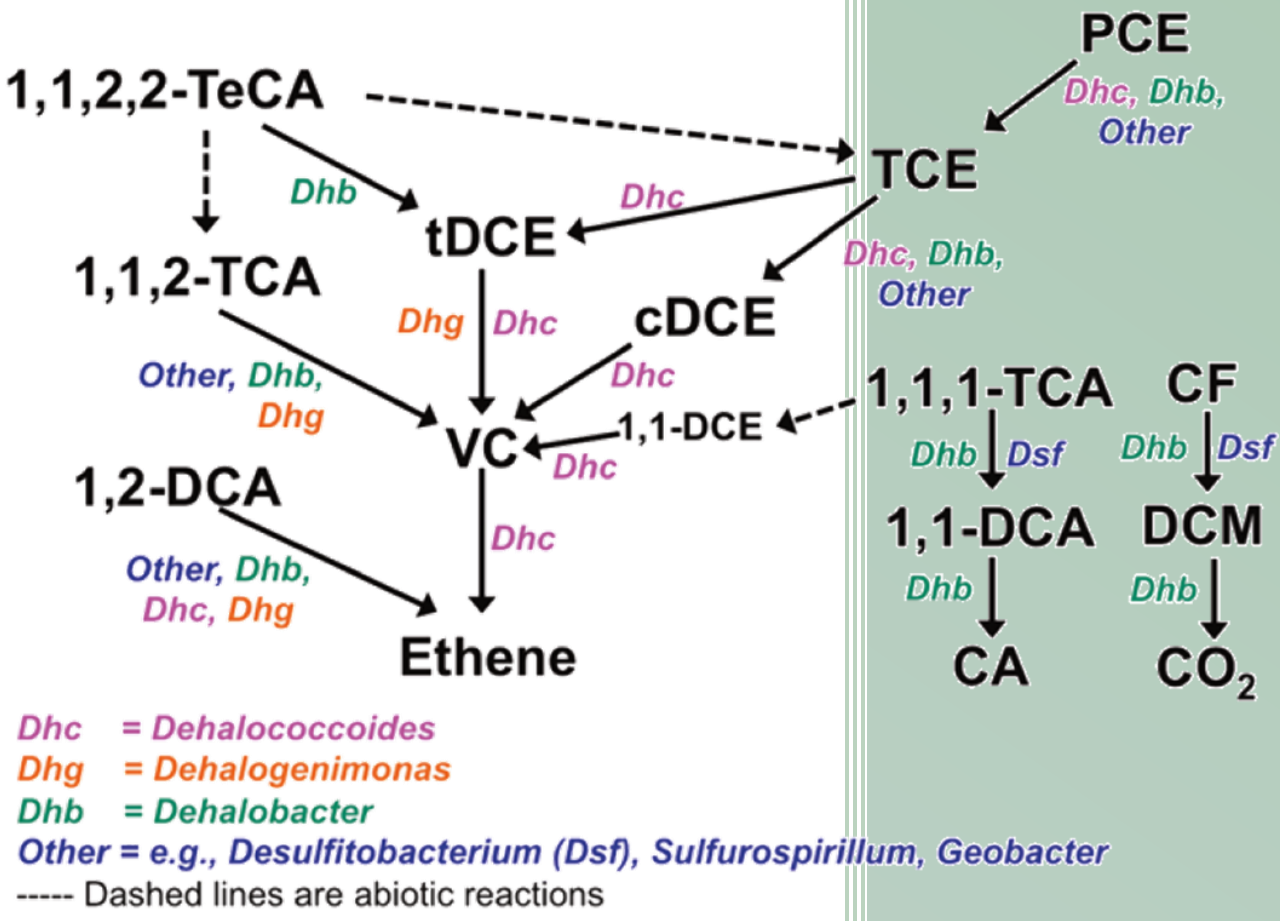
Chlorinated Solvents

Remediation Technologies and Services



Overview of common chlorinated solvent dechlorination pathways and organisms responsible.

Wei K., Grostern A., Chan W.W.M., Richardson R.E., Edwards E.A. (2016) Electron Acceptor Interactions Between Organohalide-Respiring Bacteria: Cross-Feeding, Competition, and Inhibition. In: Adrian L., Löffler F. (eds) Organohalide-Respiring Bacteria. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-49875-0_13

Tersus Environmental
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Dissolved-Phase Treatment
Chlorinated Solvents

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

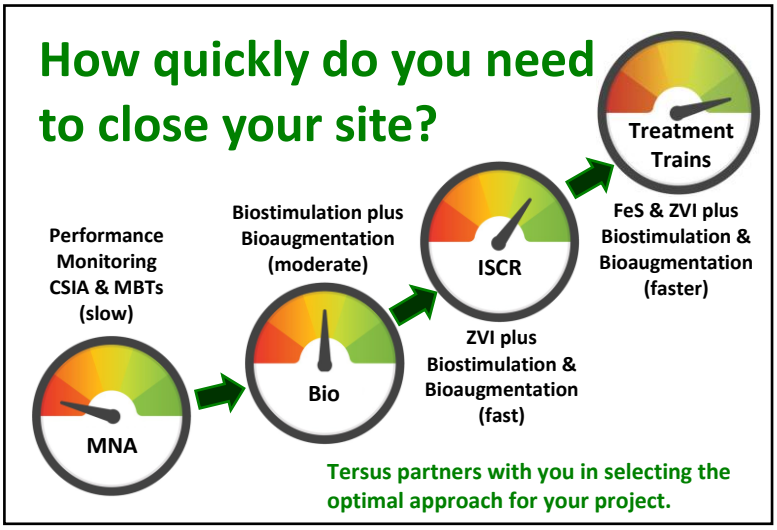
Company Information:

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

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.



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

ironGel™ is a paradigm shift in the preparation of microscale zero-valent iron (mZVI) colloidal suspensions. 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.

ironGel™

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

Iron Sulfide Reagent (Tersus ISR-Cl)

Sulfide-modified zero-valent iron is attracting more attention due to its ability to achieve much higher contaminant removal efficacy than unmodified ZVI due to its selectivity to pollutants over water. "For dechlorination, sulfidation not only inhibits the reaction between Fe(0) and H2O but creates a nucleophilic zone on the particle surface which is favorable for β-elimination" (Yiming Su, Gregory V. Lowry, David Jassby, and Yalei Zhang, 2019).

Without sulfidation, ZVI will generate both H_2 to promote biological processes and electrons for abiotic pathways. With sulfidation, the production of electrons for abiotic pathways will dominate the reactions.

Sulfide-modified zero-valent iron forms ferrous sulfide (FeS) which promotes the abiotic pathways. FeS (Tersus' *ISR-Cl*) is highly reactive with chlorinated organic compounds. Tetrachloroethene (PCE) is mainly reduced by FeS to acetylene via β-elimination (dominating reaction), to trichloroethene (TCE) via hydrogenolysis, and to 1,1-dichloroethene (DCE) via α-elimination; TCE transforms to acetylene also via β-elimination (dominating reaction) and to DCE via hydrogenolysis (Jeong et al., 2007a, b).

The point of Tersus *ISR-Cl* is to promote the same abiotic pathways that sulfidated ZVI promotes. *ISR-Cl* is a liquid iron-based reagent that mimics naturally occurring biogeochemical reduction of solvents in aquifers. Adding this product to your aquifer quickly creates conditions that promotes abiotic and biotic activity that degrades chlorinated ethenes, ethanes, and precipitates toxic metals. The product has an ORP of -700 to -1,300 mV. Injecting this liquid iron sulfide solution is easier than directly adding a solid material, so better subsurface distribution is possible, including situations with lower permeability. The cost for *ISR-Cl* is also typically less than sulfidated ZVI. The product can also be used in combination with ZVI and organic hydrogen donors.

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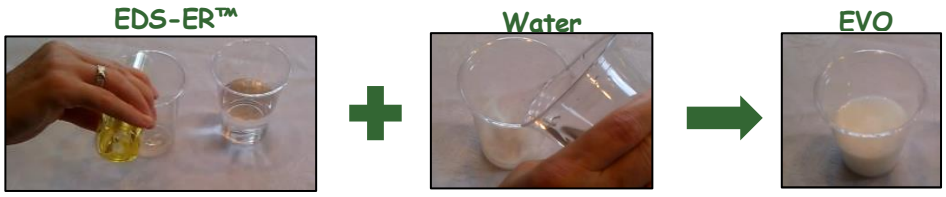
EDS-ER™ (electron donor solution – extended release)

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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Dissolved-Phase Treatment
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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.

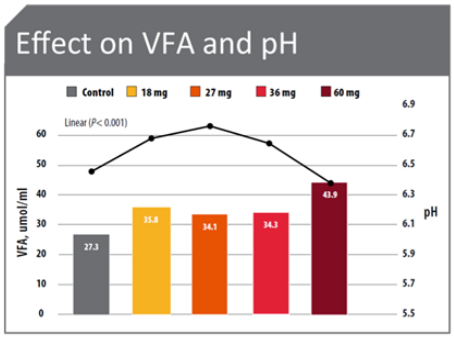
Features & Benefits

- 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

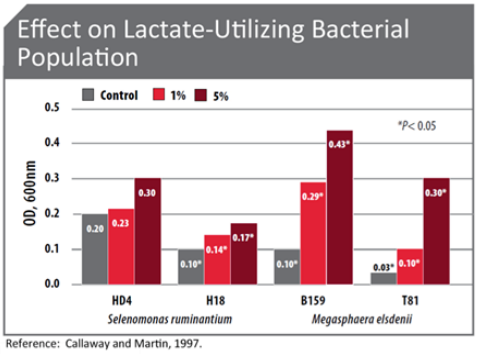
Optimizing Anaerobic Bioremediation

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.

Enhancement Options
& Performance Monitoring

Nutrients

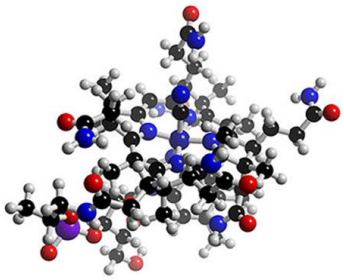
Contaminated matrices are usually deficient in nitrogen and phosphorus content, key elements in biological activities during microbial destruction of organic contaminants. *TersOx™ Nutrients* provides a unique, balanced blend of limiting nutrients to enhance the rate and consistency of biological degradation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

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.

Tersus Provides Site-Specific Remediation Programs and Performance Monitoring Plans To Meet Your Budget

Interested in a Site Evaluation? Scan the code to the right or visit tersusenv.com/support

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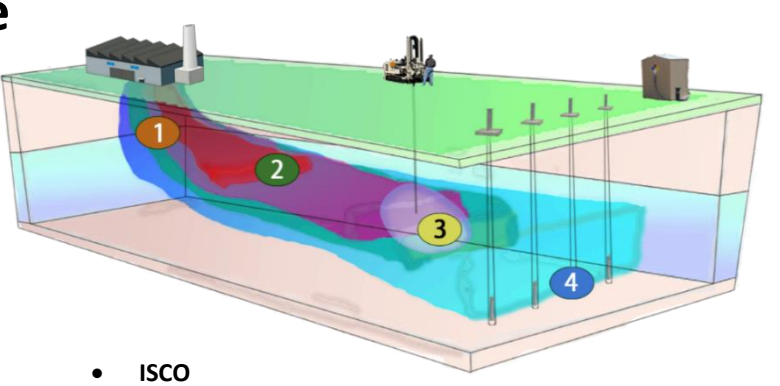
Chlorinated Solvent Remediation Technologies
Tersus Options by Zone



1 Vadose Zone

- ***In-Situ* Chemical Oxidation (ISCO)**
  Modulated TersOx™ Liquid
- ***In Situ* Chemical Reduction (ISCR)**
  Microscale ZVI Suspensions

2 Source Zone

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

3 Dissolved Phase

- ***In Situ* Sorption and Biodegradation**
  NutriBind®
- **ISCR**
  Microscale ZVI Suspensions
  Iron Sulfide Reagent (ISR)
- **Anaerobic Reductive Bioremediation**
  Emulsified Vegetable Oils (EVO): *EDS-ER™* and *EDS-Advanced™*
  EVO Emulsifiers: *TASK™ MicroEVO™ Self-Emulsifier*
  Soluble electron donors: *EDS-QR™* and *Nutrimens®*
- **Anaerobic Reductive 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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