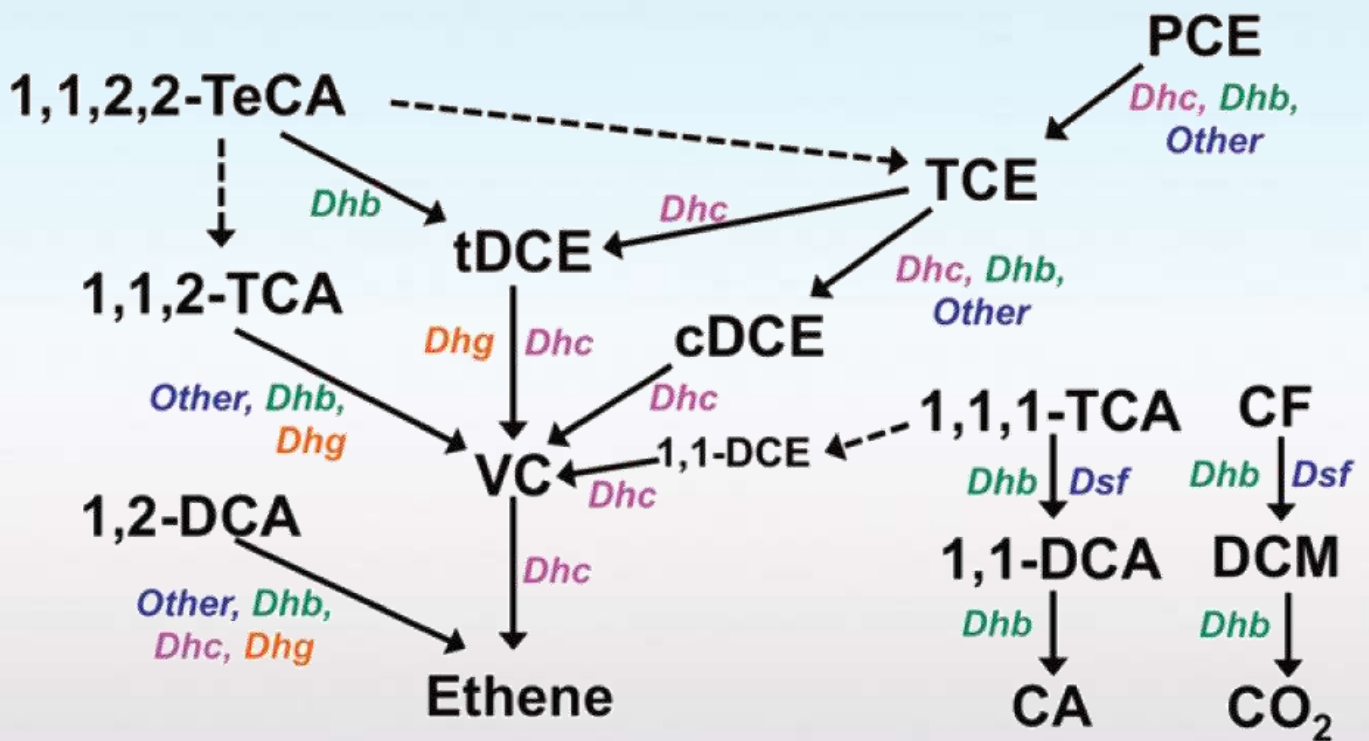


Chlorinated Solvent Remediation Technologies



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.*

About Tersus Environmental

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 the optimally cost-effective, remediation approach.

Soil and Groundwater Remediation of:

- Chlorinated Solvents
- Petroleum Hydrocarbons
- Other Recalcitrant Contaminants

Abiotic and Biotic Treatment

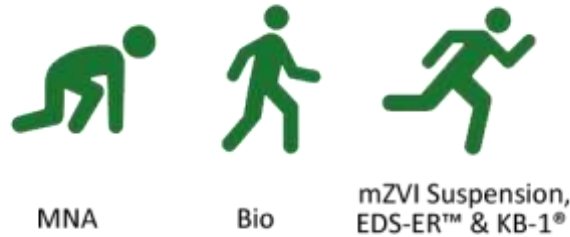
Saturated Zone NAPL Treatment

Emulsified Zero-Valent Iron (*eZVI*) combined with anaerobic *in situ* remediation has emerged in recent years as a viable and cost-effective remediation strategy for chlorinated solvents. The process involves injecting *eZVI* where the presence of DNAPL is suspected and the addition of amendments to groundwater and/or soil to stimulate and increase the number and vitality of existing bacteria capable of degrading the contaminant to innocuous end products. Tersus offers specialty products to successfully implement this remediation approach.

In Situ Chemical Reduction (ISCR)

Biochemical Remediation Fast & Easy!

ISCR combines both biological processes and ZVI-driven abiotic pathways to chemically reduce persistent organic compounds such as chlorinated solvents, pesticides and energetics into harmless end products. The incorporation of ZVI particles to injectable amendments enhances chlorinated contaminant remediation by enabling various chemical reduction pathways.



Dissolved Contaminant Anaerobic Remediation

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

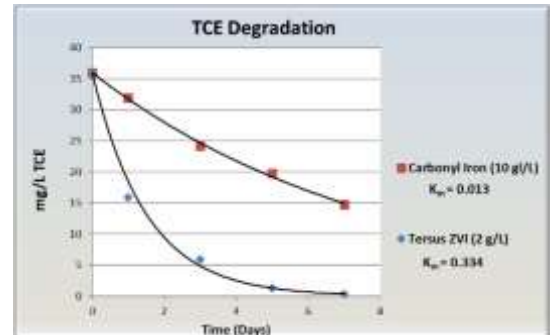
The complete reductive dechlorination of chlorinated ethenes yields non-toxic ethene as a final product. Absent the right bacteria, you could see an accumulation of vinyl chloride. Although not necessary at every site, Tersus recommends the use of *KB-1®* Bioaugmentation Culture.

*ISCR products sold under a License Agreement for U.S. Patent Nos. 7,129,388 and 7,531,709 relating to use of a mixture of organic hydrogen donors and zero valent metal used for environmental remediation applications.

The Tersus Advantage

All Zero-Valent Iron is Not the Same!

Recent studies were undertaken to evaluate the reactivity of various commercially available ZVI powders. The reactivity of sulfidated iron was compared with commercially available ZVI powders. Experiments involved adding 2 g/L of sulfidated iron to buffered tap water with 36 mg/L TCE and 3 mg/L PCE. Off-the-shelf ZVI powders were dosed at 10 g/L, five times greater.



The study concluded that the major difference between the sulfidated iron we use and off-the-shelf ZVI powders is the increased reactivity towards halogenated compounds of the modified ZVI. Sulfidated iron powders have a greater efficacy against chlorinated contaminants using a lower dose versus off-the-shelf ZVI powders. The sulfidated iron powders showed a 97% removal in five days at a dose of 2 g/L. The carbonyl iron showed a 59% removal in seven days at a dose of 10 g/L

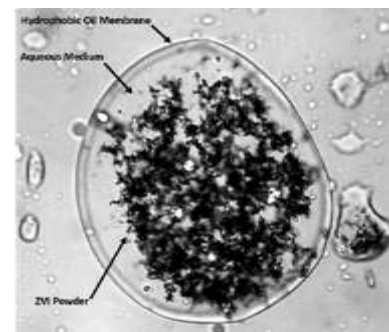
In Situ Destruction of DNAPLs

Emulsified Zero-Valent Iron (eZVI)

eZVI is an emulsion of powdered zero-valent iron, surfactant, vegetable oil, and water specifically designed for the remediation of source zones impacted with halogenated hydrocarbons. eZVI has the unique ability to mix with dense non-aqueous phase liquids (DNAPLs) by capitalizing on the ability of food-grade surfactants, biodegradable vegetable oil, water, and zero-valent iron to form hydrophobic emulsion droplets (micelles) that are miscible with DNAPL material *in situ* due to matching physical chemistries. Abiotic reductive dechlorination occurs as the halogenated hydrocarbons in DNAPL diffuse through the outer oil membrane into the interior aqueous phase of the emulsion, which contains zero-valent iron. Encapsulating zero-valent iron with a hydrophobic membrane protects the nano- and microscale iron from native groundwater constituents that might otherwise waste the iron's reducing capacity, and thereby reduce the mass of eZVI available to treat target contaminants and overall project costs. In addition to the abiotic reactions provided by the ZVI, the vegetable oil and surfactant components present in eZVI act as a long-term electron donor for enhanced biological reductive dechlorination.

Features & Benefits

- Effective for *in situ* treatment of source zones
- Directly treats residual DNAPLs
- Requires less treatment time and reduces total treatment costs
- Produces less-toxic and more easily degradable byproducts
- Environmentally safe
- Field-tested by the U.S. EPA under the SITE program
- Typical source concentration decrease by over 90% within 3 months
- Hydrophobic, dense emulsion absorbs DNAPL, delivering contaminant to iron





In Situ Chemical Reduction (ISCR)

Biochemical Remediation Fast & Easy!

mZVI Suspension is engineered to accomplish the rapid and sustained degradation of chlorinated hydrocarbons and other toxic groundwater contaminants. With 40% ZVI in glycerol and biodegradable food grade biopolymer, no other ZVI product 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 |
| Specific Gravity (Density) | 1.9 (15.8 lbs./gal) |
| Viscosity (cP) | ~ 3,000 |
| Water | 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.

No other zero-valent metal products can be injected with such 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**
- Sulfidated ZVI for efficient dehalogenation: *mZVI*
- 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**
- Can address DNAPL: **eZVI**
- Abundant hydrogen (H₂) for biotic degradation: **EDS-ER™ and ZVI**
- Complete degradation to ethene: **ZVI, KB-1® and KB-1® Plus**

Long-lasting Electron Donor

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

As delivered, the physical state of *EDS-ER™* is significantly different than standard emulsified vegetable oil (EVO) products. Whereas other EVO products are concentrated emulsions containing water, *EDS-ER™* is a water-mixable oil; it contains no water. 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.

At room temperature, *EDS-ER™* is a liquid material with an appearance and viscosity roughly equivalent to vegetable oil. Unlike common EVO products, *EDS-ER™* will not freeze and has a shelf life of two years without spoilage.



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

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.

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.

Chlorinated site stalled? Give it a push with *EDS-ER™* and *KB-1®*



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 drawn out natural attenuation approach.

Features & Benefits

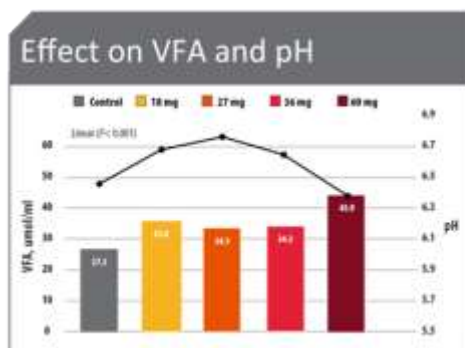
- Increase bioremediation kinetics
- Decreases remediation time
- Reduces the amount of substrate required
- Can be used as a standalone electron donor, combined with our substrates or hydrogen
- Food-grade carbon
- Clean, low-cost, non-disruptive application (e.g., direct-push, wells and excavations)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



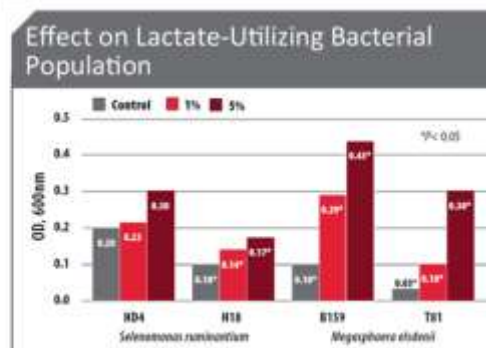
Optimizing Anaerobic Bioremediation

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 covert lactate to propionate (Callaway and Martin, 1997.).



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



Reference: Callaway and Martin, 1997.

Anaerobic Media for Bioaugmentation

Effective bioaugmentation for enhanced reductive dechlorination projects require the following geochemical conditions:

- Redox levels (ORP) below -75 mV
- Dissolved oxygen levels less than 0.2 mg/L
- pH between 6 and 8.5

Tersus provides food-grade amendments that, when added to water, instantly create hundreds of gallons of anoxic media to protect bioaugmentation cultures during injection. This shield allows single mobilization for both biostimulation and bioaugmentation events.



KB-1® Primer powder is shipped in vacuum sealed pouches

Vitamin B₁₂ Supplement for Dhc

Dhc cultures require the cobalt-containing transition-metal coenzyme vitamin B₁₂. It is reported that optimal dechlorination and growth occur at vitamin B₁₂ concentrations ranging from 25 to 50 micrograms per liter (25 µg/L) (Stroo et al., 2013). Vitamin B₁₂ is not commonly found in simple substrates such as emulsified vegetable oil (EVO) and at considerably lesser amounts in micronutrient blends. To answer the growing demand for vitamin B₁₂ and to provide for flexibility in adding vitamins in the field, Tersus offers Cyanocobalamin (Vitamin B₁₂ USP) packaged in 100-gram tins.

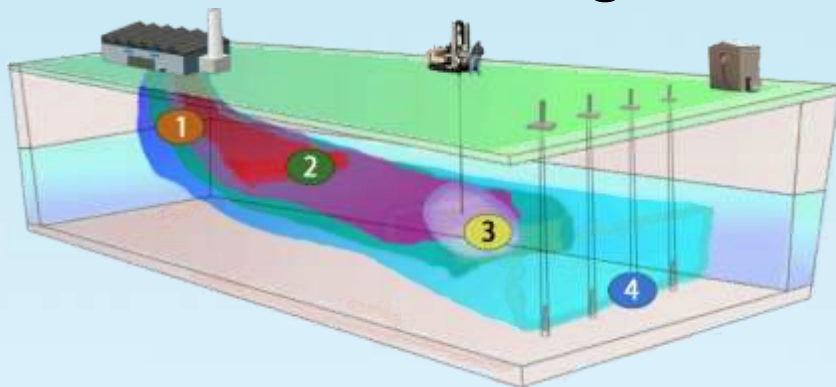


Cyanocobalamin
(Vitamin B₁₂)



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.

Chlorinated Solvent Remediation Technologies



1

Vadose Zone

- *Modulated TersOx™ Liquid*
- *Emulsified Zero-Valent Iron (eZVI)*

2

Saturated Zone DNAPL

- *eZVI*
- *TASK™* (Tersus Advanced Surface Kinetics)

Dissolved Contaminant

In Situ Chemical Reduction (ISCR)

- *mZVI Suspension*

Enhanced Anaerobic Bioremediation

- Emulsified Vegetable Oils (EVO): *NanoEVO™* and *EDS-ER™*
- EVO Emulsifiers: *TASK™ NanoEVO™* and *MicroEVO™ Self-Emulsifier*
- Soluble electron donor and nutrients: *EDS-QR™* and *Nutrimens®*
- Vitamin B₁₂ supplement for *Dhc*
- Bioaugmentation: *KB-1®* culture and anoxic media *KB-1® Primer*

3

Activated and Exothermic Controlled (ACE) ISCO

- *Modulated TersOx™ Liquid*

4

Dissolved Contaminant Aerobic

- Peroxygens (*TersOx™ Powder* and *Granular*)
- *TersOx™ Nutrients* (Slow Release, Quit Release and Custom Formulations)
- Oxygen delivery systems (*Waterloo Emitter™*)

Sales and Technical Support



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