TOP 6 REASONS

IT'S WORTH CONSIDERING AN *IN SITU* REMEDIATION APPROACH

Why *In Situ* Remediation?

When having to deal with soil or groundwater contamination, there is no shortage of remedial options. There are many factors to consider when selecting the appropriate technology, including but not limited to contaminant type, subsurface conditions, and of course cost.

One of the first decisions is whether or not to go with an *ex situ* or *in situ* approach. *Ex situ* techniques include excavation, dual and multi-phase extraction, and thermal desorption. *In situ* techniques include chemical oxidation, bioremediation, and adsorption.

While some approaches can be effective if used in the correct situation and properly implemented, oftentimes, achieving site goals will require a combination of remedies in order to achieve the desired results.

Historically, remediation practitioners have only considered *ex situ* methods, but more and more today's environmental professionals are turning to an *in situ* approach.

While *ex situ* approaches can be considered as part of any remediation plan, there are a variety of reasons why an *in situ* strategy can be a better option.

> "Achieving site goals will often require a combination of remedies in order to achieve the desired results."

In Situ Remediation Can Cost Less #1

> 30 Sites Closed Across Indiana Using *In Situ* Approach Saves Clients Millions of Dollars

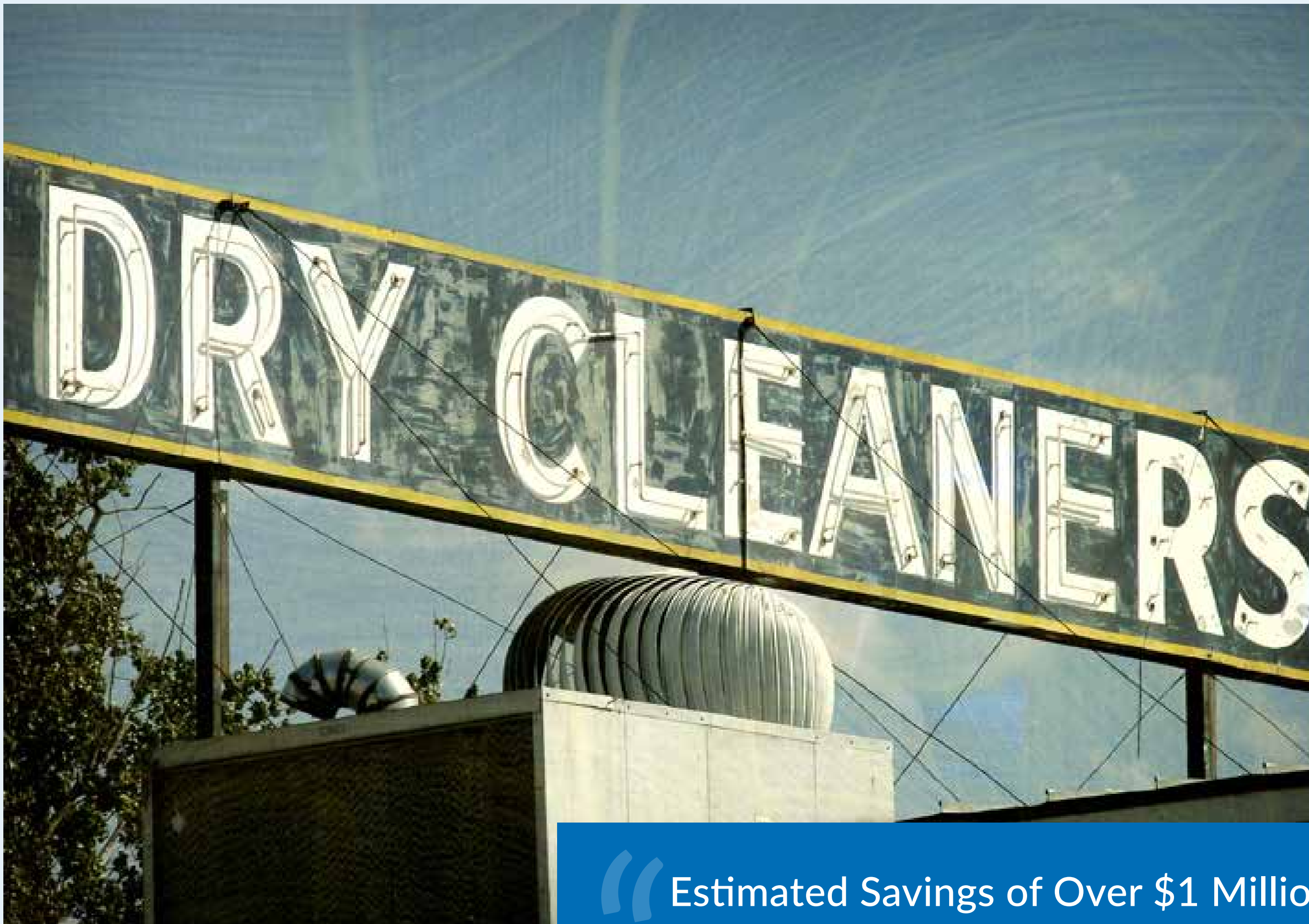
When compared to other techniques, *in situ* strategies can be more cost-effective. With a large-scale excavation, the transportation and disposal costs can be significant versus a chemical or biological *in situ* approach, particularly if the site is located far away from suitable landfills. In these cases, *in situ* soil mixing is a viable strategy where a chemical oxidant such as RegenOx® or PersulfOx® is mixed into the soil, typically using an excavator equipped with either a bucket or a specialized mixing head. Such an approach can mitigate the costs of excavating and transporting soils to a landfill.

If an enhanced bioremediation approach can achieve site cleanup goals within a compatible time frame, it can also represent sizable cost reductions over methods that involve excavation and transportation. Bioremediation costs are estimated at $20 to $80 per cubic yard whereas excavation costs can start at $120-$150 per cubic yard depending on the geographical area.

For example, 30 service station/bulk storage terminals were targeted for closure in Indiana. Instead of relying on only excavation, the sites were cleaned up intelligently using a combination of source-area removal and Oxygen Release Compound (ORC) injections for bioremediation of the remaining soil and groundwater. ORC was either applied via direct-push or, in some cases, installed in the excavation prior to backfilling.

With only a few exceptions, most of these sites achieved closure with just a single application of ORC. Ultimately, all the sites were closed with an average time to reach site closure of three years and an average cost of $70,000.

Cost analyses indicated that a traditional remediation approach for each site would have cost anywhere between $100,000 to upwards of $1 million. This example is just one of many reasons to consider a creative approach using a combined treatment strategy.



> Estimated Savings of Over $1 Million

CASE STUDY: Effective *In Situ* Approach Addresses PCE levels at Dry Cleaner Site

An active dry cleaner site located within a multi-use commercial development strip was impacted by high levels of PCE vapor which an investigation revealed to be the result of groundwater impacts both below and outside the building.

The original remediation plan involved a dual-phase extraction system with an estimated cost of $1.3 million. As an alternative, the consultant devised a plan involving *In Situ* Chemical Oxidation (ISCO) and Enhanced Reductive Dechlorination (ERD) using RegenOx®, 3-D Microemulsion® (3DME), and BDI-Plus®.

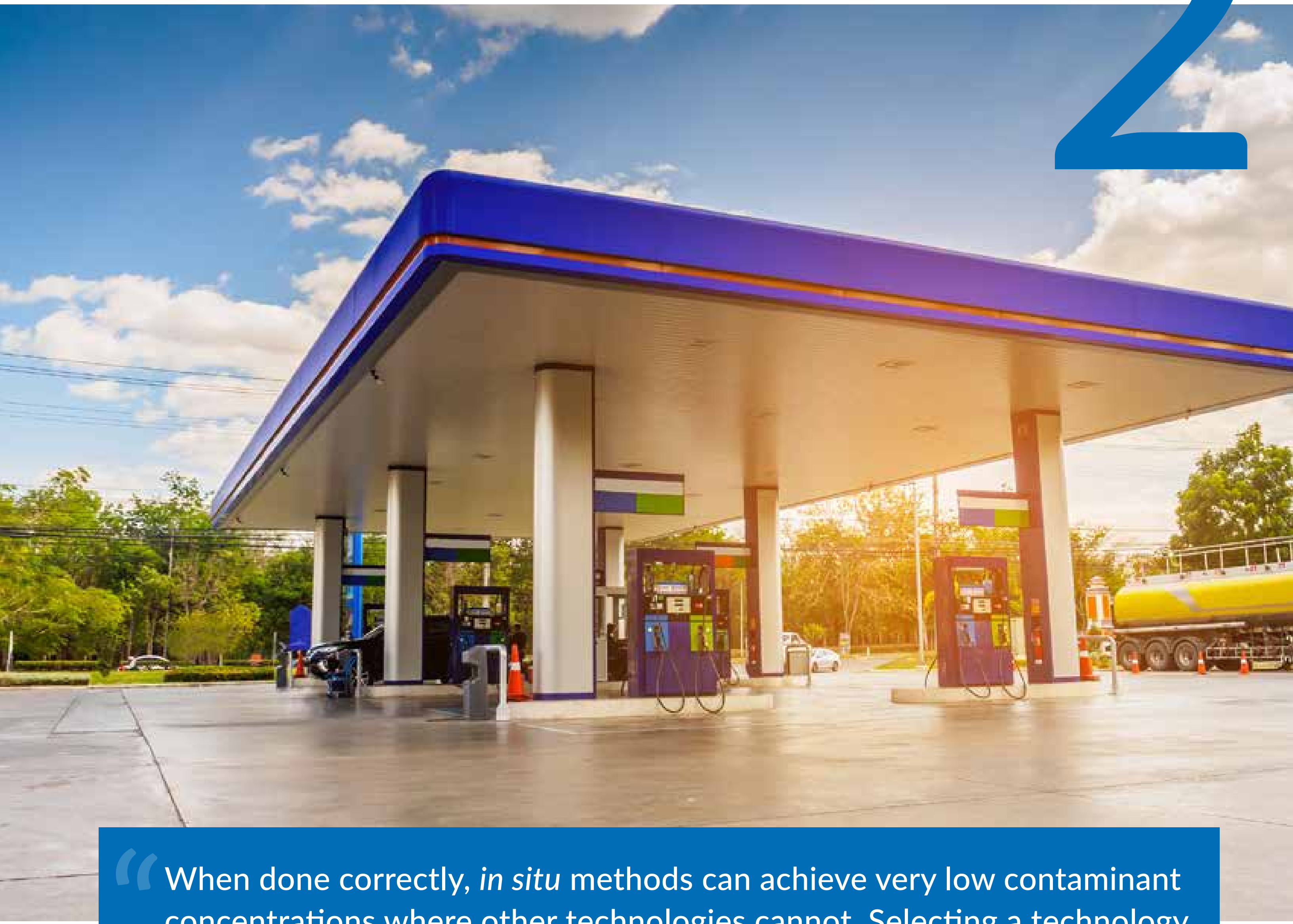
This plan was approved and, to-date, has cost less than $200,000 including monitoring and multiple indoor air/sub-slab vapor sampling events. Almost all the monitoring wells on site are now within compliance of remedial standards and it is estimated that an additional $50,000-$75,000 should be sufficient to achieve full site closure. This represents an estimated savings of over $1 million.

With mechanical systems such as pump and treat, dual-phase, or multi-phase extraction, there are not only the capital costs of building and installing the equipment, but also ongoing operation and maintenance costs that will continue to accumulate as long as the system is still running.

These systems often remain operational for far longer than necessary, accruing additional costs despite the system being asymptotic and no longer efficient at removing contamination.

While there are many options to choose from, *in situ* remediation often comes out ahead in the cost analysis, proving that it is possible to accomplish the same goals for less.

In Situ Remediation Delivers Results #2



> When done correctly, *in situ* methods can achieve very low contaminant concentrations where other technologies cannot. Selecting a technology capable of meeting prescribed remediation targets is the goal.

While *ex situ* methods such as excavation can very quickly remove impacted soil and achieve those standards, albeit expensively, other *ex situ* techniques such as pump and treat or soil vapor extraction (SVE), might not even be able to reach remedial goals. In contrast, when done correctly, *in situ* methods can achieve very low contaminant concentrations where other technologies cannot.

The success of an *in situ* remediation project is always contingent on sufficient contact between the amendment and the contaminant. Achieving contact is one of the most common problems, particularly when tackling contamination in low-permeability soils where the dominant mode of transportation transitions from advection to diffusion.

Slow-release oxidants like ORC or electron donors such as 3DME can remain active in the subsurface for one to five years. Because of that longevity, the active components of these products, whether it be oxygen or hydrogen, have the time required to move through the subsurface and attain the level of contact required to achieve low, even non-detect results.

With mechanical extraction systems like pump and treat or dual-phase extraction, a diminishing rate of contaminant extraction over time is typically observed due to decreasing contaminant mass and/or slow rates of removal for contamination in low-permeability zones.

When these systems become inefficient, oftentimes, *in situ* techniques such as chemical oxidation or bioremediation are employed to either enhance or replace the existing system.

Chemical oxidation, particularly a product such as RegenOx that generates surfactant-like molecules *in situ*, can help to desorb contaminants and improve the extraction efficiency of the existing system. With bioremediation, the longevity of the product continually degrades dissolved-phase contaminants, creating a solubility gradient that drives desorption.

Whether it is the first option or the final step, *in situ* remediation can be a valuable part of any effort to reduce contaminant concentrations to below regulatory standards, achieve site closure, and to make our environment a cleaner place to live.

“Whether it is the first option or the final step, *in situ* remediation can be a valuable part of any effort to reduce contaminant concentrations to below regulatory standards.”

CASE STUDY: Gas Station Sites Effectively Treated with ORC Advanced to Reach Regulatory Closure

Five gas stations in Southern California were contaminated with low levels of petroleum hydrocarbons, methyl tertiary butyl ether (MTBE) and associated daughter products. The initial approach for each site was soil vapor extraction, air sparging, and dual-phase extraction. However, despite some intial mass reduction, contaminant concentrations remained elevated, impeding regulatory closure.

In order to treat the remaining contamination, RegenOx and ORC were applied using direct-push injections for a chemical oxication and bioremediation combination approach. Both of these products are compatible with subsurface infrastructure so the key challenge was the proper distribution of remediation chemicals into the silty sand lithology. The result allowed the consultant to reach site goals at all five sites within budget and timeline.

#3 *In Situ* Remediation Can Go Where Others Cannot

> Oxidants and substrates can be strategically delivered directly to contaminated areas that might otherwise be inaccessible.

In some cases, it simply may not be physically accessible or economically feasible to treat contaminants using *ex situ* methods due to location and accessibility.

With contamination located deep below the subsurface, an excavation would require the removal of massive amounts of overlying soil that would be prohibitively expensive to both transport and dispose.

Similarly, it can be challenging to access contaminants located beneath a building where an excavation would either require demolition of the above ground structure or require expensive underpinning.

Using a variety of drilling methods such as direct-push, rotary vibration or augers; oxidants and substrates can be strategically delivered directly to contaminated areas that might otherwise be inaccessible.

While *ex situ* methods have their place, sometimes *in situ* remediation is the only viable option for environmental cleanup.

In Situ Remediation is Less Disruptive #4

> "The remedial system will remain active in the subsurface for years."

When a site undergoes *ex situ* remediation, such as a major excavation or the installation of a pump and treat or soil vapor extraction (SVE) system, there is a visual aspect that creates a perception problem. There are times when a property owner would benefit from a more inconspicuous remedial approach in order to avoid excessive public inquiry.

For example, environmental professionals treating an impacted site located near a residential neighborhood may benefit from using a more low-key remedial approach so as to not alarm residents and invite more scrutiny. With an excavation, there can be dusting, increased traffic, and a rather noticeable hole in the ground attracting attention.

By contrast, *in situ* remediation techniques are more discreet, often involving just a day or two of injection work. In the case of bioremediation such as ORC Advanced and Hydrogen Release Compound (HRC®) or adsorption technologies such as PlumeStop® Liquid Activated Carbon™, the remedial system will remain active in the subsurface for years while, above ground, there is no visual evidence of ongoing environmental remediation.

Public support can be a critical part of an environmental cleanup plan, and a lack of support, or worse, opposition, can make remediation efforts much more complicated.

#5 *In Situ* Remediation is Sustainable

In recent years, the Environmental Protection Agency (EPA) introduced the term "green remediation," which they defined as the practice of considering all the environmental effects of implementing a remedial strategy and incorporating options to minimize the ecological footprint of cleanup.

Contributing factors to an ecological footprint include greenhouse gas and hazardous air pollutants emissions, electricity usage, and potable water consumption associated with the off-site manufacture of chemicals and materials used on-site, laboratory analysis, and the burning of fossil fuels related to the operation of vehicles and equipment.

> "Looking at total footprints, the bioremediation option had the smallest environmental footprint for all parameters by a relatively wide margin"

While ecological footprint analyses can be site-specific and the level of detail required to make an informed decision is quite high, it is a valuable exercise for those practitioners for whom sustainability is a concern.

Studies have shown that any remediation effort requiring long-distance transportation has a significant footprint. *Ex situ* techniques such as excavation and disposal require the hauling of impacted soils to a suitable landfill which will generate large ecological impacts.

By contrast, an *in situ* technique which leaves the soil in place and eliminates the need for extensive transportation tends to have a much smaller footprint.

In a recent study, the EPA conducted a footprint analysis comparing a pump and treat approach with *in situ* bioremediation.

Operation and maintenance of the pump and treat system represented the largest contributor to the total energy, water, CO_2, NOx, and SOx footprints for all the options considered. The pump and treat system also had a significant air toxin footprint related primarily to the air stripper off-gas.

Off-site manufacturing of chemicals and construction materials used on-site represented a significant percentage of the total footprint (particularly off-site releases of mercury, lead, and dioxins) for all the alternatives, but the overall magnitude of the releases were relatively small.

Looking at total footprints, the bioremediation option had the smallest environmental footprint for all parameters by a relatively wide margin, with the exception of local potable water usage (for blending and injection) and dioxins released to the environment during the off-site manufacturing of polyvinyl chloride (PVC) for injection well casings.

While each footprint analysis will be heavily affected by site-specific conditions, and remedial design has almost as much influence on the size of an ecological footprint as the choice of remedial technology, it is clear that *in situ* remediation can be an environmentally friendly approach to environmental cleanup.

(2010). Comparison of the Secondary Environmental Impacts of Three Remediation Alternatives for a Diesel-contaminated Site in Northern Canada. Soil and Sediment Contamination: An International Journal: Vol. 19, No. 3, pp. 338-355.

Ongoing Innovation Drives Improved Outcomes #6

> "This solution gave practitioners a new option to use persulfate but alleviated the cost and safety issues related to caustic solutions."

The environmental remediation landscape is constantly evolving, and new scientific discoveries, products, and tools are continually emerging, making remedial efforts more effective and providing environmental practitioners with improved ways to approach old problems.

For example, persulfate is one of the most commonly used oxidants for *In Situ* Chemical Oxidation (ISCO). In order to increase its oxidative power, persulfate must be activated. Traditional methods included iron, heat, hydrogen peroxide, or alkaline activation.

Alkaline activation often involves injection of persulfate along with caustic soda and is most effective at generating the primary sulfate and hydroxyl radicals when the pH is kept above 11. A major limitation is the cost and logistics of injecting caustic solutions multiple times to maintain alkaline conditions. This requirement is driven by the natural buffering capacity of the aquifer and the acidic conditions produced as the persulfate decomposes.

Although persulfate had been used commercially in environmental remediation for over a decade, there had not been many advancements to the activation technology. Practitioners using persulfate for ISCO were often forced to deal with large volumes of caustic solution which increased costs and created health and safety concerns.

Persulfate activation technology improved with the introduction of REGENESIS' PersulfOx®.

PersulfOx employs a unique catalyst, composed of amorphous silica, designed so that if the pH drops into a circumneutral range, a heterogeneous catalyst forms within the aqueous medium and activates the persulfate. This solution gives practitioners an option to use persulfate, and alleviates the cost and safety issues related to caustic solutions.

> "PlumeStop, through the use of unique organic polymer dispersion chemistry, flows smoothly into the subsurface and moves through the aquifer freely, following contaminant pathways improving contact and resulting in more efficient treatment."

Similarly, injectable activated carbon had been used as an *in situ* remedy to adsorb contamination and remove it from the groundwater. However, previous iterations of the carbon had particle sizes that were typically larger than the pore space of the soil into which it was being injected. This resulted in the propagation of fractures that led to preferential pathways allowing activated carbon to enter monitoring wells. This had the effect of monitoring programs returning clean groundwater results even though, in reality, the surrounding area remained contaminated.

Advancements in injectable carbon technology resulted in PlumeStop, a suspended Liquid Activated Carbon with a particle size milled to the size of >1 micron which is much smaller than previously available options. This smaller-sized activated carbon, suspended in colloid through the use of unique organic polymer dispersion chemistry, flows smoothly into the subsurface and moves through the aquifer freely, following contaminant pathways improving contact and resulting in more effective treatment.

With any remedial effort, it is important to know where the contaminant is in order to treat it. With the advent of high-resolution site characterization tools such as membrane interface probes, hydraulic profiling, and laser-induced fluorescence, contaminant maps can be much more accurate, increasing the effectiveness of remediation efforts, in particular *in situ* techniques that rely on contact between the product and the contaminant and thus require a higher-degree of precision.

As environmental technology and the knowledge base continues to improve, there will be more and more reasons to consider *in situ* approaches as a viable option.

In Situ Remediation Effectively Treats Wide Variety of Sites

Whether it is the first option or the final step, *in situ* remediation can be a valuable part of any effort to reduce contaminant concentrations to below regulatory standards, achieve site closure, and to make our environment a cleaner place to live. For more information on applying an *in situ* approach to remediate your site, please contact a REGENESIS Technical Sales Manager.

About the *In Situ* Products Featured

PLUMESTOP Liquid Activated Carbon

PlumeStop rapidly removes contaminants from groundwater and stimulates their permanent degradation.

Key Benefits:

- Rapid reduction of dissolved-phase plumes.
- Distribution of widely under low injection pressures.
- Achievement of stringent groundwater clean-up standards.
- Providing a long-term means of addressing matrix back-diffusion, so contaminants do not return.
- Elimination of excessive time and end-point uncertainty associated with groundwater remediation.

3-D MICROEMULSION

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.

Key Benefits:

- Engineered, wide-area subsurface distribution mechanisms significantly reduct the number of injection points and events required.
- Three stage; immediate, mid-range and long-term controlled-release of lactic, organic and fatty acids for the steady production of hydrogen for optimized enhanced anaerobic biodegradation.
- High volume application optimizes contact with contaminants and reduces number of injection points required for treatment.
- A viable, long-term source of staged-release hydrogen, on the order of 2-4 years from single application.

REGEN Ox

RegenOx is designed specifically for the rapid, *in situ* and/or *ex situ* chemical oxidation of a broad range of contaminants including both chlorinated solvents and petroleum hydrocarbons. RegenOx delivers rapid and effective contaminant mass reduction using a solid alkaline oxidant that is activated to a very high performance level through the action of a unique catalytic complex.

Key Benefits:

- Promotes rapid and sustained *in situ* oxidation of a wide-range of organic contaminants.
- Provides a unique catalytic surface on which oxidants and contaminants react in a process known as "surface mediated oxidation."
- Non-corrosive, with minimal heat and pressure compatible with underground infrastructure, tanks, piping, etc.
- Creates a significant, short-term oxygen footprint to quickly establish follow-on aerobic biodegradation conditions.
- Readily desorbs contaminants from soil surfaces allowing for more effective ISCO and/or mechanical removal/extraction.
- Longer-term ISCO reactivity on the order of 30 days post-injection.

PERSULF Ox Catalyzed Persulfate

PersulfOx 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.

Key Benefits:

- Eliminates the need for the co-application of alternate and potentially hazardous activation chemistries.
- Contaminant oxidation performance equivalent to best alternative persulfate activation methods.
- Fewer health and safety concerns than with use of traditional activation methods such as heat, chelated metals, hydrogen peroxide or base.
- Single component product results in simplified logistics and application.
- No additional containers or multi-step mixing ratios required prior to application.
- Compatible with combined remedy approaches including enhanced biodegradation.

BIO-DECHLOR INOCULUM

Bio-Dechlor INOCULUM Plus (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.

Key Benefits:

- Rapid and effective treatment of undesirable anaerobic dechlorination intermediates such as dichloroethene (DCE) and vinyl chloride (VC).
- Highly compatible with a range of electron donors such as 3-D Microemulsion and HRC.
- Easy to apply and handle.

OXYGEN RELEASE COMPOUND

Oxygen Release Compound (ORC Advanced) is specifically designed and used for the enhanced or accelerated, *in situ* aerobic biodegradation of a wide-range of petroleum hydrocarbons or any aerobically degradable substance.

Key Benefits:

- Decreased time to site closure, degradation rates accelerated up to 100 times faster than natural attenuation.
- A single application can support aerobic biodegradation for up to 12 months.
- Minimal site disturbance, no permanent or emplaced aboveground equipment, piping, tanks, and power sources.
- Lower costs and greater efficiency/reliability than engineered mechanical systems, oxygen emitters and bubblers.
- Simple and easy application using a variety of available methods.

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