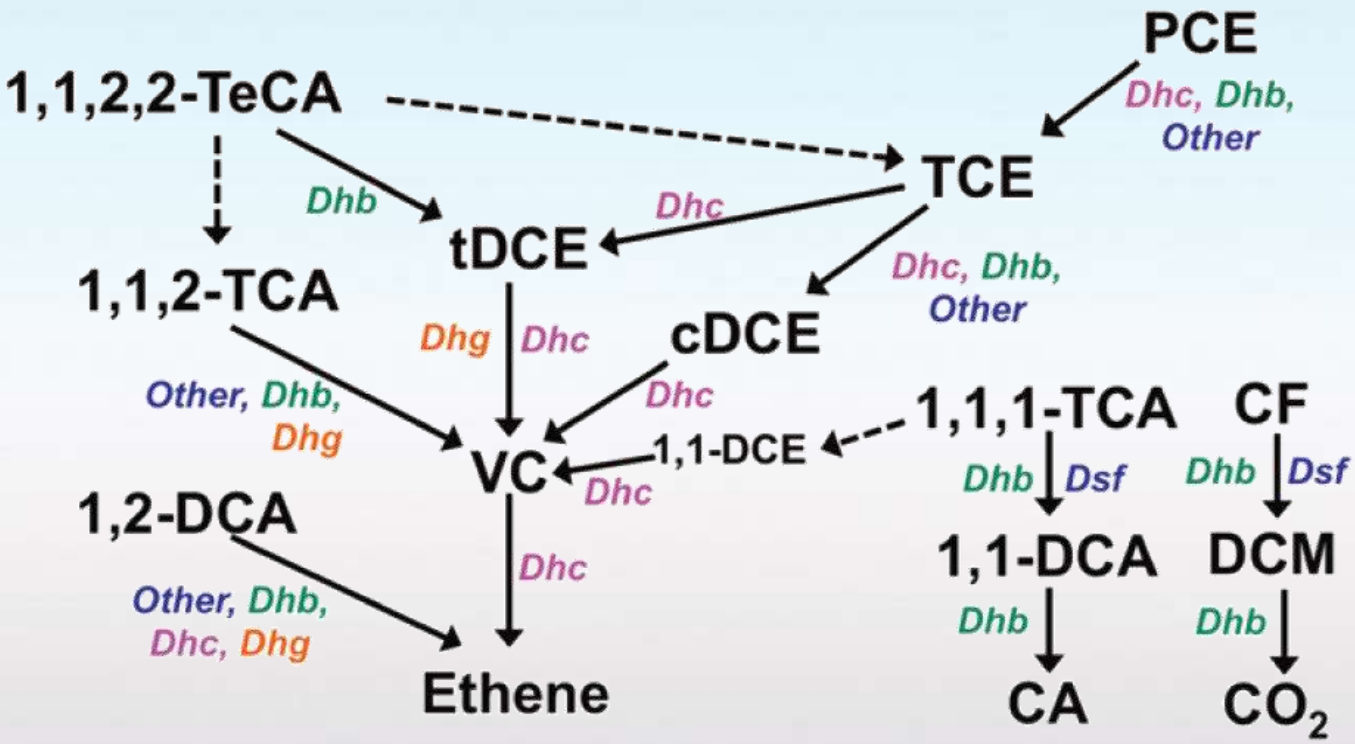
tersus environmental

Advancing the Science of *In Situ* Groundwater Remediation

CELEBRATING 10 YEARS 2011 2021 ANNIVERSARY

Chlorinated Solvent Remediation Technologies



Dhc = Dehalococcoides
Dhg = Dehalogenimonas
Dhb = Dehalobacter
Other = e.g., Desulfitobacterium (Dsf), Sulfurospirillum, Geobacter
----- Dashed lines are abiotic reactions

Overview of common chlorinated solvent dechlorination pathways and organisms responsible.

Wei, Kai & Grostern, Ariel & W. M. Chan, Winnie & E. Richardson, Ruth & Edwards, Elizabeth. (2016). *Electron Acceptor Interactions Between Organohalide-Respiring Bacteria: Cross-Feeding, Competition, and Inhibition.*

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Dissolved-Phase Treatment
Abiotic & Biotic Reduction

About Tersus Environmental

Tersus Environmental is extremely proud to be marking our 10th anniversary with the support of our dedicated associates, collaborative partnerships, and loyal clients. Tersus 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 an optimally cost-effective, remediation approach for your next project.

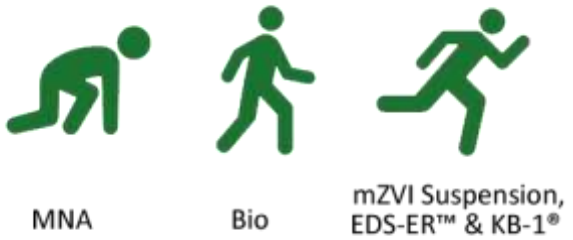
Soil and Groundwater Remediation of:

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

Abiotic and Biotic Treatment

In Situ Chemical Reduction
Biochemical Remediation Fast & Easy!

In Situ Chemical Reduction (ISCR) involves the placement of reductive additives 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 incorporation of or co-injection of ZVI particles with electron donor substrates like *EDS-ER™* further enhances chlorinated contaminant remediation.



Dissolved Contaminant Anaerobic Remediation

Enhanced reductive dechlorination (ERD) requires adding sufficient organic substrate (electron donor, such *EDS-ER™* or *EDS-QR™*, and nutrients, such as *Nutrimens®*) to satisfy electron acceptor demand from both inorganic and organic compounds (i.e., chlorinated solvents) in the treatment zone.

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. Although not necessary at every site, Tersus Environmental recommends use of the *KB-1®* family of bioaugmentation cultures to enhance reductive dechlorination of chlorinated solvent sites.

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In Situ Chemical Reduction

mZVI Suspension

mZVI is a colloidal suspension composed of ZVI particles in glycerol and dispersants designed to accomplish rapid and sustained degradation of chlorinated hydrocarbons and other toxic groundwater contaminants. With 40% ZVI in glycerol, *mZVI Suspension* provides the unique combination of small particle size, ease of use, and reactivity with many common groundwater contaminants. With *mZVI Suspension* you get a one-two punch: (1) rapid abiotic reactions along with (2) the polishing effects of anaerobic bioremediation processes.

Chemical & Physical Properties

mZVI Suspension

Parameter	Typical Values
ZVI (% by wt.)	40
ZVI average particle size	<10 µm
Organic Carbon (% by wt.)	60
Density	14 lbs./gal
Viscosity (cP)	~ 3,000
Water (% by wt.)	0

Easy to Use

The Tersus family of ISCR products are very easy to mix and inject into contaminated groundwater. The fluid is pumped or poured into mixing tanks containing water and optionally, other remediation amendments. The resulting aqueous suspension is then pumped directly into the contaminated groundwater at pressures that are often below 20 psi.

Our zero-valent metal products can be injected with a diverse set of equipment including pneumatic diaphragm pumps, progressing cavity pumps, and centrifugal pumps. A unique feature of our ISCR products is the ability to be injected through horizontal and vertical screened wells as well as sampler screens via DPT.

Metal-Assisted Bioremediation

Benefits and How They Are Attained:

- Low DO and ORP (< -200 mV): ***ZVI***
- Immediate onset of bioremediation: ***EDS-ER™***
- Enhanced bacterial populations; faster degradation: ***KB-1® and KB-1® Plus***
- Parallel abiotic degradation, Elimination of inhibitory contaminants (1,1,1-TCA): ***ZVI***
- Addresses recalcitrant compounds (DCM, 1,2-DCA): ***KB-1® Plus***
- Abundant hydrogen (H_2) for biotic degradation: ***EDS-ER™ and ZVI***
- Complete degradation to ethene: ***ZVI, KB-1® and KB-1® Plus***

Dissolved-Phase Treatment
Enhanced Reductive Dechlorination

Unrestricted Electron Donor Subsurface Distribution 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

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.

Dissolved-Phase Treatment
Enhanced Reductive Dechlorination

Long-lasting Electron Donor

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

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.

Fast-acting Electron Donor

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

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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Dissolved-Phase Treatment
Enhanced Reductive Dechlorination

Enhancing Electron Donor Utilization

Nutrimens®

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.

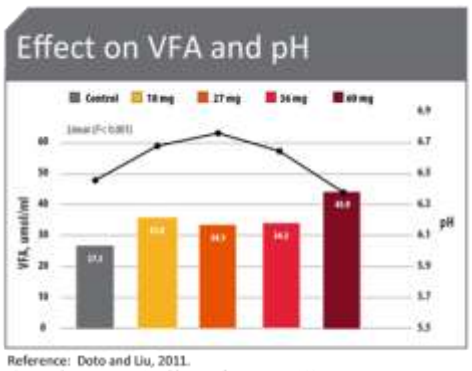
Features & Benefits

- 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

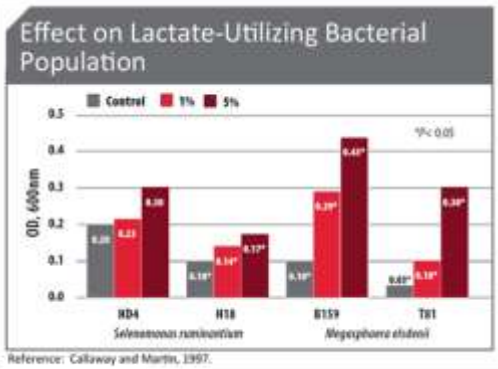
Optimizing Anaerobic Bioremediation

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.

Performance Enhancement Options

For every zone of your plume, we've got you covered!

Iron Sulfide Reagent (ISR)

ISR-Cl, an iron sulfide reagent (FeS), provides the benefits of sulfide-modified zero-valent iron and higher contaminant removal efficacy at a lower cost. Our abiotic *ISR-Cl* is synthetically manufactured and delivered to the site as an easy to inject colloidal suspension to promote effective subsurface distribution. The product works as a stand-alone amendment or in combination with other biostimulation (e.g., *EDS-ER™* and/or *EDS-QR™*) and bioaugmentation (*KB-1®*) methods.

ISR-Cl

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 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.

TersOx™ Nutrients-QR

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

The use of CSIA to assess performance of remediation treatment is quite recent and offers substantial advantages compared to traditional approaches. Whether you are conducting pilot scale or large-scale treatment, CSIA can be a valuable tool to validate if the intended mass removal process is initiated by the treatment. Here are some application suggestions related to chlorinated solvent remediation:

- Is PCE entirely degraded to ethene?
- Any DCE or VC stall?
- Any local heterogeneity on the site?

Whether your evaluation concerns forensics, natural attenuation or remediation treatment performance, our Team can offer valuable support.

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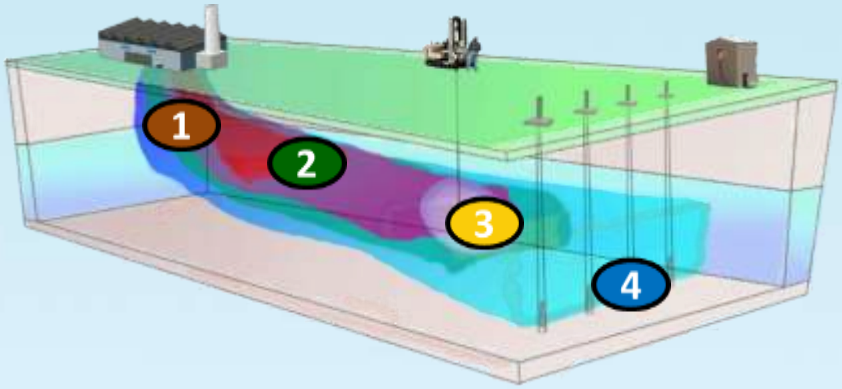
Chlorinated Solvent Remediation Technologies
Tersus Options by Zone



1 Vadose Zone

- ***In-Situ* Chemical Oxidation (ISCO)**
  Modulated TersOx™ Liquid
- ***In Situ* Chemical Reduction (ISCR)**
  mZVI Suspension

2 Source Zone

- **Surfactant-Enhanced Aquifer Remediation (SEAR)**
  TASK™ (Tersus Advanced Surface Kinetics)
- **ISCO**
  Modulated TersOx™ Liquid
- **ISCR**
  mZVI Suspension

3 Dissolved Phase

- **ISCR**
  mZVI Suspension
  Iron Sulfide Reagent (ISR)
- **Anaerobic Bioremediation**
  Emulsified Vegetable Oils (EVO): *EDS-ER™* and *EDS-Advanced™*
  EVO Emulsifiers: *TASK™ MicroEVO™ Self-Emulsifier*
  Soluble electron donors: *EDS-QR™* and *Nutrimens®*
- **Anaerobic Bioremediation (Continued)**
  Nutrients: *Nutrimens®* and *TersOx™ Nutrients*
  Vitamin B_{12} supplement for *Dhc*
  Bioaugmentation: *KB-1®* culture and anoxic media *KB-1®* Primer
- **ISCO**
  Modulated TersOx™ Liquid

4 Leading Edge

- **Aerobic Bioremediation**
  Oxygen-releasing chemistries (*TersOx™*)
  TersOx™ Nutrients (Slow Release, Quit Release, and Custom Formulations)
  Oxygen delivery systems (*Waterloo Emitter™)*

Sales and Technical Support

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For every zone of your plume, we've got you covered!
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