hazard containment.***

There are two approaches to remediating PFAS in groundwater. The first approach involves groundwater extraction and above-ground treatment. Known as pump-and-treat, this *ex situ* method employs systems that pump contaminated groundwater to the surface where PFAS contaminants are filtered using granular activated carbon (GAC), ion-exchange resin (IX) sorbents, or physically separated using foam fractionation (FF).

The second approach, *in situ* remediation with colloidal activated carbon (CAC), occurs below ground. These are the only approaches ITRC classifies as 'field implemented', defined as:

> *"technologies that have been demonstrated at multiple sites under diverse conditions, by multiple practitioners, are commercially available, and are well documented in practice or peer-reviewed literature" (ITRC, 2023).*

REGENESIS®

Fallacy and Risks of Pump-and-Treat

Pump-and-treat technologies mechanically pump contaminated groundwater to the surface for aboveground separation treatment and discharge of the treated water. The process contains a PFAS plume, by continually capturing and removing contaminated groundwater. PFAS in the extracted water is treated at the surface using GAC, IX, or FF separation methods, producing waste containing PFAS chemicals now considered 'hazardous substances' under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).[10]

Pump-and-Treat Does Not Restore Contaminated Aquifers

Pump-and-treat was a widely used method for groundwater contamination remediation in the 1980s.[11] It was initially used as a groundwater restoration strategy by attempting to eliminate contaminants such as trichloroethene (TCE) from groundwater by pumping.

> *"...deployed at most US Superfund sites only about 6% reached closure over 40 years, spanning from 1981 to 2020."*

For decades, leading academic researchers, groundwater remediation experts, and the US government have determined this approach to be incapable of achieving cleanup objectives at most sites, which are often based on the EPA's drinking water maximum contaminant levels (MCLs).[12] Indeed, although pump-and-treat systems have been deployed at most US Superfund Sites, only about 6% reached closure over 40 years, spanning from 1981 to 2020.[13]

Remediation in Perpetuity

Contaminants like TCE sorb onto aquifer materials and diffuse into zones of low transmissivity in an aquifer, where they are less mobile and not easily extracted by pumping.[14]

10. Designation of PFOA and PFOS and CERCLA Hazardous Substances-89-FR, 2024
11. Carroll, 2024
12. Mackay and Cherry, 1989; Travis and Doty, 1991; US GAO, 2005; Carroll et al, 2024
13. Carroll et al., 2024
14. NRC, 1994; Chapman and Parker, 2005; Guo et al., 2019

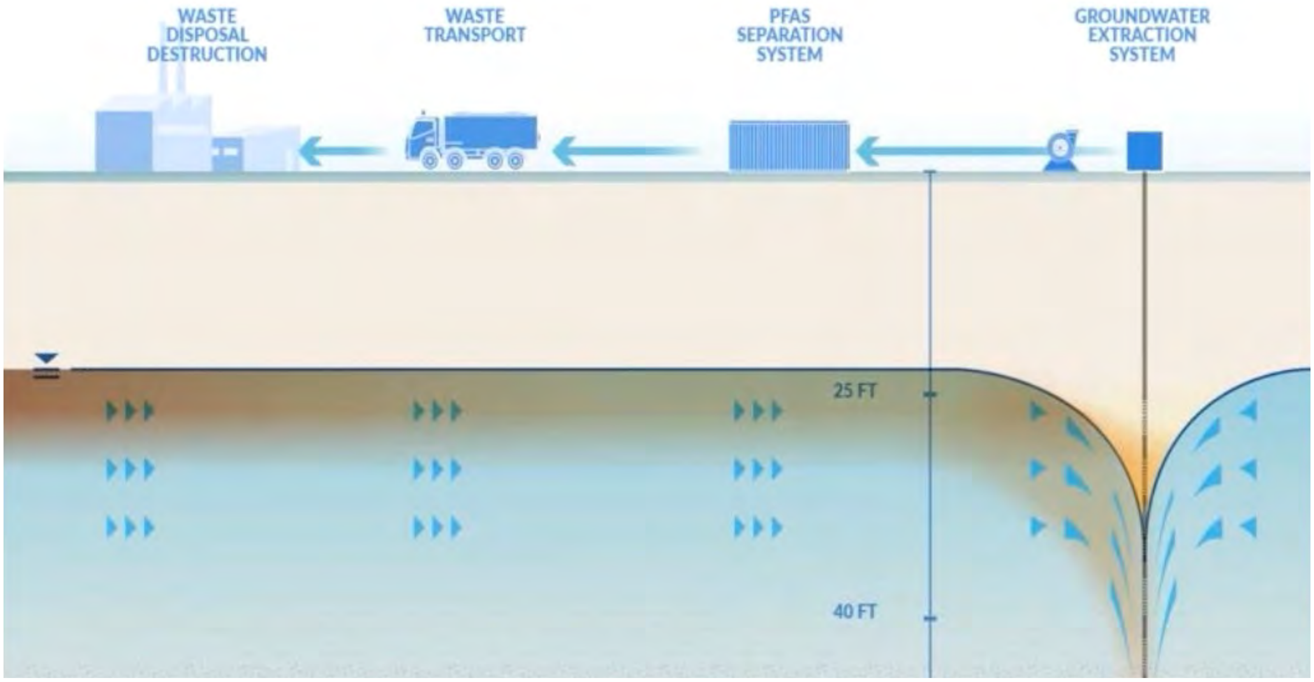


Illustration outlines the *ex situ* pump-and-treat process, ongoing PFAS waste treatment required, and potential risks for transporting PFAS waste offsite as part of the remediation process.

Further, in attempting to remove the contaminants by pumping, surrounding "clean" water is pulled into a contaminant plume. These factors extend the time required to achieve the cleanup goals and increase both the remediation cost and the volume of groundwater treated. Early on, renowned groundwater experts Drs. Doug Mackay and John Cherry described the process as "remediation in perpetuity"[15] while Drs. Travis and Doty stated, "The simple fact is that contaminated aquifers cannot be restored through pumping and treating."[16]

$20 Billion Spent on Remediation at DOD Sites

These sentiments were echoed years later when the US Government Accounting Office, in evaluating the cost-effectiveness concerning $20 billion of remedial expenditures over 10 years at Department of Defense (DOD) sites, reported the following,

"In the past, DOD primarily used pump-and-treat technologies to contain or eliminate hazardous contaminants in groundwater. However, the long cleanup times and high costs of using pump-and-treat technologies often make them expensive and ineffective for groundwater remediation." [17]

More recently, leading environmental academics have proposed, "To reassess our approach to remediation, by recognizing that pump-and-treat, due to its well-documented limitations, often maximizes the generation of contaminated groundwater needing treatment."[18]

15. Mackay and Cherry, 1989
16. Travis and Doty, 1990
17. USGAO, 2005
18. Caroll et al., 2024

If It Didn't Work for TCE, Why Consider It for PFAS?

Due to their recent hazardous waste designation under CERCLA and stringent cleanup criteria established through the Safe Drinking Water Act, PFOA and PFOS are the two compounds that will drive remediation at most PFAS-contaminated sites. Both adsorb more strongly to aquifer solids than TCE, as shown by the following organic carbon coefficient (Koc) values.

- TCE - 94 L/kg[19]
- PFOA - 448 L/kg[20]
- PFOS - 2,380 L/kg[21]

The relative difference in the Koc values suggests PFOA and PFOS will attach to aquifer solids 5x and 25x more strongly than TCE, respectively.

> *USEPA's MCLs for PFOA and PFOS are 1,250 times lower than TCE.*

This higher sorption potential results in a significantly greater amount of water needing to be extracted to flush these contaminants out of the aquifer. Moreover, the USEPA's MCLs for PFOA and PFOS are 1,250 times lower than TCE.

Given these factors, pump-and-treat will not be effective in flushing aquifers free of PFAS. It can only be used for plume containment. But can plume containment using a pump-and-treat approach effectively avoid long-term PFAS risk and liability? Leading environmental experts challenge it won't.[22]

---

19. USEPA, 1996
20. ITRC, 2023
21. ITRC, 2023
22. Hall et al., 2024

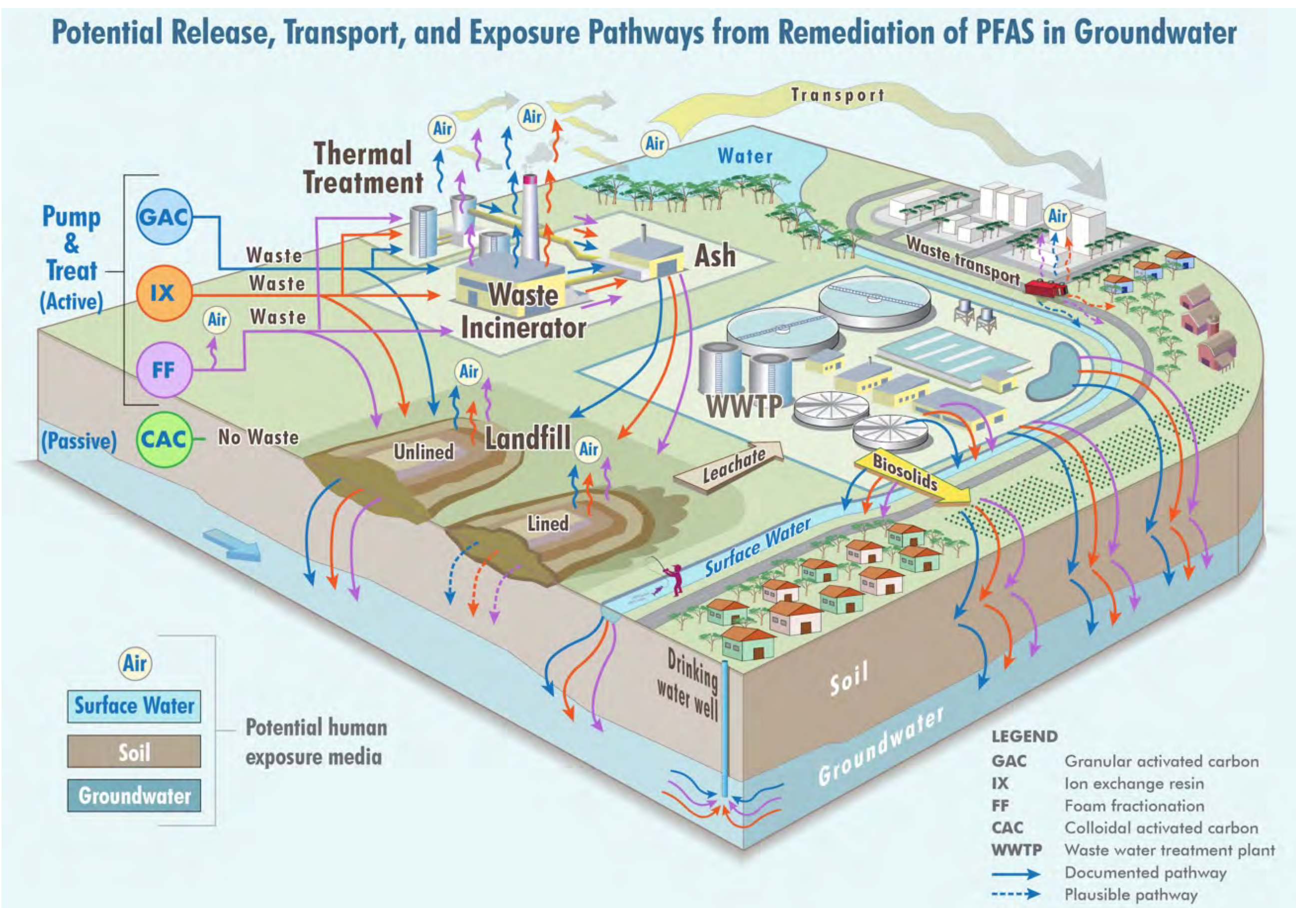
Managing Pump-and-Treat Waste Increases PFAS Exposure Risk and Liability

Pump-and-treat systems for PFAS generate concentrated waste byproducts which must be disposed of or treated. As outlined by Hall et al. (2024), there is potential for accidental release and exposure risk at each stage of the PFAS waste management process, some of which include:

- **Handling** - Direct exposures to personnel handling PFAS waste,
- **Transport** - Potential spills during transport on public roads,
- **Landfill Disposal** - PFAS leaching into groundwater, and
- **Destruction Treatment** - Products of incomplete combustion (PICs) emitted into the air via incineration.[23]

The persistent and hazardous nature of PFAS make them uniquely problematic for pump-and-treat remediation compared to other contaminants. In considering the lifecycle of potential exposures, Hall et al. compare this waste generation to a PFAS Pandora's Box.[24]

These PFAS waste streams and the associated above-ground exposure risks and liabilities, including Strict Liability and Joint and Several Liability under CERCLA, can all be avoided simply by treating the contaminants passively below ground (*in situ*), with colloidal activated carbon (CAC).



Potential release, transport, and exposure pathways from remediation of PFAS in groundwater - Figure reproduced from Hall, et al. (2024).

23. USEPA, 2020
24. Hall et al., 2024

PlumeStop is a liquid, CAC amendment developed for easy injection and subsurface distribution.

In Situ Remediation Using Colloidal Activated Carbon (CAC)

In situ remediation of PFAS applies PlumeStop and SourceStop CAC amendments directly into the subsurface to immobilize PFAS contaminants. These CAC amendments intercept and contain migrating PFAS contaminants moving through groundwater or by soil leaching.

What is Colloidal Activated Carbon?

Colloidal activated carbon or CAC is a patented technology commercially available as PlumeStop, for groundwater plume treatments and SourceStop to address PFAS source areas, respectively. These CAC materials are composed of <2-micron diameter activated carbon particles dispersed in a water-based medium to create a liquid, colloidal form of activated carbon.

How Does It Work?

When injected or mixed into the subsurface, CAC permanently coats the soils and aquifer materials with micron-scale carbon particles. PFAS sorbs much more strongly to CAC than to the native soil organic carbon. Therefore, where CAC is applied, the retardation of PFAS is dramatically increased, typically by multiple orders of magnitude. Groundwater PFAS concentrations are reduced by a corresponding degree, effectively stopping further PFAS plume migration or plume development. As PFAS become adsorbed in a CAC-treated zone, the groundwater seepage velocity remains unchanged.

How is PFAS Remediation Achieved *In Situ*?

CAC is applied directly to the subsurface, within the contaminant flux zones where PFAS are migrating. The CAC coats the aquifer matrix, converting it into a massive purifying filter for PFAS. When PFAS enters the subsurface filter, they are immediately removed from the groundwater, becoming bound to the CAC-coated matrix. The PFAS risk to public health and safety is thereby eliminated, as the exposure pathway to community resources like drinking water and surface water is removed.

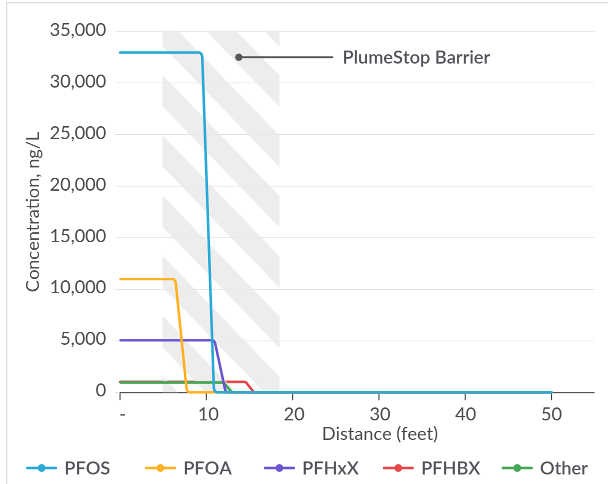
Determining the Amount of CAC Needed to Address Competing Contaminants

The amount of CAC required for each application is modeled based on sorption isotherms for PFAS and co-contaminants, the hydrology, and dynamic sorption processes occurring specific to a proposed treatment zone (e.g., a barrier).

PlumeForce Model Determines CAC Dosing

The PlumeForce™ model for determining CAC dosing is unique in the industry. It is the only model that considers competitive sorption between contaminant species. Additionally, the model applies natural biodegradation rates to the competing organic contaminant species using site-specific or estimated values.

All CAC *in situ* remediation designs account for competing contaminants and natural dissolved phase organic matter in the aquifer. CAC's performance in treating mixed plumes of PFAS and hydrocarbons or PFAS and chlorinated solvents was recently documented by leading modeling expert, Dr. Grant Carey for 17 sites.[25]

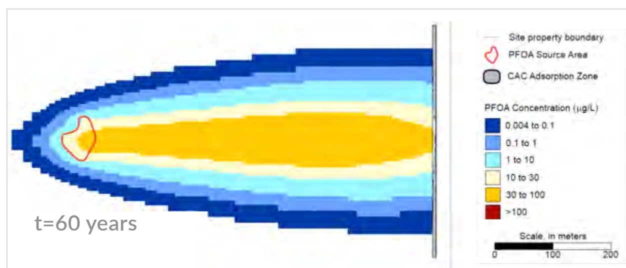


PlumeForce CAC dosing model output showing PFAS competitive sorption effects within a PlumeStop CAC barrier.

How Long Will Treatments Remain Effective?

The treatment longevity question was also addressed in three peer-reviewed modeling studies led by Carey.[26] These studies have consistently predicted that *in situ* remediation with a single injection of CAC can prevent PFAS migration caused by PFAS contaminant releases of aqueous film-forming foams (AFFF).

The most recent study uses data from a high-concentration PFAS site at a military facility to show that a CAC permeable barrier can stop a large advancing PFAS contaminant groundwater plume for over 60 years. In the process, two billion liters of groundwater could be treated to non-detect PFAS levels avoiding pumping and waste generation.[27] If after 60 years, further remediation is required, a simple reinjection would start the clock over again.



Two-dimensional model simulation depicting a PFOA plume in groundwater being contained for 60 years behind a CAC barrier placed at the downgradient plume edge (image produced from Carey, 2024 - Supporting Information).

Treating the Source Can Increase Barrier Longevity

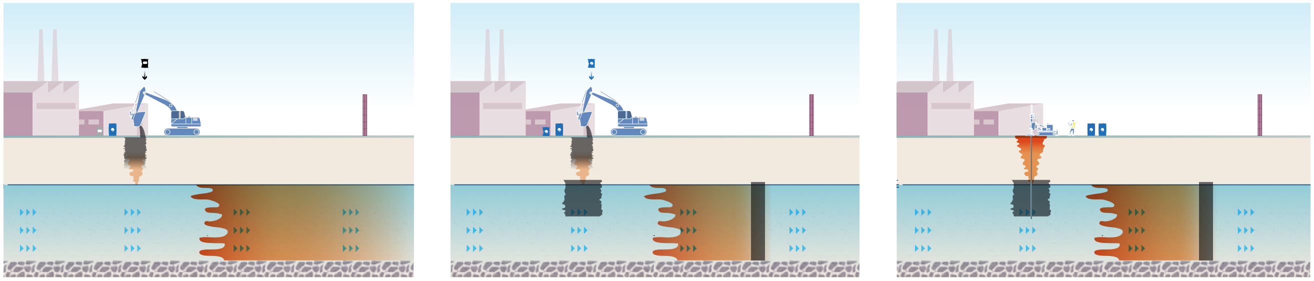
In many cases, longevity of a CAC permeable reactive barrier can be extended by treating the upgradient PFAS source area, which reduces the contaminant concentrations entering the CAC barrier. In such scenarios, a single application of CAC may effectively retard PFAS migration. Even if a breakthrough occurs at some point in the distant future, the contaminant concentration will remain sufficiently low to meet cleanup objectives, essentially mitigating the risk forever. This approach mirrors the 'peak shaving' strategy used by civil engineers in reservoir construction for flood control purposes[28]

---

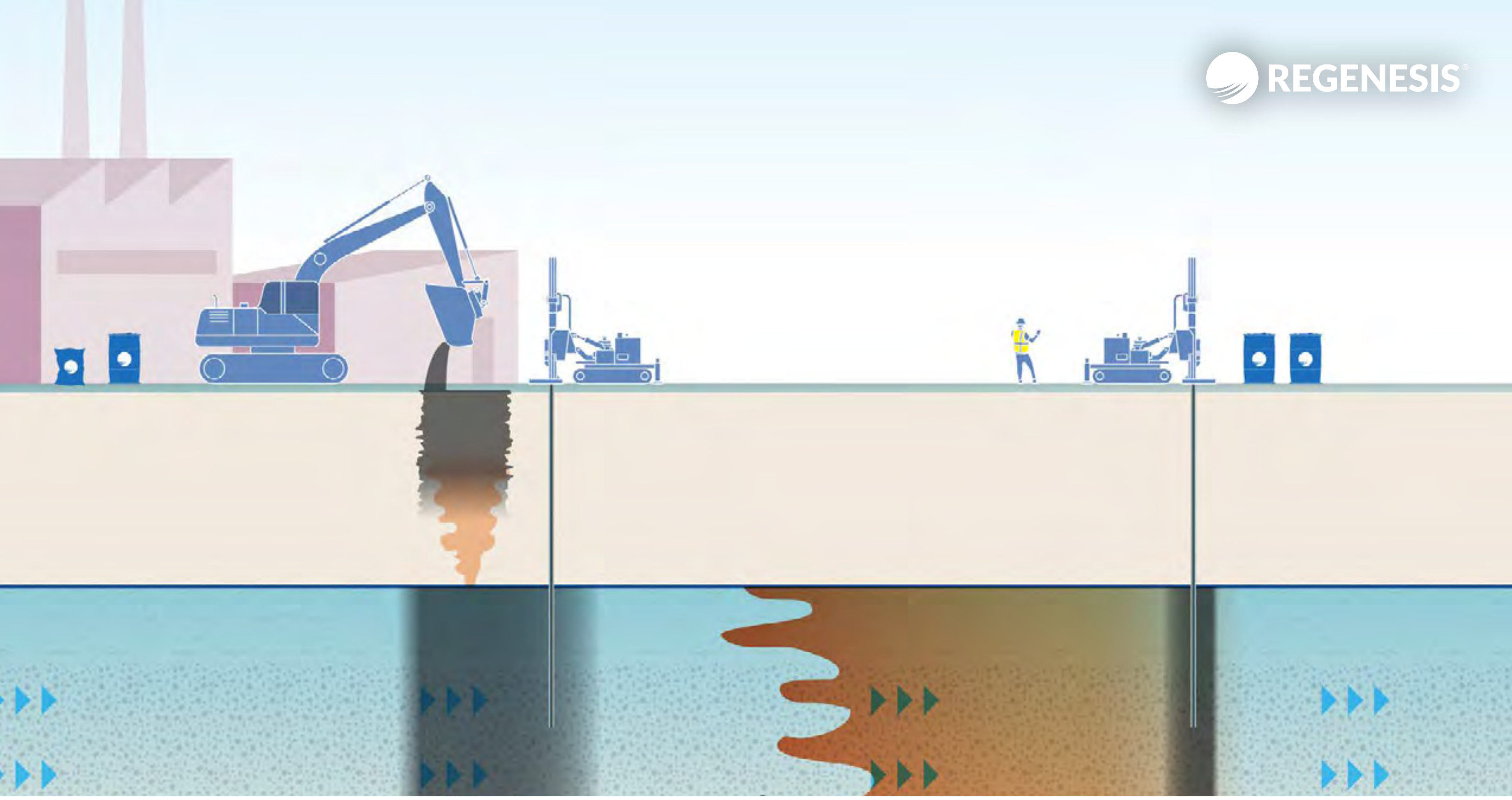
25. Carey, 2022
26. Carey et al., 2019; Carey et al.,2022; Carey et al., 2024
27. Carey et al., 2024
28. Newell, et al., 2022

Remediating PFAS Source Areas Using CAC

Following PlumeStop's success, SourceStop was developed for treating PFAS source areas. Available in liquid and solid forms, SourceStop is applied to the vadose zone, capillary fringe, or the upper saturated zone in source areas to prevent PFAS leaching into groundwater and eliminate continued PFAS influx into the plume body. PFAS source zone treatments using SourceStop have demonstrated effective PFAS leaching prevention in the field.



SourceStop is available in solid and liquid forms. It can be applied to the vadose soils, capillary fringe or groundwater at PFAS source zones.



How Can SourceStop and PlumeStop be Co-Applied to Reduce PFAS Risk Permanently?

PlumeStop and SourceStop can be flexibly applied to contaminated media from the source to the leading edge of a PFAS plume. Different combinations and application techniques for these technologies can be used to address a wide range of contamination scenarios:

- **Media** - Vadose soils, capillary fringe, and groundwater
- **Plume Zones** – Source area, plume body, downgradient plume edge
- **Application Methods** - Injections points/wells, direct mixing, spray-applied barriers, recovery trenches, etc.

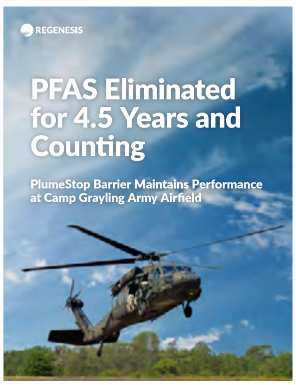
Optimized placement of these materials at strategic locations in the PFAS source-plume system can halt the influx of contaminants into a plume and eliminate further PFAS migration permanently, offering a 'one-and-done' treatment solution to remove PFAS exposure risk.

> **High Versatility:**
> *Different combinations and application techniques for PlumeStop and SourceStop can be used to address a wide range of contamination scenarios.*

In the left image, aqueous film-forming foam (AFFF) containing PFAS is sprayed on an airport runway, causing a PFAS plume to develop in groundwater. In the right image, colloidal activated carbon is applied into the subsurface beneath the release source (SourceStop) and in a downgradient permeable sorptive barrier (PlumeStop) to reduce PFAS to non-detect in groundwater and effectively eliminate PFAS risk caused by the AFFF release.

CAC's Proven Field Performance Record

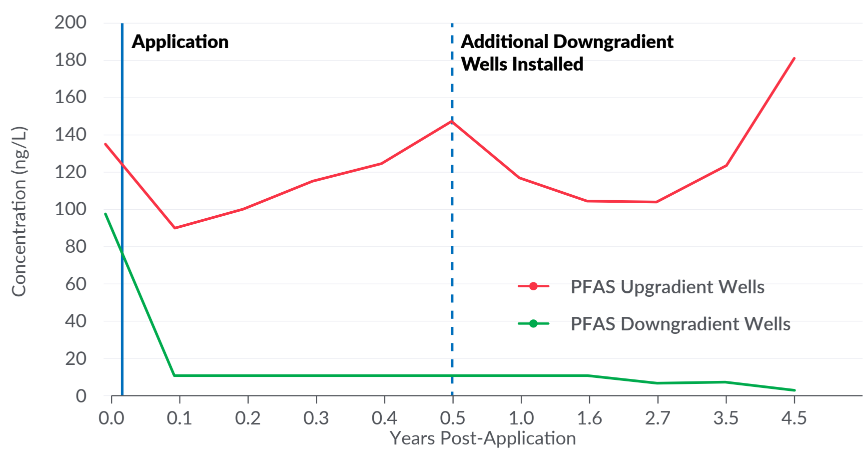
PlumeStop and SourceStop CAC applications have been implemented at over 55 PFAS sites with hundreds more in the evaluation/planning stages. The applications completed to date have demonstrated outstanding performance in eliminating PFAS in groundwater. Full-scale treatments meet the primary project remedial objectives and are predicted by modeling to be effective for decades, including 17 sites where CAC's PFAS treatment performance was reviewed and published in *Remediation* (Carey, 2022). Numerous applications have reduced PFAS to below or near detection levels for multiple years.



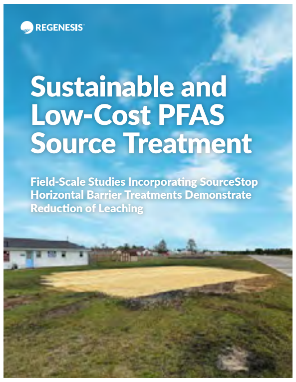
Scan or Click to Read

Case Study: PFAS Eliminated for 4.5 Years at a Former Army Airfield - Camp Grayling Joint Maneuver Training Facility, Michigan

A PlumeStop CAC barrier was installed to remediate PFAS in groundwater resulting from AFFF usage at Camp Grayling Joint Maneuver Training Center in Michigan. The approach was selected due to its low cost, easy implementation, and anticipated rapid results. The barrier eliminated PFAS within 30 days and maintained PFAS concentrations below Michigan Environment, Great Lakes and Energy's (EGLE's) stringent groundwater cleanup standards through 4.5 years of monitoring to date. These reductions have been maintained even as the PFAS concentrations fluxing into it have increased over the past 2 years (REGENESIS, 2023a).



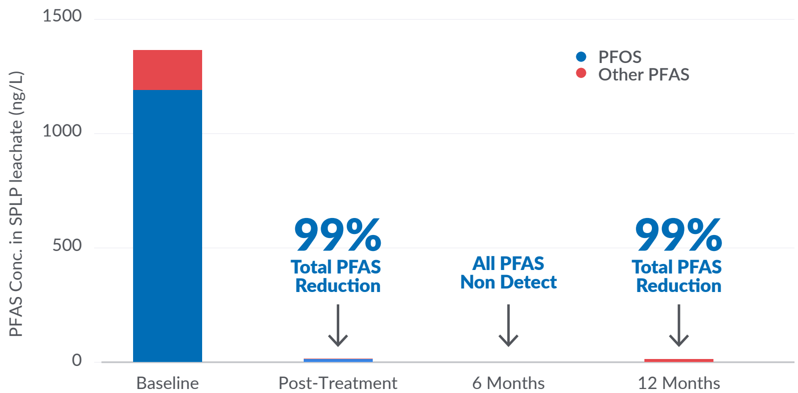
PFAS in upgradient and downgradient well pairs following the PlumeStop application. PFAS reductions are shown as an average of 4 well pairs at 6, 16, 26, and 45 feet downgradient of the barrier.



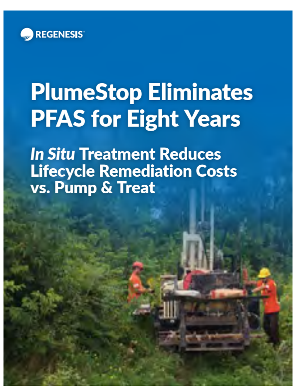
Scan or Click to Read

Case Study: SourceStop Rapidly Eliminates Soil Leaching in PFAS Source Area at Camp Grayling, MI

In situ remediation of PFAS-impacted soils was completed at a fire training source area in a separate area of the Camp Grayling site. The field trial incorporated SourceStop, applied as a horizontal barrier at the bottom of the soil treatment zone. PFAS soil leachate concentrations were reduced by >99% immediately following the application. This result has been maintained through 12 months of monitoring (REGENESIS, 2024).



PFOS (blue) and remaining PFAS concentrations (red) in soil leachate at baseline and post-treatment following source zone treatment and SourceStop horizontal barrier application at Camp Grayling Joint Maneuver Training Center, Grayling, Michigan.



Scan or Click to Read

Case Study: World's First *In Situ* PFAS Treatment Eliminates PFAS for 8+ Years, and Counting

The first known full-scale *in situ* PFAS treatment worldwide was completed in 2016 at a manufacturing and former firefighting training site in Ontario, Canada. (McGregor, 2018). PlumeStop was injected into the PFAS source zone where AFFF releases had occurred. Within the first sampling event (3 months post-application), concentrations were reduced to non-detect levels. These reductions have been maintained for more than 8 years thus far (REGENESIS, 2023b).

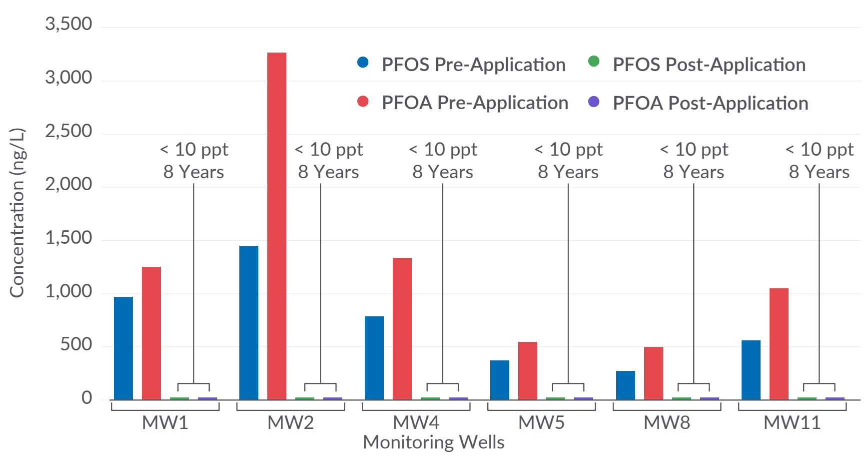
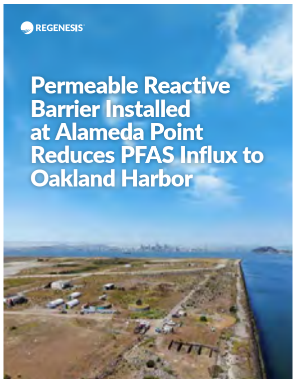


Chart showing six monitoring wells within the treatment zone maintaining complete removal of PFOA and PFOS in groundwater for eight years thus far.

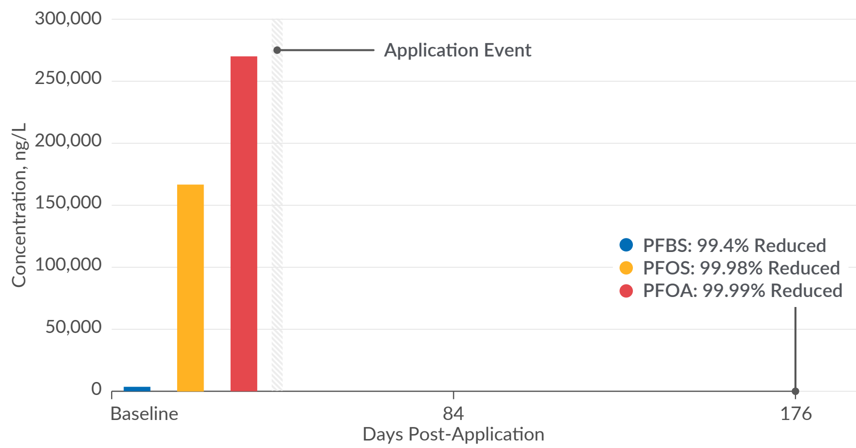
REGENESIS®



Scan or Click to Read Article

Case Study: PlumeStop CAC Barrier Eliminates PFAS by >99% at former Naval Air Station, Preventing Further Impacts on Estuary

AFFF was discharged as part of routine firefighting training exercises at a former Naval Air Station, causing PFAS contamination in groundwater, which flowed into a nearby estuary. A 720-ft-long PlumeStop barrier was installed parallel to the shoreline to prevent further PFAS migration. Following the application, concentrations of the PFAS (PFOS, PFOA, and PFBS) were reduced by 99.4% to 99.99% in the monitoring wells installed in the barrier through six months of monitoring to date. Substantial reductions have also been observed in monitoring wells installed downgradient of the barrier.



In Situ PFAS Remediation Benefits

In situ remediation of PFAS with CAC offers numerous benefits and advantages compared to pump-and-treat.

- **Low Cost** - *In situ* remediation is a significantly lower-cost alternative, less than ⅓ the cost of pump-and-treat alternatives based on cost comparisons of the technologies on actual sites.
- **Speed** - Applications are usually completed within a few days to weeks.
- **No Maintenance** - No operation and maintenance (O&M) inspections are needed.
- **Decarbonizing** - With no external power supply required, the carbon footprint is reduced by 98%.
- **Resilient** - The technology is not subject to operational downtime due to power outages or extreme weather events.
- **Warranted Performance** - A 10-year system warranty is included, with optional extended terms, up to 30 years.

RAMBOLL

Lifecycle Assessment Case Study: *In Situ* PFAS Treatment is ⅓ the Cost, Reduces Carbon Emissions by >98%, Compared to Pump-and-Treat

Ramboll, a global environmental and sustainability consultancy, conducted a full Lifecycle Assessment on a PFAS groundwater remediation project in the United Kingdom. The Lifecycle Assessment found that the PlumeStop barrier implemented at the site was a mere ⅓ the cost and reduced greenhouse gases by 98% compared to pump-and-treat. In addition, the approach avoids:

- Pumping, treating, and discharging >200 million gallons of water
- Disposing of up to 790,000 lbs of PFAS-saturated GAC filtration waste
- 60 operations & maintenance (O&M) inspections and reporting
- Permanent infrastructure, and system downtime (Ramboll, 2023).

The PlumeStop CAC barrier has successfully remediated 5,000,000 gallons of PFAS-contaminated groundwater in its first year of operation, meeting the site risk-reduction goals.

15-Year Lifecycle Assessment Parameter (post-commissioning)	Belowground Filtration with PlumeStop CAC	Pump-and-Treat
Groundwater pumping and effluent discharge	0-gal	208,000,000-gal
Energy usage	0-kwH	960,000-kwH
Carbon dioxide emissions	0 tons	2,400 to 4,300 tons
Quarterly O&M inspections and reports	0	60
Permanent infrastructure, including eight extraction wells, pumps, tanks/vessels, piping and utilities	No	Yes
System operational downtime	0 percent	Estimated 5%

Life Cycle Assessment for PFAS Groundwater Plume Containment Options at a UK Airport Site. Note that Option 2 considers separation treatment with either GAC or foam fractionation.

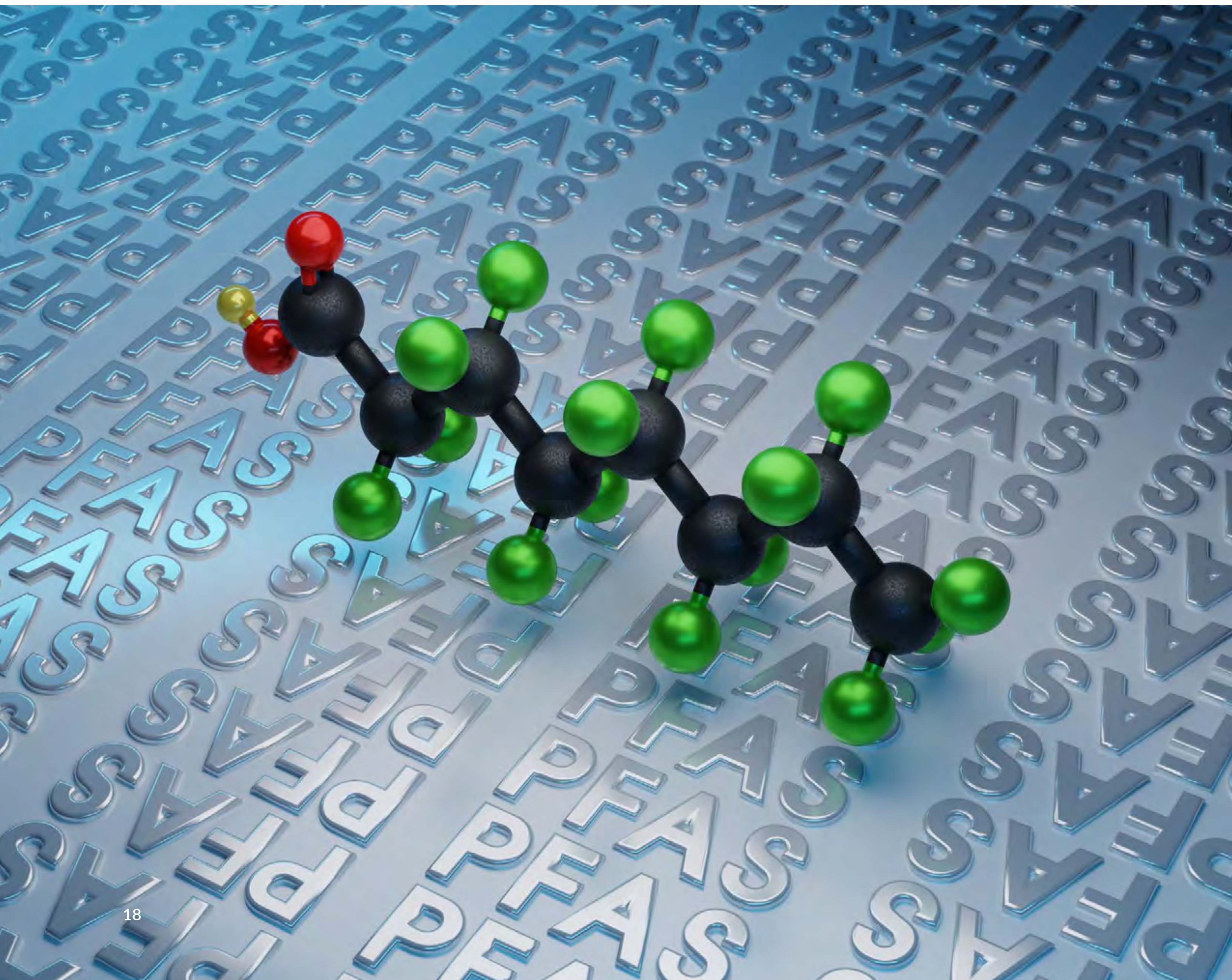
What are the Limitations of *In Situ* PFAS Remediation Using CAC?

CAC sorbs all PFAS to some degree. However, short-chain, hydrophilic species like PFBA will break through a CAC-treated zone faster than PFOA and PFOS-the two compounds that will drive remediation at most sites.

Short-chain PFAS species have higher clean-up standards than PFOA and PFOS and are generally present at lower concentrations in groundwater plumes. Most often, these compounds will not require groundwater remediation.

Despite the many advantages of remediating PFAS *in situ*, there are a few scenarios where the approach may be limited or inappropriate to achieve site-specific risk reduction goals, including the following.

- Mixed plumes with lots of hydrophobic competitors (e.g. landfill leachate),
- Extremely rapid-moving plumes in clean aquifer media (e.g. washed cobbles), and
- Deep plumes where installation costs become prohibitive.



REGENESIS®

Field Applications and Ongoing DOD Research Projects

To date, *in situ* remediation of PFAS with CAC has been applied at over 55 sites in eight countries spanning four continents. Additionally, numerous laboratory and field research projects examining various technical aspects of this innovative treatment method have been or are being conducted through the US Department of Defense's Strategic Environmental Research and Development Program (SERDP) and Environmental Security and Technology Certification Program (ESTCP) (SERDP/ESTCP, n.d.).

Furthermore, as DOD remediation projects begin to move forward under CERCLA, the US Congress House Appropriations Committee has directed the Department to prioritize *in situ* remediation to eliminate PFAS risk on its sites, per the following language attached to its 2024 DOD spending bill:

> ***"...the Committee understands that existing technologies, such as* in situ *treatment, have been evaluated and proven effective by the Environmental Protection Agency. The Committee is therefore disappointed that the Department has not begun to employ these technologies in lieu of costly and inefficient techniques. The Committee directs the Secretary of Defense and Service Secretaries to prioritize the utilization of proven PFAS groundwater and soil remediation and mitigation technologies that eliminate the PFAS risk to human health and the environment in the most cost-effective and energy-efficient manner."***

— (U.S. Congress, 2023, p. 59)

President Biden signed the DOD funding bill for Fiscal Year 2024 into law in March 2024.

SERDP/ESTCP Project Title	Project Start	Project Number	Principal Investigator
Validation of Colloidal Activated Carbon for Preventing the Migration of PFAS in Groundwater	2020	ER20-5182	**Paul Hatzinger** APTIM
An Investigation of Factors Affecting *In Situ* PFAS Immobilization by Activated Carbon	2021	ER21-3959	**Matt Vanderkooy** Geosyntec
Impacts of Particulate Carbon Amendments on Fate of Chemicals of Concern in Groundwater	2021	ER21-1130	**Charles Werth** UT Austin
Assessment of Long-Term Effectiveness of Particulate Amendments for *In Situ* Remediation of PFAS in Mixed Plumes	2021	WE21-1124	**Charles Schaefer** CDM Smith
Influence of Particulate Amendments on TCE Reductive Dechlorination in the Presence of PFAS: Laboratory and Field Studies	2021	ER21-1274	**Peter Grathwohl** University of Tuebingen
Dynamic Interactions between Sorption and Biodegradation: Implications for Long-Term Performance of Activated Carbon-Based Technology for *In Situ* Groundwater Remediation of Chlorinated Solvents	2021	ER21-1224	**Dimin Fan** Geosyntec

List of SERDP/ESTCP research projects studying *in situ* remediation of PFAS using CAC.

Conclusion

The USEPA's recently imposed regulatory changes, including designating PFOS and PFOA as hazardous substances under CERCLA and finalizing the National Drinking Water Primary Regulations for six PFAS under the Safe Drinking Water Act, will require responsible parties to address PFAS contamination. The available options to remediate these contaminants involve *ex situ* mechanical pump-and-treat systems or *in situ* remediation. Both approaches contain PFAS plumes from migrating, thereby preventing exposure risk, however, *in situ* remediation has several important advantages, including the following:

- **Zero waste** - *In situ* remediation using PlumeStop and SourceStop CAC technologies avoids generating waste containing 'forever chemicals' that persist in environmental media and bioaccumulate in humans and animals. Waste generation is an unavoidable feature of pump-and-treat approaches, creating new avenues of potential exposure and long-term liabilities under CERCLA.
- **Low cost** - Remediating PFAS in groundwater at a global scale will be extraordinarily costly. *In situ* remediation of PFAS will help alleviate this cost burden. It has proven to be less than 1/3 the cost of pump-and-treat.
- **Easy implementation with no ongoing O&M** - *In situ* treatments are easier and faster to implement and require no ongoing O&M.
- **Proven rapid and long-term effectiveness** - As demonstrated through numerous case studies, *in situ* remediation rapidly achieves stringent cleanup goals and maintains these goals over the long term.
- **Sustainable and resilient** - *In situ* remediation drastically reduces energy consumption/carbon emissions and is resilient to power disruptions and other environmental factors.

Considering these benefits, *in situ* remediation with PlumeStop and SourceStop will emerge as the only logical solution to prevent PFAS exposure risk at many impacted facilities. This approach is poised to quickly become the go-to option for site owners, responsible parties, and consulting engineering firms managing historical PFAS releases.

References

1. Andrews, D. Q., & Naidenko, O. V. (2020). Population-Wide Exposure to Per- and Polyfluoroalkyl Substances from Drinking Water in the United States. Environmental Science & Technology Letters, 7(12), 931–936. https://doi.org/10.1021/acs.estlett.0c00713

2. Black & Veatch for American Water Works Association (AWWA). (2023, March 7). WITAF Technical Memorandum: PFAS National Cost Model Report. Retrieved from https://www.awwa.org/Portals/0/AWWA/Government/2023030756BVFinalTechnicalMemoradum.pdf?ver=2023-03-14-102450-257

3. Carey GR, McGregor R, Pham ALT, Sleep B, Hakimabadi SG. (2019). Evaluating the longevity of a PFAS *in situ* colloidal activated carbon remedy. Remediation, 29(2):17-31. https://doi.org/10.1002/rem.21593

4. Carey GR, Hakimabadi SG, Singh M, et al. (2022). Longevity of colloidal activated carbon for *in situ* PFAS remediation at AFFF-contaminated airport sites. Remediation, 33(1):3-23. https://doi:10.1002/rem.21741

5. Carey, GR, Anderson, RH, Van Geel, P, et al. (2024). Analysis of colloidal activated carbon alternatives for *in situ* remediation of a large PFAS plume and source area. Remediation, 34, e21772. https://doi.org/10.1002/rem.21772

6. Carroll, et al. (2024). Rethinking pump-and-treat remediation as maximizing contaminated groundwater. Science of The Total Environment, 918, 170600. https://www.sciencedirect.com/science/article/abs/pii/S0048969724007381

7. Chapman, S. W., & Parker, B. L. (2005). Plume persistence due to aquitard back diffusion following dense nonaqueous phase liquid source removal or isolation. Water Resources Research, 41(12). Report W12411. https://doi.org/10.1029/2005WR004224

8. Dagorn, G., et al. (2023, February 23). 'Forever pollution': Explore the map of Europe's PFAS contamination. Le Monde. https://www.lemonde.fr/en/les-decodeurs/article/2023/02/23/forever-pollution-explore-the-map-of-europe-s-pfas-contamination_6016905_8.html

9. Designation of Perfluorooctanoic Acid (PFOA) and Perfluorooctanesulfonic Acid (PFOS) as CERCLA Hazardous Substances, 89 Fed. Reg. 39124 (May 8, 2024). https://www.federalregister.gov/documents/2024/05/08/2024-08547/designation-of-perfluorooctanoic-acid-pfoa-and-perfluorooctanesulfonic-acid-pfos-as-cercla-hazardous

10. Environmental Working Group (EWG). (May 2024). New EPA data confirm widespread 'forever chemicals' in drinking water. https://www.ewg.org/news-insights/news-release/2024/05/new-epa-data-confirm-widespread-forever-chemicals-drinking-water

11. Guo, Z., Brusseau, M. L., & Fogg, G. E. (2019). Determining the long-term operational performance of pump-and-treat and the possibility of closure for a large TCE plume. Journal of Hazardous Materials, 365, 796-803. https://doi.org/10.1016/j.jhazmat.2018.11.057

12. Hall, L. C., Wilson, J. T., & Birnstingl, J. G. A. (2024). Pandora's PFAS box: Life cycle exposure considerations of treatment options for PFAS in groundwater. Remediation, 34, e21775. https://doi.org/10.1002/rem.21775

13. Interstate Technology and Regulatory Council (ITRC). (2020, February 25). PFAS Remediation [Video]. YouTube. https://www.youtube.com/watch?v=2OEeJ9qR9nA

14. Interstate Technology and Regulatory Council (ITRC). (2023). PFAS Technical and Regulatory Guidance Document. https://pfas-1.itrcweb.org/

15. Mackay, D.M., & Cherry, J.A. (1989). Groundwater contamination: pump-and-treat remediation. Environmental Science & Technology, 23, 630-636. https://www.semanticscholar.org/paper/Groundwater-contamination%3A-pump-and-treat-Mackay-Cherry/373168775c95b56b31849f9c89e47a1a078ef47b

16. McGregor R. (2018). *In Situ* treatment of PFAS-impacted groundwater using colloidal activated carbon. Remediation. 28(3):33-41. https://doi.org/10.1002/rem.21558

17. National Groundwater Association (NGWA) (n.d.) Groundwater | Facts about Global Groundwater Usage

18. National Research Council. 1994. Alternatives for Ground Water Cleanup. Washington DC: The National Academies Press. doi: 10.17226/2311 https://nap.nationalacademies.org/read/2311/chapter/1

19. Newell, C. J., Javed, H., Li, Y., Johnson, N. W., Richardson, S. D., Connor, J. A., & Adamson, D. T. (2022). Enhanced attenuation (EA) to manage PFAS plumes in groundwater. Remediation, 32, 239–257. https://doi.org/10.1002/rem.21731

20. Ramboll. (2023). Sustainability Assessment of *In Situ* and *Ex Situ* Remediation of PFAS Contaminated Groundwater [PDF Document]. https://regenesis.com/wp-content/uploads/2019/12/Sustainability-Case-study-PlumeStop-vs-PT-Final.pdf

21. REGENESIS. (2023a). Case Study: PFAS Eliminated for 4.5 Years and Counting. https://regenesis.com/en/project/pilot-test-conducted-to-remove-pfas-risk/

22. REGENESIS. (2023b). Case Study: PlumeStop Eliminates PFAS for Seven Years. https://regenesis.com/en/project/breakthrough-treatment-for-pfas/

23. REGENESIS. (2024). Case Study: Sustainable and Low-Cost PFAS Source Treatment. https://regenesis.com/en/project/sustainable-and-low-cost-pfas-source-treatment/

24. Rep. Calvert, Ken [R A 3. Text - H.R.4365 - 118th Congress (2023-2024): National Defense Authorization Act for Fiscal Year 2024. Published July 14, 2023. Accessed July 25, 2023. http://www.congress.gov/bill/118th-congress/house-bill/2670/text

25. Salvatore D, Mok K, Garrett KK, et al. Presumptive Contamination: A New Approach to PFAS Contamination Based on Likely Sources. Environmental Science & Technology Letters. Published online October 12, 2022. https://doi:10.1021/acs.estlett.2c00502

26. Scaggs, Alexandra. Anything can be a PFASt-growing industry. Financial Times. (January 24, 2024). https://www.ft.com/content/cf9a2df4-49bd-4c00-8e71-cf192563df0f

27. Smalling, K. L., Romanok, K. M., Bradley, P. M., Morriss, M. C., Gray, J. L., Kanagy, L. K., Gordon, S. E., Williams, B. M., Breitmeyer, S. E., Jones, D. K., DeCicco, L. A., Eagles-Smith, C. A., & Wagner, T. (2023). Per- and polyfluoroalkyl substances (PFAS) in United States tapwater: Comparison of underserved private-well and public-supply exposures and associated health implications. Environment International. 178, 108033. https://doi.org/10.1016/j.envint.2023.108033

28. Strategic Environmental Research and Development Program (SERDP) and Environmental Security and Technology Certification Program (ESTCP) (n.d.). Per- and Polyfluoroalkyl Substances & Aqueous Film-Forming Foam. (n.d.). https://serdp-estcp.mil/focusareas/e18ec5da-d0de-47da-99f9-a07328558149/pfas-afff

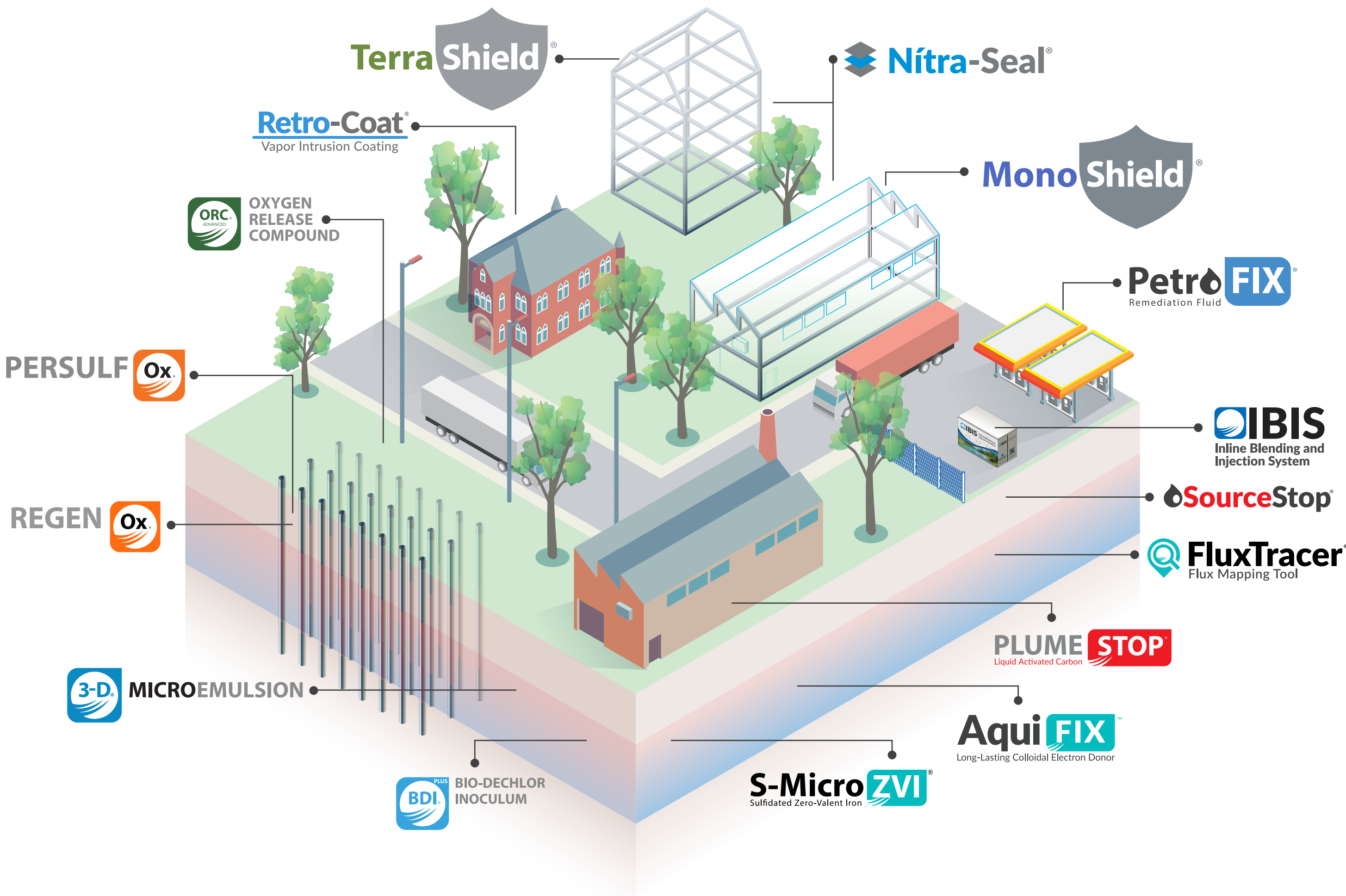
29. Travis, C. C., & Doty, C. B. (1990, October). Can contaminated aquifers at Superfund sites be remediated? Environmental Science & Technology, 24(10), 1464-1466. https://doi.org/10.1021/es00080a600

30. U.S. Congress. (2023, October 16). H.R.4365 - 118th Congress (2023-2024): Department of Defense Appropriations Act, 2024. Congress.Gov | Library of Congress. https://www.congress.gov/bill/118th-congress/house-bill/4365

31. US Environmental Protection Agency (USEPA). (1996). Soil Screening Guidance: User's Guide. Publication 9355.4-23. EPA/540/R-96/018. July 1996. Appendix K – Soil Organic Carbon (Koc) / Water (Kow) Partition Coefficients. https://semspub.epa.gov/work/HQ/175223.pdf

32. US Environmental Protection Agency (USEPA). (2020). Interim Guidance on the Destruction and Disposal of Perfluoroalkyl and Polyfluoroalkyl Substances and Materials Containing Perfluoroalkyl and Polyfluoroalkyl Substances (Technical Brief, p. 2). https://www.epa.gov/sites/default/files/2019-09/documents/technical_brief_pfas_incineration_ioaa_approved_final_july_2019.pdf

33. U.S. Government Accountability Office (US GAO). (2005). Groundwater Contamination: DOD Uses and Develops a Range of Remediation Technologies to Clean Up Military Sites, GAO 05-666. Accessed February 21, 2023. https://www.gao.gov/products/gao-05-66



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.

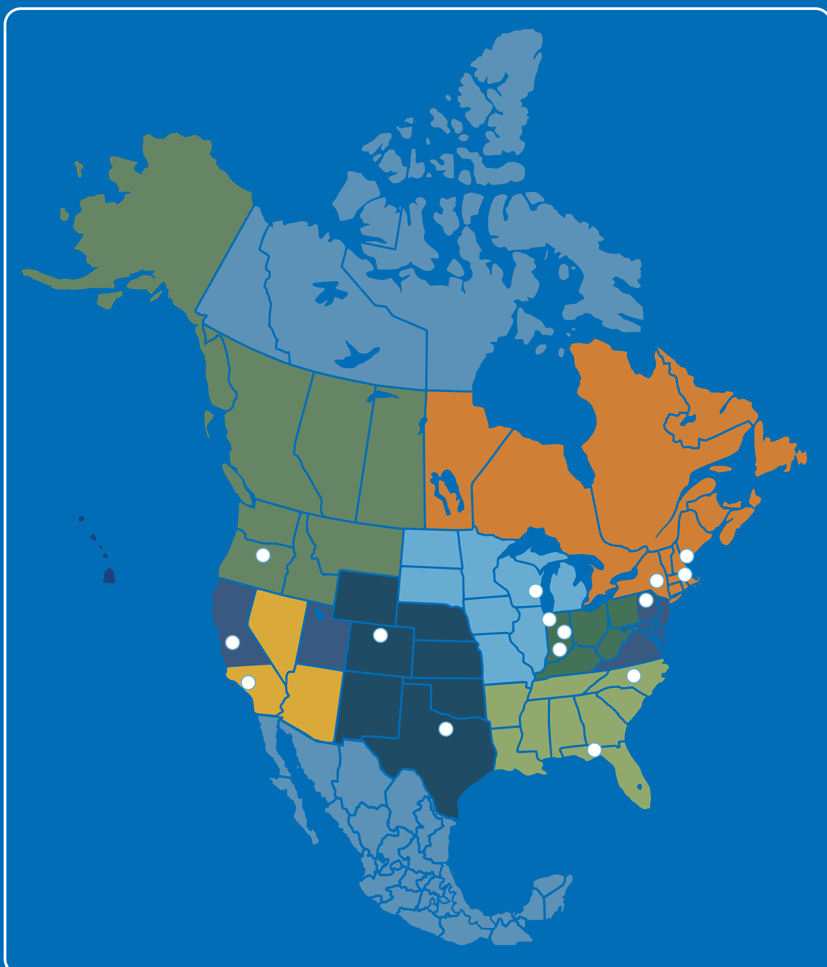
Inherently, innovation imparts new and better ways of thinking and doing. For us, this means delivering expert environmental solutions in the form of the most advanced and effective technologies and services available today.

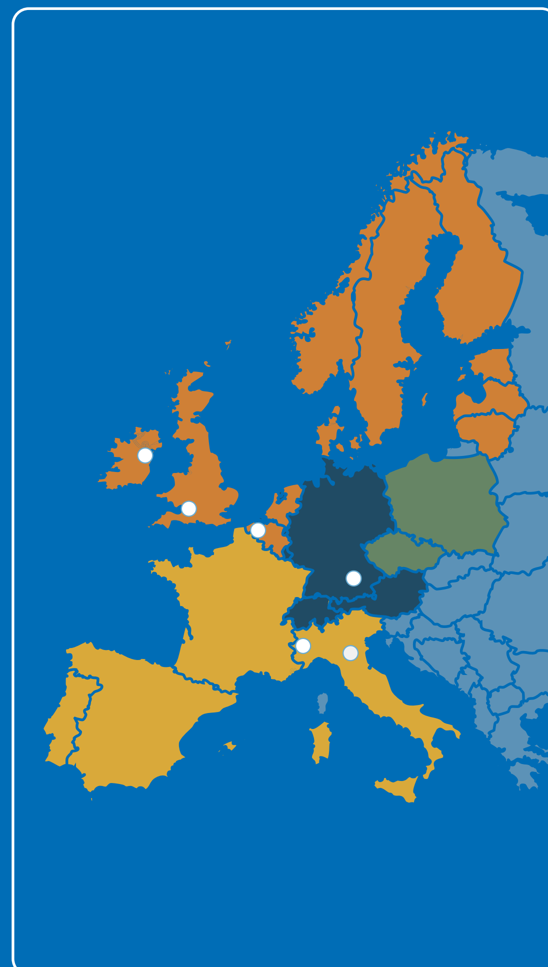
We value expertise, both our customers' and our own. We find that when our experienced staff collaborates directly with customers on complex problems, there is a high potential for success including savings in time, resources and cost.

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





Global Headquarters

1011 Calle Sombra
San Clemente, CA 92673 USA

Ph: (949) 366-8000
Fax: (949) 366-8090

Europe

Bath, United Kingdom
Ph: +44 (0) 1225 61 81 61

Dublin, Ireland
Ph: +353 (0) 9059 663

Torino, Italia
Ph: +39 338 8717925

Ieper, België
Ph: +32 (0) 57 35 97 28

REGENESIS®
www.REGENESIS.com