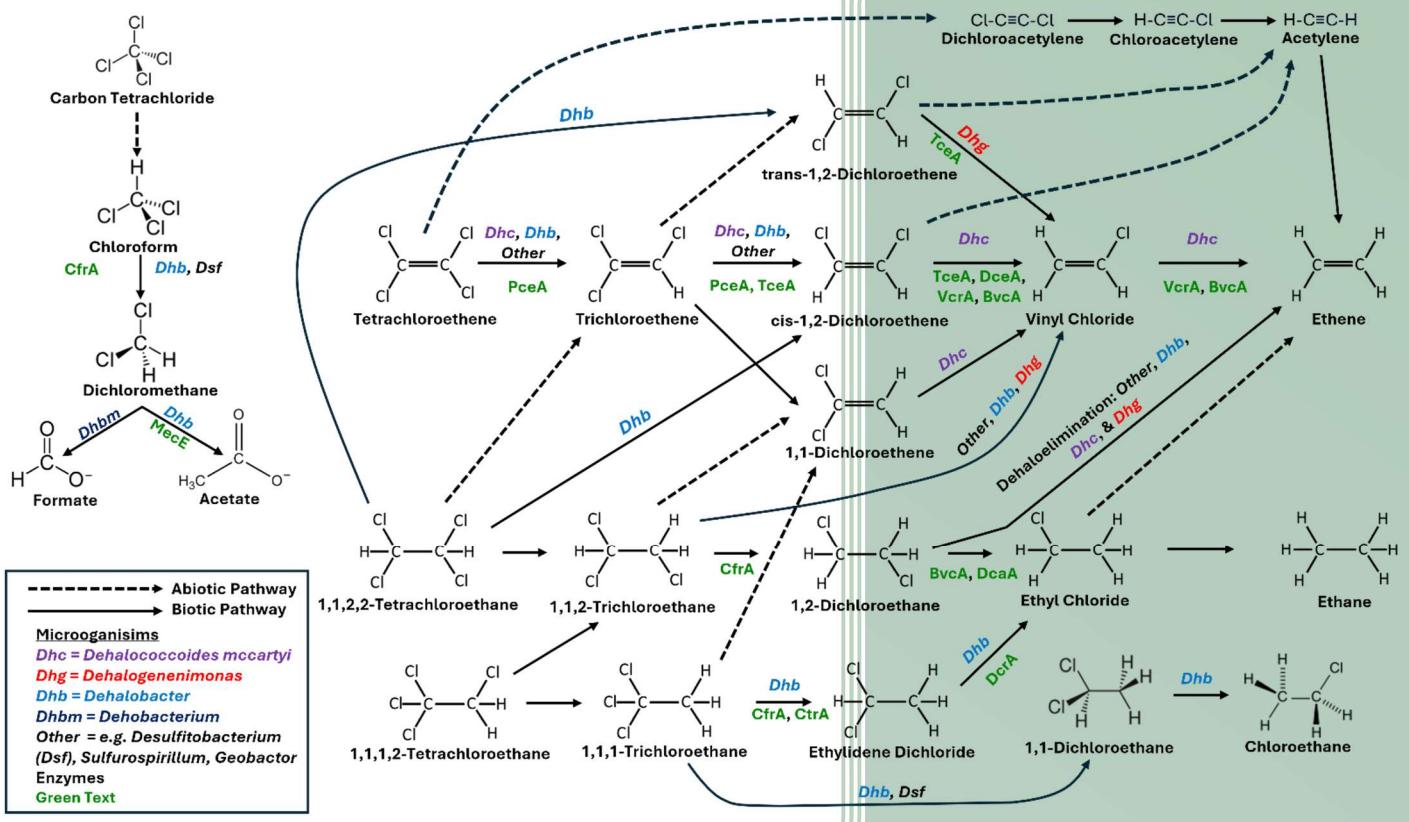
Chlorinated Solvents

Remediation Technologies and Services

Abiotic and Biotic Degradation Pathways



Adapted From: Judger et al., 2016; Wei et al, 2016; Grosten et al., 2010; Sakmaryova et al., 2017; Scheutz et al. 2011; Bowman et al, 2013; Grostern & Edward, 2006; Maness et al., 2012; Manchester et al., 2012; Tang et al., 2013; and Lee et al., 2011.

Tersus Environmental
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About Tersus Environmental

Tersus Environmental started in 2011 focusing on the commercialization of Gas Infusion Technology for bioremediation. The company expanded to become a leading provider of amendments, technologies, and services specific to soil and groundwater remediation.

To keep pace with the demand for our effective solutions, we began opening product distribution centers. Today, Tersus clients can take advantage of our distribution centers strategically located in California, Chicago, North Carolina, and France.

We research, develop, and commercialize innovative soil and groundwater remediation solutions through university and professional relationships to meet the advancing technological requirements at contaminated sites. Our proven technologies help our clients reduce uncertainty, minimize risks, and achieve cost-effective results.

We have a passion for supporting our clients by delivering outstanding customer service every day. Not focused on a single technology, Tersus Environmental offers the right solution for your site-specific needs. We look forward to helping you develop a cost-effective, remediation approach for your next project.

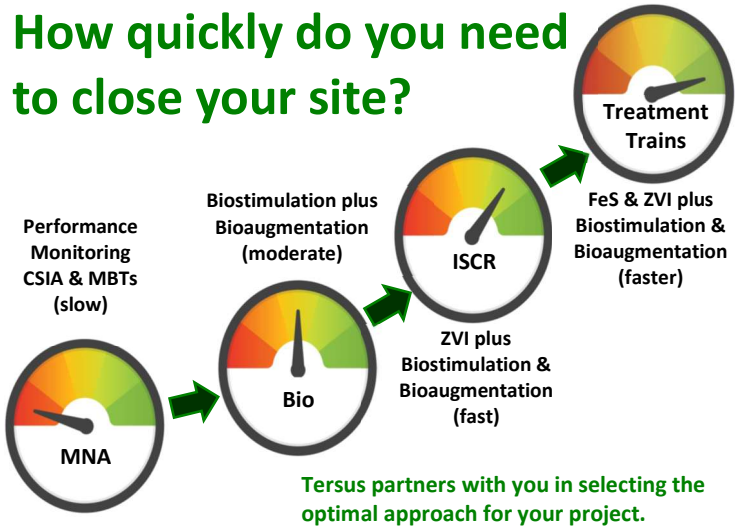
Soil and Groundwater Remediation of:

- Chlorinated Solvents
- Petroleum Hydrocarbons
- Metals
- Other Recalcitrant Contaminants

Company Information:

- CAGE Code: 70SW7
- DUNS: 03-778-7719
- SAM Entity ID: D53BSVAMRJA7
- NAICS: 562910 (Small Business)

How quickly do you need to close your site?



Tersus partners with you in selecting the optimal approach for your project.

Abiotic and Biotic Treatment

In Situ Chemical Reduction

In Situ Chemical Reduction (ISCR) involves the placement of chemical reductants into the contaminated area or in the path of the plume to help change contaminants into less toxic or less mobile forms. The most common reducing agent for remediation of chlorinated hydrocarbons, energetics, and some metals/metalloids is zero valent iron (ZVI). The co-injection of ZVI particles with electron donor substrates like *EDS-ER™* is a common strategy to encourage both biotic and abiotic degradation pathways of contaminants, as shown in figure on page 2.

In Situ Anaerobic Bioremediation

Enhanced reductive dechlorination (ERD) requires adding sufficient organic substrate (such as *EDS-ER™* or *EDS-QR™*, and nutrients, such as *Nutrimens®*) to satisfy electron acceptor and nutrient demand to allow biological dechlorination of halogenated compounds.

The complete reductive dechlorination of chlorinated solvents yields non-chlorinated and non-toxic final products. Absent the right bacteria, an accumulation of undesirable degradation intermediates can occur. Tersus offers the *KB-1®* family of bioaugmentation cultures to prevent degradation stalls.

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In Situ Chemical Reduction Amendments

Microscale ZVI Suspensions

ZVI-ironGEL™ is revolutionizing the field of in situ chemical reduction (ISCR) with an advanced microscale zero-valent iron (mZVI) colloidal suspension. Designed for superior performance, *ZVI-ironGEL™* is a powerful solution for the treatment of chlorinated solvents, heavy metals, and other recalcitrant contaminants in groundwater and soil

ZVI- ironGel™ contains environmentally friendly polymers specifically engineered to create a viscoelastic gel with shear-thinning behavior upon dilution with water. The gel properties offer mZVI suspensions high colloidal stability, good injectability, and enhanced distribution in the subsurface.

Key Features & Benefits

- **Enhanced Reactivity & Longevity**: The engineered formulation includes sulfidated and non-sulfidated ZVI particles ranging from 1 to 100 microns. Sulfidation enhances selectivity and effectiveness against highly substituted hydrocarbons such as PCE and TCE, while the non-sulfidated fraction ensures fast reaction kinetics with less substituted solvents like VC.
- **Shear-Thinning Viscoelastic Gel**: The environmentally friendly biopolymer formulation creates a gel that exhibits shear-thinning behavior upon dilution with water. This ensures high colloidal stability, improved injectability, and superior distribution in the subsurface.
- **Optimized Injection Concentration**: Delivered as a 45% ZVI colloidal suspension with a mean particle size under 10 microns, *ZVI-ironGEL™* is designed for injection at a 30 g/L ZVI concentration, facilitating ease of application.
- **Broad-Spectrum Action**: *ZVI-ironGEL™* rapidly initiates reductive processes in the subsurface. The smaller particles provide immediate reactivity, while larger particles extend the longevity of the treatment.
- **Improved Corrosion Resistance**: Sulfidation partially suppresses iron corrosion, extending the effectiveness of ZVI in groundwater environments.
- **Versatile Application Strategies**: Ideal for creating permeable reactive barriers (PRBs) and targeting secondary contamination sources through injection.

ZVI-ironGel™

- Easy to apply
- Does not require high pressure or large pumps for injection
- Disperse widely in the subsurface aquifer
- Mitigates ZVI aggregation and toxicity to bacteria
- Enhanced reactivity and longevity

Application & Deployment

ZVI-ironGEL™ can be injected into the subsurface to form reactive zones for contaminant treatment or deployed as a permeable reactive barrier to intercept and remediate contaminant plumes. Its advanced formulation ensures effective dispersion and longevity, making it a cost-effective and high-performance choice for environmental remediation professionals.

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Biostimulation Amendments for Anaerobic Bioremediation

EDS-Advanced™

All soybean oil emulsified vegetable oil (EVO) products ferment to acetic acid and hydrogen. Although emulsifying vegetable oil allowed overcoming limitations of pure vegetable oil injection and minimize field interventions by using a long-lasting electron donor, hundreds of EVO injection events over the past years has demonstrated that EVO effects are limited to the area in the immediate vicinity of the injection point. This is evident through low TOC values measured even tens of meters downgradient of injection points where only acetic acid predominates. A favorable fatty acid diversity seems to be limited to the injection points immediate vicinity (< 15 feet).
While acetate will migrate some distance downgradient, acetate:

- Only stimulates PCE -> TCE -> cDCE
- Will not stimulate cDCE -> VC -> ethene

Further, for anaerobic remediation, distribution of the correct type of fatty acids is essential for effective reductive dechlorination. Hydrogen (H_2) is required for cDCE -> VC -> ethene. It is produced from linolenic acid, propionate, butyrate, etc. However, hydrogen does not migrate any significant distance from injection point.

Our Approach: Unrestricted Electron Donor Subsurface Distribution

Surfactant specialists at Tersus developed an *in situ* alcoholysis approach, *EDS-Advanced™*, to overcome two of the main challenges associated with EVO injection: poor fatty acid subsurface distribution and biofouling. This approach enables the generation of both soluble and slowly fermenting electron donors. The addition of a substrate shuttle creates a solution that is more readily dispersible than EVO in aquifers and the subsurface by advection. An easy-to-distribute substrate means that an injection point can create greater radii of influence (ROI) which in turns reduces the required number of injection points to adequately supply a contaminated aquifer with electron donor. In other words, a larger volume of substrate can be dispersed from a single injection point.

Features & Benefits

EDS Advanced™ is shipped as a three-part reagent: *EDS-ER™*; a substrate shuttle; and an alkaline methylate solution, *EDS-Activator™*. All three reagents are mixed in the field with water and injected as a single solution. *EDS-Activator™* reacts *in situ* with the vegetable oil cleaving the fatty acids of the oil's triglyceride molecule. The reaction produces fatty acid esters, carboxylic acids, and glycerol, that are easy to distribute in the subsurface by advection. Their properties allow increasing the ROI and reducing the required number of injection points as larger volumes of substrate could be dispersed from a single injection point.

$$EDS-ER™ + Substrate\ Shuttle \xrightarrow{EDS-Activator™} \begin{matrix} Mixture\ of \\ Fatty\ Acid\ Esters \end{matrix} + \begin{matrix} Salts\ of\ the \\ Carboxylic\ Acids \end{matrix} + Glycerol$$

In addition to the benefits listed above, *EDS Advanced™* also increases VFA production (key to stimulate cDCE -> VC -> ethene) and inhibits methanogens. The pH of this system plays a key role in VFA production. *EDS Advanced™* is designed to enhance the activity of fatty acid-producing bacteria and inhibits the activities of methanogens, resulting in higher production of VFAs.

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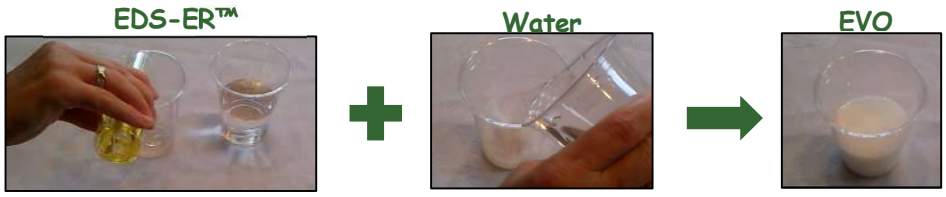
EDS-ER™ (electron donor solution – extended release)

Long-lasting Electron Donor

Released in 2011, *EDS-ER™* was the first water-mixable vegetable oil based organic substrate to provide a lasting source of carbon and hydrogen for enhanced reductive dechlorination and other bioremediation processes. *EDS-ER™* is shipped as a 100% fermentable substrate concentrate to create the right aquifer conditions for anaerobic remediation. *EDS-ER™* contains refined, bleached, and deodorized soybean oil and surfactants. The main role of the surfactant is to sufficiently reduce the energy (γo/w) required to increase the surface area so that spontaneous dispersion of oil droplets occurs, and the system is thermodynamically stable. When mixed with water, *EDS-ER™* spontaneously becomes an EVO. With 100% fermentable substrate, 60 lbs. of *EDS-ER™* provides the same amount of electron donor as 100 lbs. of a 60% EVO. The costs for shipping *EDS-ER™* are about 50% less than conventional EVO products.



EDS-QR™ (Electron Donor Solution – Quick Release)

Fast-acting Electron Donor

EDS-QR™ is a fast-acting, completely soluble amendment engineered for enhanced reductive dechlorination of chlorinated solvents or any other anaerobically degradable substance. Our *EDS-QR*™ product is USP Kosher Grade 99.7% purity USA sourced from an ISO Certified Plant. A key benefit is that *EDS-QR*™ provides more electron equivalence per pound than sodium lactate, so you buy and ship less product. With 99.7% organic carbon, 60 lbs. of *EDS-QR*™ provides the same amount of carbon as 100 lbs. sodium lactate. *EDS-QR*™ is an ideal choice for projects that are on a fast track. One injection will typically enhance biological activity for 2 to 3 months.

Bioaugmentation Cultures

KB-1® and *KB-1® Plus* are a consortium of microbes that are extremely effective in completing the reductive dechlorination of chlorinated solvents. Bioaugmentation leads to faster bioremediation, which means more efficient use of electron donors and reduced O&M requirements, thereby lowering overall project costs. The *KB-1®* family of bioaugmentation cultures is the most widely used culture in the world for remediating chlorinated solvents.

Our skill and experience implementing in situ bioremediation along with in situ chemical reduction creates high-value solutions to complex groundwater and soil contamination and related issues at a lower cost. Contact us today to find out more about partnering together to score a remediation touchdown at your chlorinated solvent sites.

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Nutrimens®

Enhancing Electron Donor Utilization

Nutrimens® provides reduced carbon and a wide array of beneficial vitamins, minerals, and metabolites to microbes for enhanced bioremediation of contaminated sites. It can be utilized in groundwater remediation efforts using the liquid or granular formulation or in bioreactors and constructed wetland treatment systems to improve remediation of effluents and surface waters for various metals. *Nutrimens®* increases removal rates of many priority pollutants and aids in maintaining circumneutral pH.

Our *Nutrimens®* technology has the potential to offer significant cost savings to the groundwater remediation industry. *Nutrimens®* offers a faster and lower cost alternative to a drawn-out natural attenuation approach.

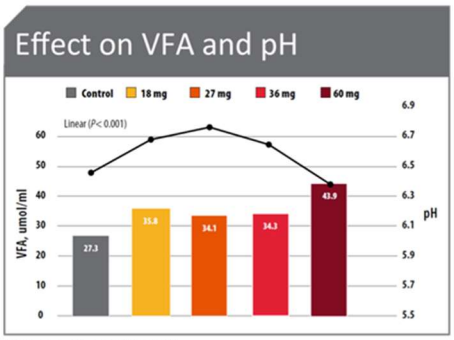
Features & Benefits

- Increase bioremediation kinetics
- Decreases remediation time
- Reduces the amount of substrate required
- Can be used as a standalone electron donor, combined with *EDS-ER™ or EDS-QR™*
- Food-grade carbon
- Clean, low-cost, non-disruptive application (e.g., direct-push, wells, and excavations)
- Green sustainable chemistry

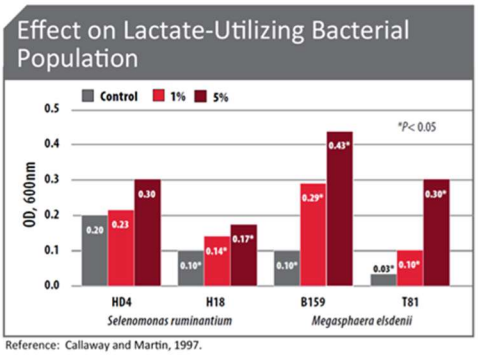
Optimizing Anaerobic Bioremediation

Bacteria are very sensitive to low pH. The optimal pH for bioremediation is between 6 and 8.5. To keep your *in-situ* bioremediation project on track, pH should be maintained within a range where bioremediation is maximized. In general, more fermentation means more volatile fatty acid (VFA) production and lower pH. A major consequence when pH falls below 6 is a dramatic decline in enhanced reductive dechlorination.

One of the unique features of Tersus' *Nutrimens® Granular* product is that the product stimulates fermentation resulting in more VFA production. Yet, its impact on pH is minimal. Doto and Liu (2011) reported an increase in total VFA production with increasing amounts of Tersus' *Nutrimens® Granular*, while the pH was maintained at a higher or equal level to the control. This change could be a result of more lactate-bacteria that convert lactate to propionate (Callaway and Martin, 1997.).



Reference: Doto and Liu, 2011.
Line graph represnts pH and bar graph represents VFA.



Reference: Callaway and Martin, 1997.

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Nutrients

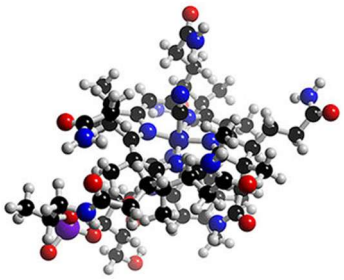
Contaminated matrices are usually deficient in nitrogen and phosphorus content, key elements in biological activities during microbial destruction of organic contaminants. *TersOx™ Nutrients* provides a unique, balanced blend of limiting nutrients to enhance the rate and consistency of biological degradation of contaminants.

TersOx™ Nutrients-QR

TersOx™ Nutrients-QR is a specialty blend of nitrogen, phosphorus, and microbial growth enhancers to stimulate biological activity. Tersus can blend site-specific combinations of macro and micronutrients to meet high biodegradation rate demands. Urea-Nitrogen, phosphates, dissolved iron, and pH buffers can be added to the mix after reviewing site conditions.

Vitamin B_{12} Supplement for *Dhc*

Dhc cultures require the cobalt-containing transition-metal coenzyme vitamin B_{12}. It is reported that optimal dechlorination and growth occur at vitamin B_{12} concentrations ranging from 25 to 50 micrograms per liter (25 to 50 µg/L) (Stroo et al., 2013). Vitamin B_{12} is not commonly found in simple substrates such as EVO and at considerably lesser amounts in micronutrient blends. To answer the growing demand for vitamin B_{12} and to provide for flexibility in adding vitamins in the field, Tersus offers Cyanocobalamin (Vitamin B_{12} USP) packaged in 100-gram tins.


Cyanocobalamin
(Vitamin B_{12})

Performance Monitoring

CSIA: A Powerful Tool for Remediation Assessment

The use of Compound-Specific Isotope Analysis (CSIA) to evaluate remediation performance is relatively recent but offers significant advantages over traditional methods. Whether for pilot- or full-scale treatment, CSIA helps confirm whether the intended mass removal process is occurring.

Applications for Chlorinated Solvent Remediation:

- Is PCE fully degraded to ethene?
- Are DCE or VC stalls occurring?
- Is there local heterogeneity at the site?

Monitor Groundwater Dynamics with iFLUX Samplers

iFLUX samplers simultaneously measure groundwater flow velocity (**water flux**) and contaminant transport (**compound flux**). By tracking these factors over time, they enable faster, more cost-effective remediation. Learn more at **tersusenv.com/iflux**.

Whether your focus is forensics, natural attenuation, or remediation performance, our team is here to support you.

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Products & Services for *In Situ* Remediation

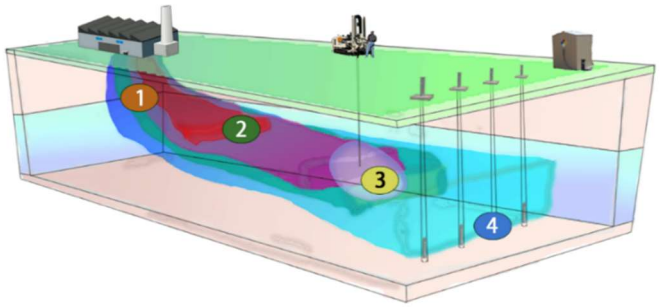
For Every Zone of Your Plume, We've Got You Covered!

1 Vadose Zone

- ***In-Situ* Chemical Oxidation (ISCO)**
- ***In Situ* Chemical Reduction (ISCR)**

2 Source Zone

- **Surfactant-Enhanced Aquifer Remediation (SEAR)**
- ***In-Situ* Chemical Oxidation (ISCO)**
- ***In Situ* Chemical Reduction (ISCR)**



3 Dissolved Phase

- ***In-Situ* Chemical Oxidation (ISCO)**
- ***In Situ* Chemical Reduction (ISCR)**
- **Carbon-Based Injectates (CBI) for *In Situ* Sorption and Bioremediation**
- **Anaerobic Oxidative Biostimulation**
- **Anaerobic Reductive Bioremediation**
- **Bioaugmentation**

4 Leading Edge

- **Aerobic Biostimulation**
- **Aerobic Bioaugmentation**

Professional Services

- **Contaminant Mass Flux Measurements**
- **Enviromental Forensics**
- **Performance Monitoring Plans**

Field Services

- **Treatability Studies**
- **Deployment Assistance**
- **Turn-key Services**

REQUEST A SITE EVALUATION AND COST ESTIMATE

If you have a project and need a remediation solution, visit **tersusenv.com/support** and complete the Site Evaluation Form. Our team will then reach out to offer options that best suit your goals.

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Sales and Technical Support
For every zone of your plume, we've got you covered!
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