REGENESIS®

7 REASONS

to Consider an *In Situ* Permeable Reactive Barrier to Treat Groundwater Contaminants

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Why Implement an I-PRB?

In Situ-Permeable Reactive Barriers (I-PRBs) are permeable treatment zones designed to passively intercept and treat contaminated groundwater. They are called permeable because, unlike traditional barriers such as sheet piling (i.e. Waterloo Barriers) slurry walls (i.e. cement and bentonite), they allow water to flow through while treating dissolved-phase contaminants.

> ***In Situ Permeable Reactive Barriers (I-PRBs) are permeable treatment zones designed to passively intercept and treat contaminated groundwater.***

If designed intelligently and installed correctly, I-PRBs can be a highly cost-effective and customizable remediation tool that environmental practitioners can use to achieve cleanup goals.

#1 I-PRBs Can Last a Long Time

Because I-PRBs are often used to mitigate plumes that may remain persistent for years and even decades, longevity is a primary concern. I-PRBs generally function by intercepting a groundwater contaminant plume through the hydraulic capture and transformation of those contaminants to less toxic or mobile constituents. The longevity of an I-PRB refers to its ability to effect hydraulic capture with sufficient residence time for the desired reactions to take place. With many long-term remedial solutions, performance tends to degrade over time, and if the material in the I-PRB loses sufficient performance, then it will likely fail.

There are a wide variety of I-PRB materials an environmental professional can consider when designing the best solution for a site. By selecting the right treatment approach and taking into account parameters such as groundwater velocity and contaminant flux, an environmental professional can design an I-PRB that will remain active in the subsurface for a long time, which is crucial to achieving site goals, whether preventing off-site migration, protecting sensitive receptors, or dealing with back-diffusion.

> ***"I-PRB's are a smart solution when longevity and reducing risk to sensitive receptors are concerns."***

Let's start with I-PRB material options that operate based on biological mechanisms. Oxygen releasing compounds such as REGENESIS' ORC Advanced® can last up to a year while, under the right circumstances, a I-PRB constructed with slow-release electron donors such as Hydrogen Release Compound (HRC®) and 3-D Microemulsion® (3DME) have proven to remain active for up to five years in the subsurface.

For even longer lasting I-PRBs, environmental professionals are turning to PlumeStop® a micron-scale colloidal activated carbon, and S-MicroZVI®, a sulfidated zero valent iron (ZVI).

PLUME STOP
Liquid Activated Carbon

PlumeStop® Liquid Activated Carbon™ is a fast-acting groundwater remediation reagent which captures and biodegrades a range of contaminants.

S-Micro ZVI™
Sulfidated Zero-Valent Iron

S-MicroZVI® is an *In Situ* Chemical Reduction (ISCR) reagent that promotes the destruction of many organic pollutants and is most commonly used with chlorinated hydrocarbons.

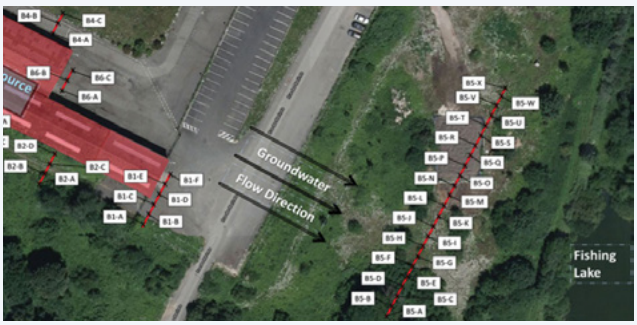
These compounds work to remove contaminants either through enhanced reductive dechlorination, transformation involving chemical reactions, or sequestration involving adsorption, reduction, and co-precipitation.

While native dissolved constituents in groundwater can reduce the hydraulic and reactive performance of traditional PRBs over time, I-PRBs constructed with PlumeStop and S-MicroZVI are designed to last for over ten years and beyond.

PlumeStop is a very fine suspension of charged particles enhanced with a proprietary dispersant to prevent clumping of activated carbon that can be injected directly into the subsurface. Once installed, carbon particles disperse and diffuse, adhering to the surface of soil particles, and converting a contaminated aquifer into a purifying filter.

Case Study:
I-PRB Protects Nearby Fishing Lake at Metal Fabrication Works in Eastern France

On an active metal fabrication works in Eastern France, perchloroethylene (PCE) from historic leaks and spillages at the facility were moving through a fast-flowing sand aquifer and migrating off site towards a nearby fishing lake. In order to minimize disturbance to site operations and protect sensitive receptors, the consultant elected to install a series of six barriers placed perpendicular to the flow of the groundwater.



This reduced the total number of injection points required while still ensuring complete site coverage, as groundwater transported the contaminants of concern to the barriers for treatment. Following the application of 3D Microemulsion (3DME) and Hydrogen Release Compound (HRC), a rapid reduction in PCE was seen in all wells downgradient of the barriers across the entire site. Within five months, PCE was at non-detect. The installation work was completed in 15 days while the treatment is expected to last for several years.

PlumeStop works by capturing target contaminants via sorption. Once sorbed, the contaminants can be consumed by the local microbial community (or microbial amendments), freeing up sorption sites for further remediation. Crucial to its performance, PlumeStop does not lose significant sorptive capacity over time, making it a viable long-term solution.

Case Study:
I-PRB Treats PFAS at Former Fire Fighting Training Site

At a former furniture facility in Ontario, Canada that had also been used as a fire training area, groundwater had been impacted by PFAS from Aqueous Film Forming Foams (AFFF). PlumeStop was installed as a barrier to prevent off-site migration and proved to be very effective, reducing almost all PFAS compounds to below detection limits. Post-application modeling indicates that the barrier will be effective for decades following the initial application.[1]

[1] Read the full article here:
http://www2.regenesis.com/pfas-wiley-article

By maintaining its ability to capture contaminants and by creating an environment where biological degradation can flourish, a single application of PlumeStop can remain functional for an indefinite period of time.

While historically ZVI barriers can also last for years to decades (depending on groundwater chemistry, contaminant flux, and other factors), recent advancements in ZVI technology have only served to enhance its longevity. Typically, ZVI treatment efficiency is reduced when the amendment reacts with water, resulting in surface corrosion that limits reaction between ZVI and target contaminants. S-MicroZVI is a colloidal sulfidated ZVI product in which ZVI particles are surface-treated with a reduced sulfur species. Sulfidated iron inhibits the reaction between unmodified ZVI and water, which extends the longevity of the amendment.

Bench studies were performed comparing unsulfidated ZVI with S-MicroZVI. Samples were spiked with PCE six times over a period of 42 days and observed. After approximately 2 weeks, PCE began to accumulate in the samples containing unsulfidated-ZVI while S-MicroZVI retained its reactivity for the duration of the experiment. ***After 42 days, it was observed that 58% of PCE had been removed by the unsulfidated ZVI while the S-MicroZVI removed 92%.*** The results of this study indicate that while both unsulfidated ZVI and S-MicroZVI can degrade PCE, the S-MicroZVI demonstrated both greater reactivity and longevity.

With longevity ranging from years to decades, I-PRBs can be a very effective solution for long-term plume management.

#2 I-PRBs Can Treat a Wide Range of Contaminants

> ***Zero valent iron (ZVI), can effectively treat a number of chlorinated solvents including PCE, TCE, and carbon tetrachloride, along with heavy metals such as chromium, lead, copper, zinc, and uranium and nitroaromatic compounds (NACs).***

First used in the early 1990s by the University of Waterloo at the famed Borden Aquifer, PRBs consisted of an excavated area filled with a mixture of granular iron and sand to treat chlorinated ethenes. Since then, the technology has continued to evolve with novel construction techniques and innovative new amendments that have expanded the list of treatable contaminants.

The types of contaminants that an I-PRB can treat depends on the amendment used in its construction. Each amendment utilizes different methods for contaminant removal with the primary options being:

- **Sorption and precipitation**
- **Chemical reaction**
- **Biological mechanisms**

In a traditional PRB, one of the most commonly used fill materials is zero valent iron (ZVI), a reductant that can effectively treat chlorinated solvents such as tetrachloroethene (PCE), trichlorothene (TCE), and carbon tetrachloride, heavy metals such as chromium, lead, copper, zinc, and uranium, as well as nitroaromatic compounds (NACs) such as nitrobenzene and 2,4,6-trinitrotoluene (TNT).

These contaminants listed can also be treated using biological additives such as 3DME and HRC which are controlled-release electron donors that stimulate anaerobic degradation *in situ*.

Aerobically treatable compounds such as BTEX (benzene, toluene, ethylbenzene, and xylene), polyaromatic hydrocarbons (PAHs), and other petroleum hydrocarbons (TPH) can be treated both biologically (using oxygen releasing compounds such as ORC Advanced), or through innovative sorptive technologies such as PlumeStop.

> ***PlumeStop can also be used to treat emerging contaminants of concern such as per- and polyfluoralkyl substances (PFAS).***

PlumeStop can rapidly remove a wide variety of contaminants from groundwater, both anaerobically and aerobically degradable, ranging from BTEX and PAHs to chlorinated solvents and oxygenates such as methyl tert-butyl ether (MTBE) and ter-butyl alcohol (TBA). PlumeStop can also be used to treat emerging contaminants of concern such as per- and polyfluoroalkyl substances (PFAS).

Environmental standards for PFAS are very low (with regulatory guidelines ranging from <20 ng/L to 70 ng/L) and being able to reach those targets poses a significant challenge to environmental practitioners. Despite those hurdles, PlumeStop has successfully been used at a number of sites.

It was recently employed at Camp Grayling, a military training center located in Crawford County, Michigan, to create an I-PRB that resulted in immediate reductions of PFAS and chlorinated solvent concentrations to below EPA guidelines.

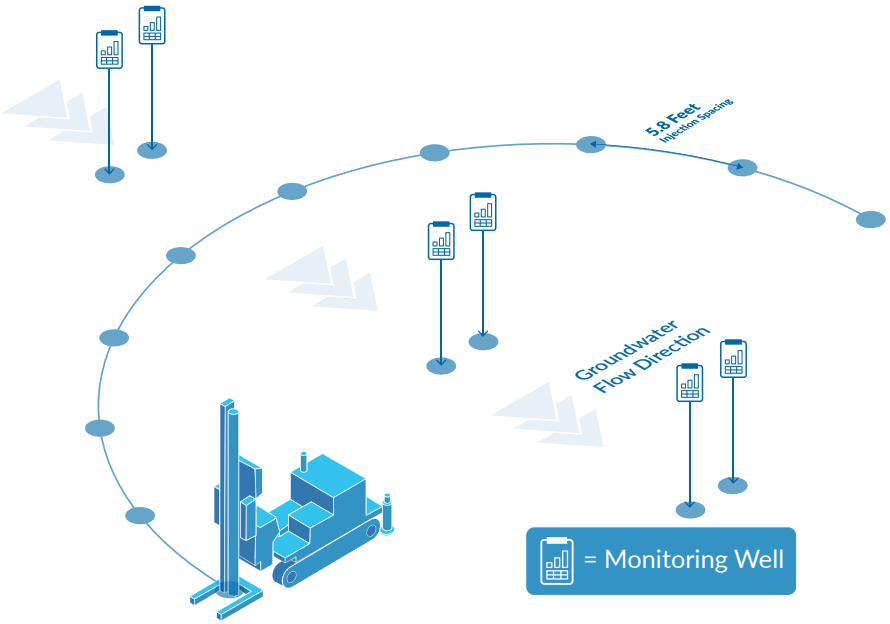


Illustration depicting the PlumeStop I-PRB design used at Camp Grayling in Crawford County, Michigan. PFAS concentrations in downgradient wells have remained at non-detect more than two years post-application.

The range of contaminants that can effectively be treated by PRBs is limited only by the capabilities of the material used in its construction and will only widen as technology continues to evolve.

#3 I-PRBs Can Work Quickly

> ***Bench tests were conducted comparing the reactivity of S-MicroZVI with unsulfidated ZVI against TCE. The results showed that the reactivity of S-MicroZVI was 28 times higher.***

Although I-PRBs are generally designed as long-term solutions, they can quickly produce short term results. As with all *in situ* remediation projects, effectiveness is based on the degree of contact. But once there is contact, there can be rapid, localized results.

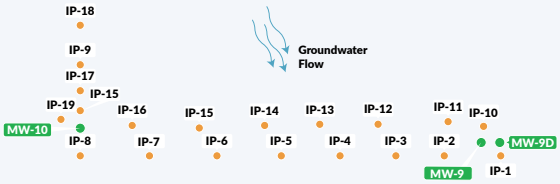
Sulfidation of ZVI particles enhances the rate of reduction for common groundwater contaminants such as PCE and TCE and allows for the degradation of 1,1,1,-TCA without forming significant concentrations of toxic daughter products.

Bench tests were conducted comparing the reactivity of S-MicroZVI with unsulfidated ZVI against TCE. The results showed that the reactivity of S-MicroZVI was 28 times that of unsulfidated ZVI as well as a significant difference in degradation pathways for 1,1,1-TCA that minimized the generation of 1,1-DCA. With this increase in reactivity, it is possible to drastically increase the rates of contaminant removal and simultaneously decrease the amount of material required to achieve the same results as traditional ZVI.

Similarly, I-PRBs constructed with PlumeStop have also demonstrated the benefits of rapid interactions with contaminants of concern. Many sites incorporating PlumeStop have seen significant drops in contaminant concentrations in a very short period of time, sometimes resulting in achieving site goals within days. This speed of reaction is especially important for barrier applications in areas with high groundwater velocities.

Case Study:
PlumeStop I-PRB Treats Chlorinated Solvents at Former Dry Cleaning Site

At a former dry-cleaning site in Martinsville, Indiana, a plume of PCE in excess of 370 ppb was traveling through a sand and gravel aquifer. The groundwater velocity of 1,560 ft/year and oxygenated geochemistry which limited natural attenuation posed a challenge for many of the considered technologies. After a thorough evaluation, PlumeStop, in combination with HRC and Bio-Dechlor Inoculum® (BDI Plus), was selected for a pilot test.



The I-PRB design used to treat a PCE plume at a former dry-cleaning site in Martinsville, Indiana.

PlumeStop proved that, despite the fast-moving groundwater, the speed of the reaction was enough to effectively treat the plume in a well-oxygenated, sand and gravel lithology. Monitoring results showed 99% reduction of PCE 30 days after application in key monitoring wells. As a result, plans are in motion for a full-scale application.

Similarly, on a site in Panama City Beach, Florida, a solution was required to degrade petroleum contaminants within a fast-moving 150-yard plume. Although initial remediation attempts using hydrogen peroxide and nutrients temporarily reduced contaminant concentrations, these reductions could not be sustained. Needing a more effective solution, the consultant selected PetroFix, a dual-functioning activated carbon solution designed to remediate petroleum spills and provide immediate results.

PetroFix was successfully applied at a site in Panama Beach achieving non-detect.

PetroFix works by removing hydrocarbons from the dissolved phase through sorption and then stimulating hydrocarbon biodegradation by adding electron acceptors (sulfate and/or nitrate) and is supported by a robust online design tool that enables users to individually tailor site design and self-apply.

Installed as an I-PRB, PetroFix rapidly removed hydrocarbons and met targets within 60 days, and unlike previous approaches, has been able to sustain these reductions for over a year following injection.

Because of how quickly I-PRB materials such as 3DME, S-MicroZVI, PlumeStop, and PetroFix can react with target contaminants, it opens up a wider range of conditions under which they can be successfully applied and can lead to more rapid results while using less material.

#4 I-PRBs Can Reduce Liability

> ***In Situ Permeable Reactive Barriers (I-PRBs) are permeable treatment zones designed to passively intercept and treat contaminated groundwater.***

One of the primary goals of remediation is to reduce or eliminate any potential future liabilities arising from environmental impacts. I-PRBs can be very useful to prevent off-site migration and preventing contaminants from reaching sensitive site receptors either as part of a remedial plan to completely remove the source or by providing a cost-effective long-term solution for plume management.

For example, on a large site in Northern Italy, TCE impacts had previously been treated with a combination of slow release electron donors such as 3DME and HRC, allowing for regulatory closure on internal portions of the site. However, just beyond the downgradient boundary of the site was a river which represented a sensitive site receptor, so the cleanup criteria at the site boundary were far stricter (< 1 µg/L) and required further action to address.

There was a pump and treat system, that had been operating on the site for the past ten years. However, while this system was hydraulically confining the aquifer, it would not be able to ensure contaminant concentration levels were below regulatory standards. Based on an assessment of available I-PRB technology, the consultant elected to design a barrier employing PlumeStop.

Starting with two successful pilot tests to confirm the efficacy of this approach and to inform dosage for a full-scale application, PlumeStop was implemented along the site boundary, creating a subsurface activated carbon filter along its entire length. The PlumeStop was installed using two Geoprobe rigs in parallel to advance approximately 150 injection points in a 90-meter barrier. Dosage was tailored based on the contaminant concentration in discrete areas and heterogeneity of the alluvial subsurface.

> ***The barrier has been successful enough that the pump and treat system has been decommissioned and the site owner can pursue complete regulatory site closure***

This barrier is currently working to prevent any environmental impacts from reaching the river and thus presenting potential liability to the site owner. The barrier has been successful enough that the pump and treat system has been decommissioned and the site owner can pursue complete regulatory site closure.

In a similar approach, there are plans in place to install I-PRBs, consisting of PetroFix, to transect, intercept, and treat a large contaminant plume of polyaromatic hydrocarbons at the Buxton Naval Facility, a former Naval Auxiliary Air Station in Dare County, North Carolina, in the Cape Hatteras National Park System. The Buxton Naval Facility is located right next to the Atlantic so I-PRBs are being installed to prevent environmental impacts from reaching the ocean and preventing any resulting liability.

Plans are also in motion to install an I-PRB on a brownfield site in the UK impacted with petroleum hydrocarbons (and to a lesser extent, chlorinated solvents). The site owner is a multinational developer who specializes in redevelopment of brownfield sites for light commercial/industrial usage. This developer is fairly risk-averse, often going above and beyond on cleanup of sites that they acquire. To prevent off-site migration and reduce liability, they elected to install an I-PRB.

Part of a larger remediation program that includes source removal and targeted grid injections of RegenOx® and ORC Advanced to target contaminant hotspots, the barrier is made up of PetroFix (35,373 kgs) and ORC Advanced (10,130 kgs), and has a planned length of 840 meters. Once installed, it will represent the longest barrier to date for any REGENESIS product.

Length:	**840 Meters**
ORC Advanced — Oxygen Release Compound	**10,130 kgs**
PetroFIX Remediation Fluid	**35,373 kgs**

For a site owner, I-PRBs can reduce liability by preventing off-site migration of contaminants to sensitive site receptors as well as limit potential health risks by eliminating environmental impacts on site. With their ability to treat a wide range of contaminants, achieve very low target concentrations, and remain active in the subsurface for long periods of time, I-PRBs are an excellent option for the owners looking to limit their legal and financial exposure.

#5 I-PRBs Can Save Money

I-PRBs are typically installed when dealing with plumes over a relatively large time-scale. The other technology most often used in these situations is pump and treat so that is the most common basis for comparison. Determining a budget for any project typically considers both the capital investment and operation and maintenance (O&M). For short-term applications, these two components can simply be added together, but for long-term projects, O&M must be considered over a period of time to factor in a reasonable rate of return to estimate present value over the life cycle of the entire project.

For pump and treat systems, capital costs include site characterization, engineering design, site preparation, aboveground treatment systems, and installation, while for I-PRBs, capital costs include bench-scale tests, site characterization, engineering design, materials, and barrier construction. While the capital costs for I-PRBs, particularly ZVI, may be higher than that of pump and treat in the short term, the major factor, is O&M over time.

> ***A Department of Defense (DOD) study demonstrates $3M savings using ZVI approach vs. Pump & Treat***

Because I-PRBs treat groundwater passively, annual O&M costs tend to include only monitoring and replenishing the I-PRB material as necessary (i.e. iron replacement every 10 years) whereas pump and treat systems must account for system operation and maintenance, monitoring costs, and carbon/catalyst replacement which are far more frequent in comparison.

A Department of Defense (DoD) study conducted at former Naval Air Station (NAS) Moffett Field compared an I-PRB constructed with traditional ZVI versus an equivalent pump and treat system and found that while the capital costs for I-PRBs were higher, the pump and treat system would end up costing three million dollars more (~$17M vs. ~$14M) due to the accumulated cost of O&M over a thirty-year lifespan.

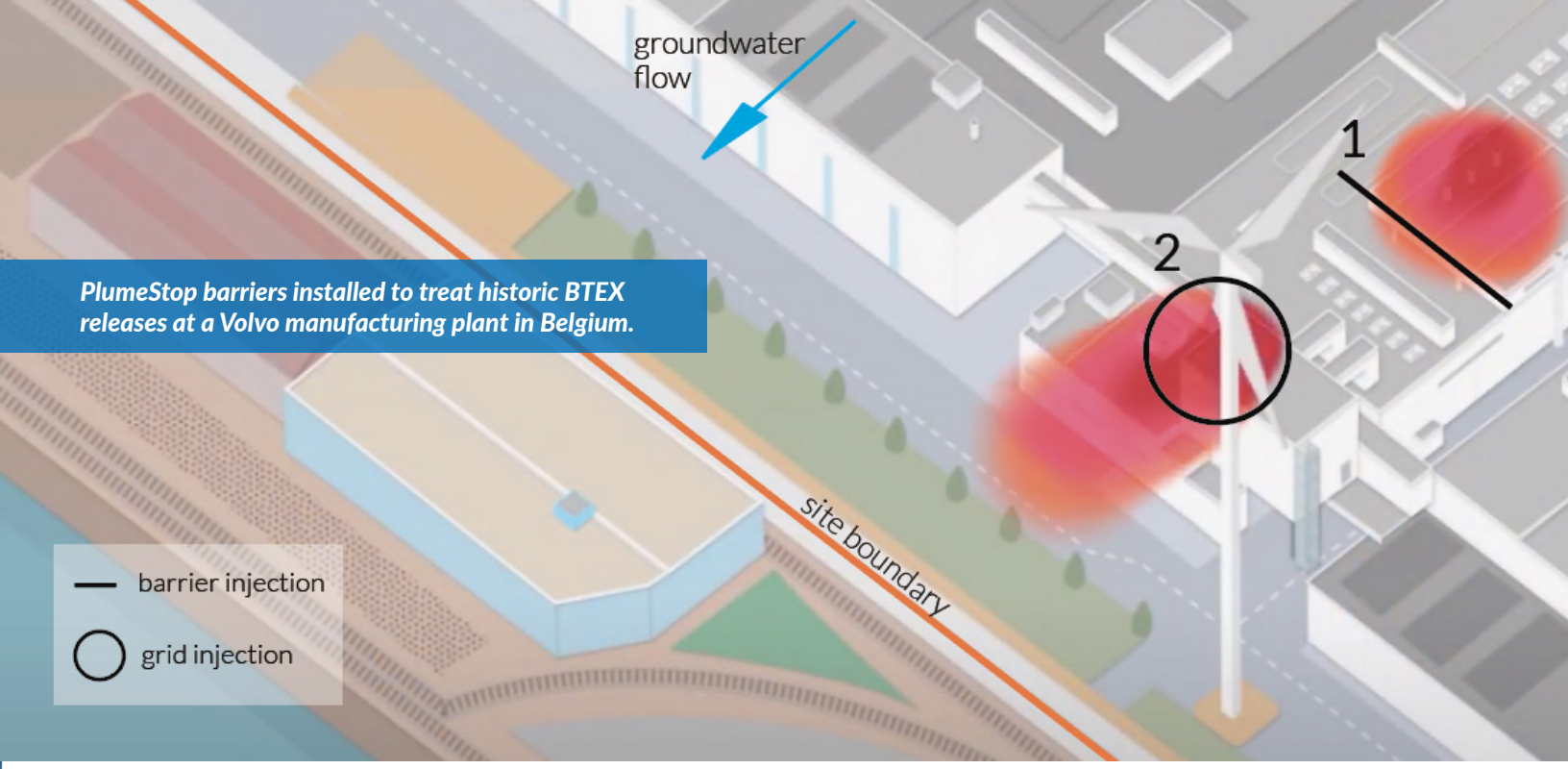
> ***The introduction of S-MicroZVI, which is shipped as a ready-to-install liquid, eliminates the need for dust management, additional handling equipment, or pre-application mixing and associated costs.***

If the lifespan of the plume lasts more than thirty years, as expected, then these savings will only increase. The budget for the I-PRB also included approximately a quarter million additional dollars every ten years for replenishing the iron which is considered a conservative estimate. If the iron in the initial application lasts more than ten years, then this would also contribute significantly to the overall savings.

The largest component contributing to the cost of an I-PRB is the installation. In the case of ZVI technology, S-MicroZVI significantly brings those costs down. Traditionally, ZVI is delivered in dry form in either super sacks or barrels. This requires the use of forklifts, powder handling equipment, and measures put into place for managing dust and other inhalation hazards. Additionally, traditional ZVI requires a medium to both suspend and transport the iron in the subsurface. Biopolymers such as guar gum are typically used which represent additional cost for both material and time spent mixing it prior to application.

That changed with the introduction of S-MicroZVI, which is shipped as a ready-to-install liquid, eliminating the need for dust management, additional handling equipment, or pre-application mixing and all its associated costs. Similarly, colloidal activated carbon like PlumeStop also eliminates the need for dust management or pre-application mixing as it is shipped ready to inject.

With the advent of colloidal I-PRB materials such as 3DME, PlumeStop, PetroFix and S-MicroZVI, costs can be reduced further as they are both easily injectable and can be installed either using low pressure, direct-push injection (DPI) techniques or even gravity fed into dedicated injection wells. They have good mobility in the subsurface which results in widespread coverage within contaminated zones, allowing for greater spacing between injection points while still achieving the necessary contact with target contaminants, which translates directly to lower application costs.

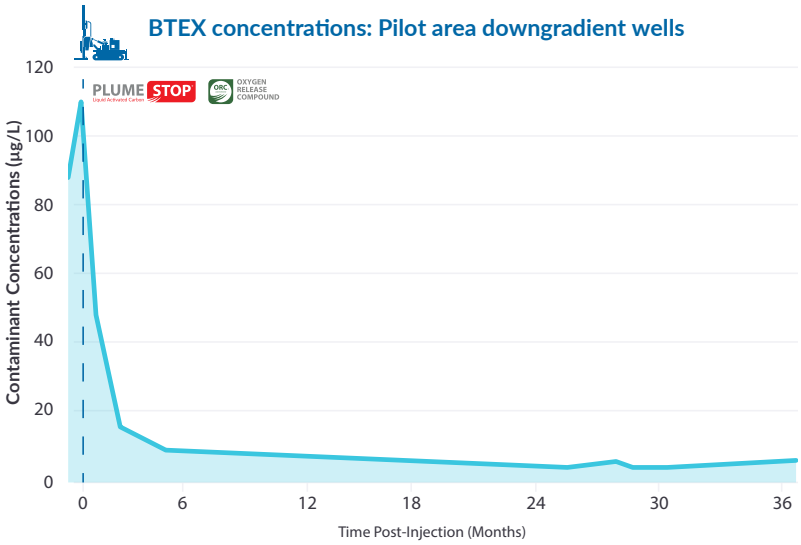


PlumeStop barriers installed to treat historic BTEX releases at a Volvo manufacturing plant in Belgium.

Unlike approaches using granular activated carbon or zero valent iron in powder form, which requires large rigs capable of high pressure, these products can be installed using small, portable injection equipment which has additional economic benefits.

For example, at a Volvo manufacturing plant in Belgium, a PlumeStop barrier, in concert with a grid application, was installed to treat BTEX and cleaning solvents resulting from historic spillages, and prevent off-site migration. Site access was limited due to existing building structures and underground services and part of the mandate from the client was to keep disruptions to site operations to an absolute minimum.

Following a successful pilot test, a full-scale barrier was installed and downgradient monitoring wells showed an immediate reduction in contaminant concentrations that have remained low and continue to trend downwards. Because of the self-regenerating capability of the PlumeStop, plume management can take place without the necessity for re-injections over time, and it is expected that this I-PRB will continue to contain and biodegrade the plumes for decades to come.



PlumeStop was installed through a combination of injection via small portable rigs and dedicated injection wells. The installation process successfully minimized disruption and remediation costs, with no interruptions to site operations.

Either through reduced installation costs, lowered O&M costs, or longevity of the material, I-PRBs can result in significant cost savings compared to equivalent technologies such as pump and treat.

6

I-PRBs are Environmentally Friendly

Aerial view of the Naval Weapons Industrial Reserve Plant in Dallas, Texas, where the DoD study took place.

Given that the purpose of I-PRBs is to treat environmental contaminants, one can assume they are, by definition, environmentally-friendly. However, I-PRBs, as with all other human activity, come with additional environmental costs.

It is a good practice to understand that even with its advantages, I-PRBs still have carbon footprints including greenhouse gas (GHG) emissions and energy consumption related to the production, transportation, and emplacement of the selected materials.

A DoD study of I-PRBs constructed with ZVI installed at a Naval Weapons Industrial Reserve Plant (NWIRP) in Dallas, TX found that production and transportation of the iron accounted for 95% of the carbon footprint and approximately 80% of the release of priority pollutants. The transportation of waste soils accounted for the remaining 20% of the priority pollutant release.

I-PRB footprints can be reduced during the construction phase by using recycled materials and hiring local suppliers of materials and equipment to reduce transportation costs. Advances in geotechnical techniques (i.e. slurry trenching, deep soil mixing, grouting) compared to more traditional methods (i.e. trench and fill) can reduce the amount of soil waste produced. Carbon footprints can be further reduced during the operation phase by using telemetric monitoring methods or passive and automatic samplers.

The Naval Weapons Industrial Reserve Plant (NWIRP) in Dallas, Texas, where the DoD Study on I-RPBs constructed with ZVI was conducted.

The same DoD study at the NWIRP in Dallas, TX found that the carbon footprint from production, transportation, and construction was offset by the short duration of the I-PRB installation and negligible maintenance over the life of the project.

> ***With the advent of I-PRB materials such as 3DME, PetroFix, S-MicroZVI and PlumeStop, all designed for ease of installation, reducing the carbon footprint associated with construction time and equipment is assured.***

With the advent of I-PRB materials such as 3DME, PetroFix, S-MicroZVI and PlumeStop, which are designed for ease of installation, this will only further help to reduce the carbon footprint associated with construction by reducing the amount of time and equipment required. And because of the improved performance of these products, it can reduce time to site closure, again reducing the carbon footprint by eliminating the need for any further action.

When comparing the passive treatment of an I-PRB to equivalent technologies such as pump and treat, which require active maintenance and ongoing energy consumption over its entire lifetime, I-PRBs can be a much more sustainable option.

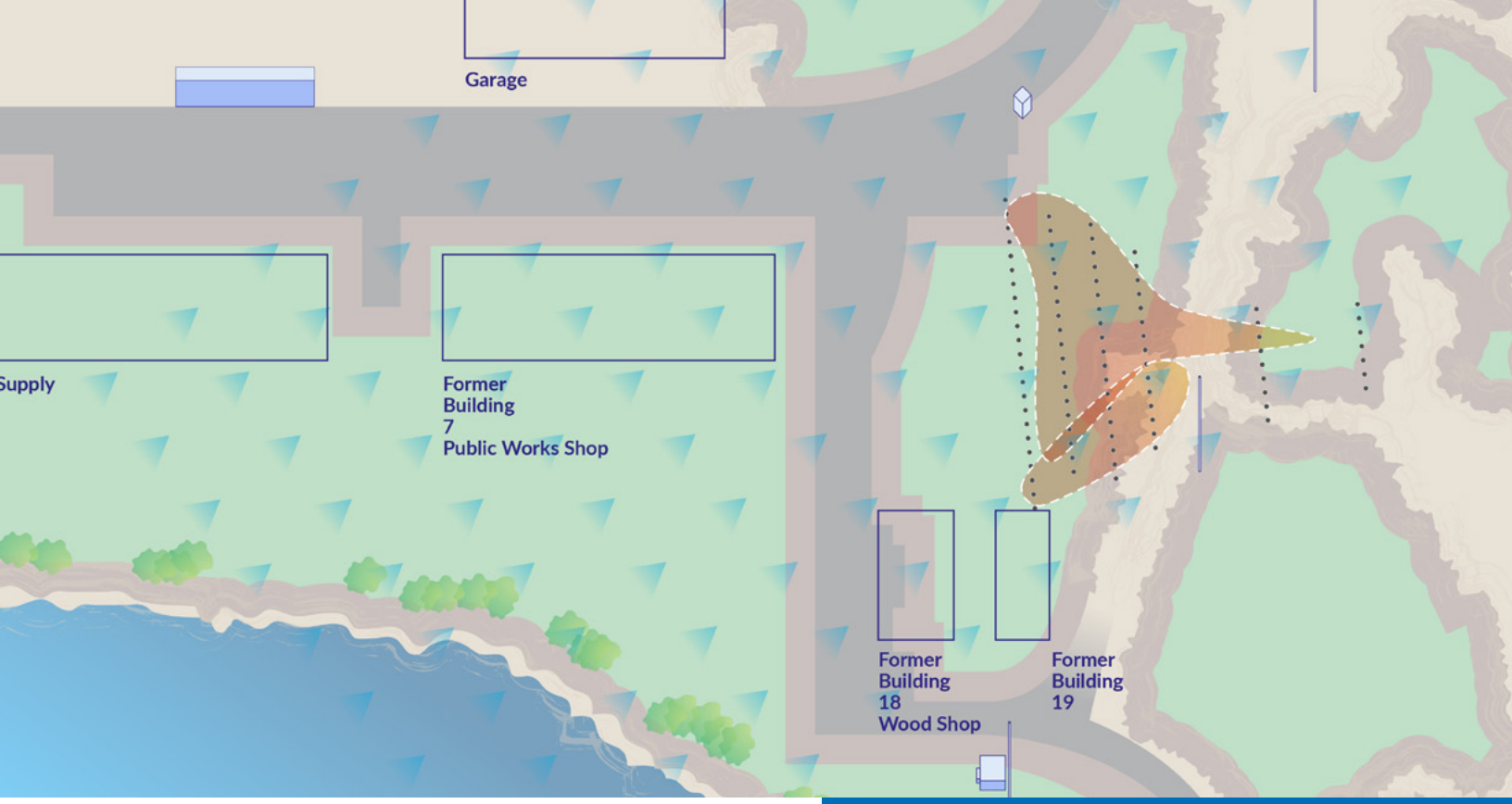
#7 I-PRBs are Flexible

Advances in I-PRB technology allow for treatment to take place at a variety of sites with unique paramters.

Advances in I-PRB technology such as improved installation techniques, increased injectability, excellent subsurface distribution characteristics, and intelligent amendment combinations mean that environmental professionals now have much more flexibility when optimizing remedial design for a wide range of sites.

Starting with the first PRB at the University of Waterloo in 1991 which was a granular iron-filled wall constructed inside a sheeted excavation, construction methods have evolved to include continuous trenchers, hydraulic/pneumatic fracturing, and direct-push injection.

Unlike more traditional granular iron that has large particles which are difficult to distribute *in situ*, and essentially impossible to distribute using low-pressure techniques, I-PRB amendments such as 3DME, PetroFix, and PlumeStop are designed to disperse in the subsurface to improve their radius of influence and allow for improved spacing between injection points. This ability to disperse in the subsurface allows for more contact between these reactive materials and the target contaminants showing improvements over other injection methods such as fracturing while being less intrusive than techniques such as soil mixing.



Because of the injectability of these colloidal suspension products, it is possible to apply them using small portable equipment which allows for access to tight spaces. The ease by which these products can be injected also make them suitable for use on treating plumes in deep aquifers where the installation of traditional powdered ZVI would be prohibitively expensive, difficult to control and impractical.

> ***"The ease by which these products can be injected also make them suitable for use on treating plumes in deep aquifers where the installation of traditional powdered ZVI would be prohibitively expensive, difficult to control and impractical."***

Many I-PRB amendments can be combined to create even more robust remedial systems. For example, ZVI and biological amendments (i.e. HRC and 3DME) can be combined where the use of iron provides an alternative abiotic pathway for the degradation of PCE and TCE that can avoid the formation of toxic daughter products such as dichloroethylene (DCE) and vinyl chloride (VC).

Additionally, PlumeStop can be combined with biological amendments (i.e. ORC Advanced, HRC, BDI Plus) to marry sorption with enhanced biological reduction. This is a synergistic pairing in which a more robust microbial community can more quickly degrade sorbed contaminants and free up sorption sites to handle incoming contaminant flux. As well, for sites where the contaminant concentrations are low, but still above guidelines, PlumeStop can work to concentrate the contaminants to provide enough of a food source for the aforementioned microbes to flourish.

Finally, PlumeStop, S-MicroZVI, and HRC can be combined to create an enhanced I-PRB that utilizes sorption, which rapidly removes contaminants from the aqueous phase and limits their transport, and both abiotic and biotic reduction, which destroys those contaminants and frees up sorption sites.

Case Study:
PlumeStop I-PRB Treats Chlorinated Solvents at Former Dry Cleaning Site

At a rail site in Northern Quebec, chlorinated solvent releases had impacted groundwater which was flowing towards the property boundary. The consultant, WSP, decided to install an I-PRB constructed of PlumeStop and S-MicroZVI with an additional amendment of HRC Primer and HRC to stimulate biotic degradation.

The pilot test consisted of of 1,900L of PlumeStop, 800L of S-MicroZVI, 250L of HRCPrimer, and 250L of HRC. *In Situ* Microcosms (ISM) were also deployed as part of the pilot program

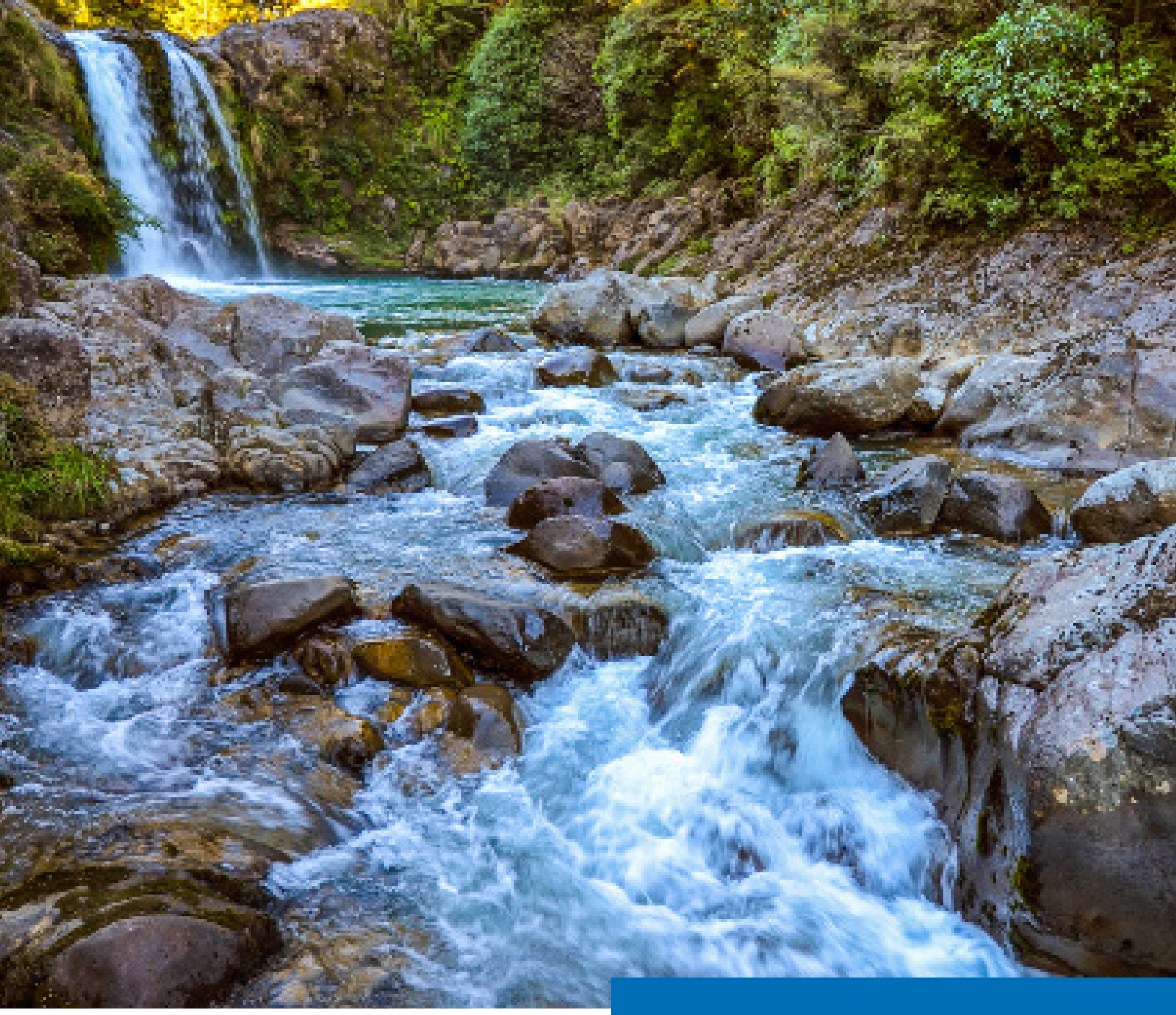
Despite winter conditions, the amendments were successfully installed and subsequent groundwater samples exhibited a strong geochemical shift compared to baseline conditions and significant decreases in contaminant concentration, with dissolved VOCs decreasing by over 95%. Data generated from the ISM's and supporting diagnostic data confirmed biodegradation.

> ***"At a storage facility in Hamilton, Ontario, a I-PRB was installed to prevent the off-site migration of chlorinated solvents."***

In a similar situation at a storage facility in Hamilton, Ontario, an I-PRB consisting of PlumeStop, S-MicroZVI, and HRC, was installed to prevent the off-site migration of chlorinated solvents from historical metal processing activities. This combination of sorption, abiotic reduction, and biological degradation proved to be highly effective with concentrations of all chlorinated solvents dropping below detection limits within days of the application and remaining below detection limits for subsequent monitoring rounds.

These case studies demonstrate how sorption, abiotic reduction, and biological degradation can be combined to create a remedy that is greater than the sum of its parts.

Through innovative installation techniques, product design, and intelligent combinations of amendments, I-PRBs can provide the flexibility required for environmental professionals to achieve site goals under a wide range of circumstances.



Conclusion

> ***Environmental practitioners have an increasingly wide array of tools to create sustainable and cost-effective remedial solutions.***

Although PRBs have been in use for nearly thirty years, with the advent I-PRB technology, the science has evolved significantly and will continue to do so in the future. With colloidal products such as PetroFix, PlumeStop and S-MicroZVI entering the market, mainstays such as ORC Advanced and slow release electron donors such as HRC and 3DME, and constantly improving installation techniques, environmental practitioners have an increasingly wide array of tools they can use to create sustainable and cost-effective remedial solutions.

Proven Technologies for Remediation Success

PlumeStop® Liquid Activated Carbon™ is a fast-acting groundwater remediation reagent which captures and biodegrades a range of contaminants, thus accelerating the successful treatment of impacted sites and leading to their permanent closure. As a science-based, *in situ* treatment technology, REGENESIS' PlumeStop rapidly removes contaminants from groundwater and stimulates their permanent degradation.

S-MicroZVI® is an *In Situ* Chemical Reduction (ISCR) reagent that promotes the destruction of many organic pollutants and is most commonly used with chlorinated hydrocarbons. It is engineered to provide an optimal source of micro-scale zero valent iron (ZVI) that is both easy to use and delivers enhanced reactivity with the target contaminants via multiple pathways. S-MicroZVI can destroy many chlorinated contaminants through a direct chemical reaction. S-MicroZVI will also stimulate anaerobic biological degradation by rapidly creating a reducing environment that is favorable for reductive dechlorination.

PersulfOx® is an advanced *in situ* chemical oxidation (ISCO) reagent that destroys organic contaminants found in groundwater and soil through abiotic chemical oxidation reactions. It is an all-in-one product with a built-in catalyst which activates the sodium persulfate component and generates contaminant-destroying free radicals without the costly and potentially hazardous addition of a separate activator. The patented catalyst enhances the oxidative destruction of both petroleum hydrocarbons and chlorinated contaminants in the subsurface.

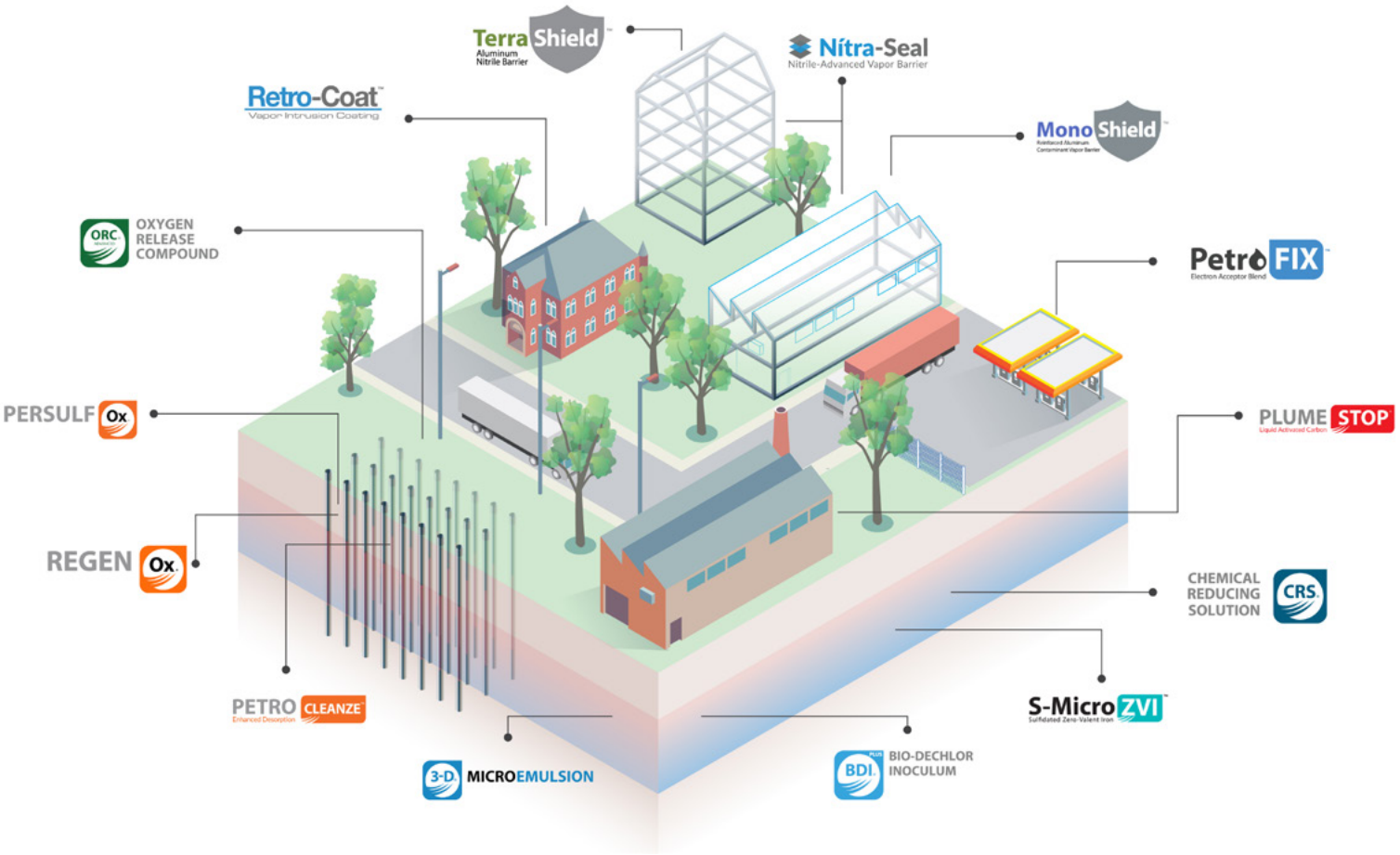
RegenOx® *in situ* chemical oxidation (ISCO) directly oxidizes contaminants while its unique catalytic component generates a range of highly oxidizing free radicals that rapidly and effectively destroy a range of target contaminants including both petroleum hydrocarbons and chlorinated compounds. RegenOx is an injectable, two-part ISCO reagent that combines a solid sodium percarbonate based alkaline oxidant (Part A), with a liquid mixture of sodium silicates, silica gel and ferrous sulfate (Part B), resulting in a powerful contaminant destroying technology.

ORC Advanced® is an engineered, oxygen release compound designed specifically for enhanced, *in situ* aerobic bioremediation of petroleum hydrocarbons in groundwater and saturated soils. Upon contact with groundwater, this calcium oxy-hydroxide based material becomes hydrated producing a controlled-release of molecular oxygen (17% by weight) for periods of up to 12 months on a single application.

3-D Microemulsion® is an injectable liquid material specifically designed for *in situ* remediation projects where the anaerobic biodegradation of chlorinated compounds through the enhanced reductive dechlorination (ERD) process is possible. ERD is the primary anaerobic biological process by which problematic chlorinated solvents such as tetrachloroethylene (PCE) and trichloroethene (TCE), dichloroethene (DCE) and vinyl chloride (VC) in groundwater are biologically transformed into less harmful end products such as ethene.

Bio-Dechlor INOCULUM® Plus (BDI Plus) is designed for use at sites where chlorinated contaminants are present and unable to be completely biodegraded via the existing microbial communities. BDI Plus is an enriched, natural microbial consortium containing species of *Dehalococcoides sp*. (DHC) which are capable of completely dechlorinating contaminants during *in situ* anaerobic bioremediation processes. BDI Plus has been shown to stimulate the rapid dechlorination of chlorinated compounds such as tetrachloroethene (PCE), trichloroethene (TCE), dichloroethene (DCE), and vinyl chloride (VC). It also contains microbes capable of dehalogenating halomethanes (e.g. carbon tetrachloride and chloroform) and haloethanes (e.g. 1,1,1 TCA and 1,1, DCA) as well as mixtures of these halogenated contaminants.

HRC® is an engineered, hydrogen release compound designed specifically for enhanced, *in situ* anaerobic bioremediation of chlorinated compounds in groundwater or highly saturated soils. Upon contact with groundwater, this viscous, poly-lactate ester material becomes hydrated and subject to microbial breakdown producing a controlled-release of hydrogen for periods of up to 18-24 months on a single application. HRC enables enhanced anaerobic biodegradation by adding hydrogen (an electron donor) to groundwater and/or soil to increase the number and vitality of indigenous microorganisms able to perform the naturally occurring process of enhanced reductive dechlorination.



REGENESIS®

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.

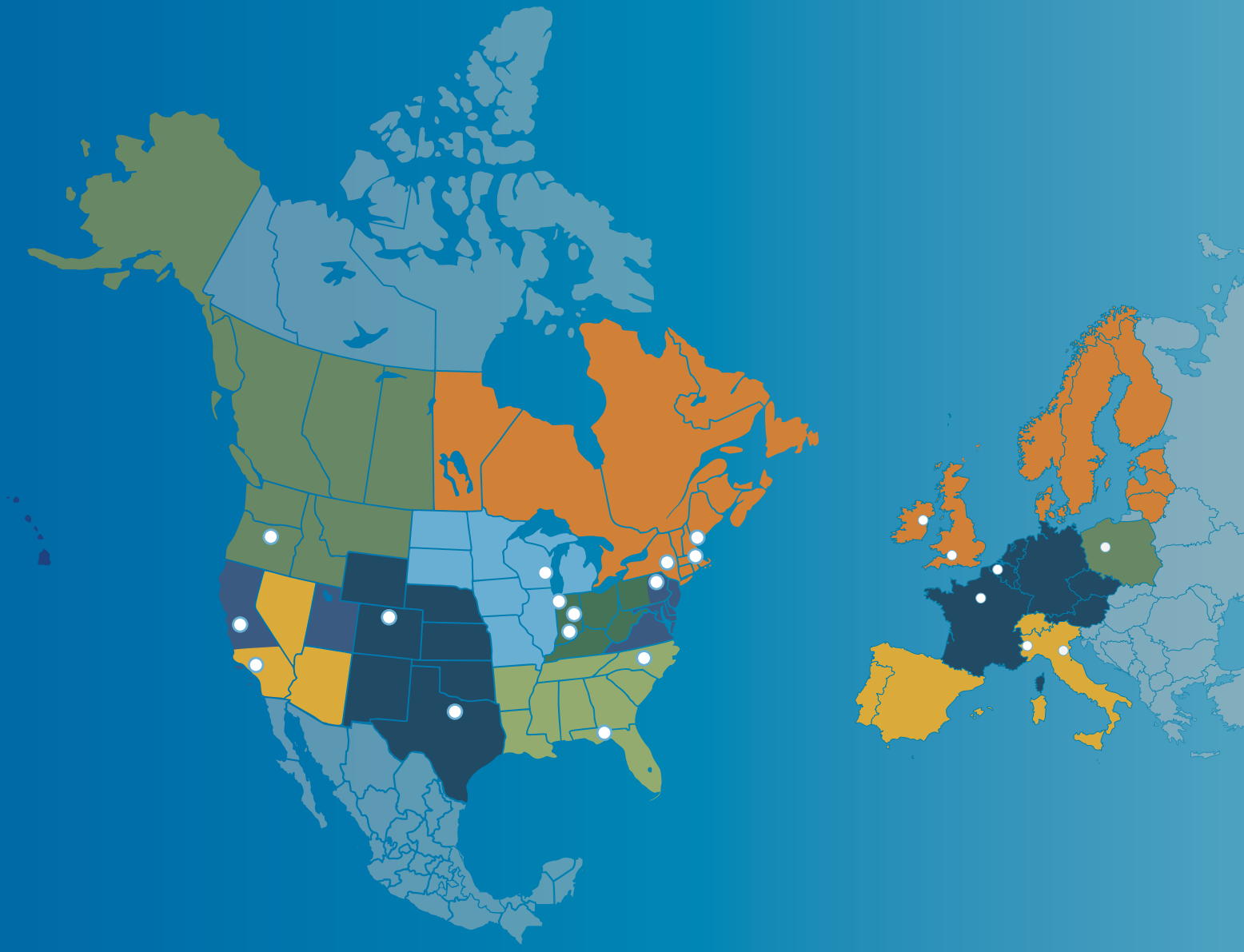
We value expertise, both our customers' and our own. We find that when our experienced staff collaborates directly with customers on complex problems there is a high potential for success including savings in time, resources and cost.

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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