

## Remedial Action Plan for Anaerobic Treatment of Chlorinated Aliphatic Hydrocarbons

### Purpose

The purpose of this document is to allow the remediation specialist to use parts of this document as a template for their specific remediation action plan (RAP) for the anaerobic bioremediation of chlorinated aliphatic hydrocarbons (CAH) using inVentures Technologies Inc. iSOC<sup>®</sup> Technology. Specific site information should be used in conjunction with the material provided herein as the specialist sees fit. This document summarizes aspects of the scope or insertions into the scope of work to be performed at a CAH impacted site to remediate groundwater contaminated with various constituents of concern including but not limited to tetrachloroethene (PCE), trichloroethene (TCE), dichloroethene (DCE) and vinyl chloride (VC). This methodology is applicable to any compound that is subject to reductive dechlorination under anaerobic conditions.

### Caution of Use

This document does not provide specific recommendations for the site. It is incumbent upon the plan designer to follow all regulatory requirements; federal, state, and local notifications; all jurisdictional permits and laws. The user assumes all responsibility for any consequences resulting from the use of this information or the use of any product described herein.

**The blue font in the document represents comments.**

**The black font in the document is text that can be inserted into the RAP.**

**The red font identifies information that the remediation designer should insert.**

### Proposed Remedial Action

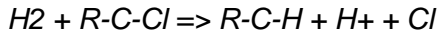
#### **Overview of Biological Reductive Dechlorination**

The in situ groundwater bioremediation process relies on microorganisms (soil bacteria) that are stimulated by adding electron donors changing, prevailing redox conditions where necessary, and leading to biological contaminant degradation in groundwater. Highly oxidized chlorinated aliphatic hydrocarbons such as tetrachloroethene (PCE) and lower CAHs are used as electron acceptors in the anaerobic process of biologically mediated reductive dechlorination. During the anaerobic biological process, hydrogen substitutes for a chlorine ion on the PCE molecule forming TCE, which can be further reduced to DCE, VC and ethene.

The effect of electron donor addition depends on electron acceptors present. Competing electron acceptors include dissolved oxygen (DO), nitrate, ferric iron (Fe<sup>3+</sup>) and manganese IV must be reduced to reach favorable conditions for reductive dechlorination.

## Reductive Dechlorination Process

*Anaerobic reductive dechlorination of CAHs using hydrogen as an electron donor proceeds by the following generalized reaction:*



*Where C-Cl represents a carbon-chloride bond in a chlorinated molecule, C-H represents a carbon-hydrogen bond, and R represents the remainder of the molecule. In these reactions, two electrons are transferred with molecular hydrogen (H<sub>2</sub>) as the electron donor (which is oxidized) and the chlorinated molecule (R-C-Cl) as the electron acceptor (which is reduced).*

(AFCEE 2004)

The reductive dechlorination of CAHs in groundwater is implemented at a site by the infusion of hydrogen as an electron donor with the iSOC<sup>®</sup> Gas inFusion delivery system. If not already present, anaerobic conditions are generated by the delivery of hydrogen. Sufficient mass of hydrogen must be delivered to satisfy hydrogen demand, calculated from estimates of competing electron acceptors and CAH mass present in the treatment zone. Where appropriate this calculation includes the mass of electron acceptors in the dissolved and solid phase within the treatment area and the mass flux of electron acceptors into the treatment area with groundwater flow. The required mass of hydrogen can then be compared to rates of hydrogen delivery by iSOCs to determine the appropriate number of treatment units necessary for the projected treatment time frame. The design layout and number of treatment wells must also be developed in consideration of site specific hydrogeologic conditions.

On a mass basis, 1.0 gram of molecular hydrogen is sufficient to dechlorinate the following mass of CAHs, assuming 100 percent utilization of molecular hydrogen by the dechlorinating microorganisms:

- 20.6 grams of PCE to ethene
- 21.7 grams of TCE to ethene
- 24.0 grams of DCE to ethene
- 31.0 grams of VC to ethene

Competing electron acceptors may be dissolved in groundwater or present as a solid. One gram of molecular hydrogen is also sufficient to reduce the following mass of competing electron acceptors:

- 7.9 grams of oxygen
- 10.2 grams of nitrate
- 55.9 grams of Iron III (reduced to Fe(II) - aquifer solid demand)
- 27.5 grams of Manganese IV (reduced to Mn(III) - aquifer solid demand)
- 10.6 grams of sulfate
- 5.5 grams of carbon dioxide

(AFCEE 2004)







### Performance Monitoring

Groundwater sampling events will be conducted on a quarterly basis. Each of the quarterly sampling events will consist of collecting groundwater samples from performance monitoring wells for analysis of the constituents of concern and indicator parameters. Sampling will be done in accordance with the approved methodology including (specify requirements).

### Baseline Sampling

Prior to system implementation, a baseline sampling event will be conducted on a minimum of 2 wells within the plume. A summary of proposed analyses is shown below:

Indicator	Analyses
Contaminant	VOCs
Microbial Activity	Polymerase Chain Reaction (PCR) for detecting the presence of the bacterium <i>Dehalococcoides ethenogenes</i>
Field parameters	Dissolved Oxygen (DO) Oxidation-Reduction Potential (ORP) Temperature, pH, conductivity
Dissolved gases	Hydrogen, ethene, ethane, carbon dioxide and methane
Electron acceptors	Total and dissolved iron and manganese, nitrate, sulfate

This data will be used to assess remedial progress at the site for optimization as necessary.

### iSOC<sup>®</sup> Bioremediation System Costs

(Insert site specific cost information where required)

The system capital costs include groundwater treatment system components and construction engineering. The suggested component headings for the system design include:

- Groundwater Treatment System
  - Infusion Well Installations
  - Hydrogen Infusion Equipment
  - Miscellaneous (Baseline Sampling Event)
- Construction Engineering
  - Construction Labor & Equipment Rental
  - Engineering Oversight
  - Utility Clearance & Mobilization
  - Proposal Preparation

Construction Drawings & Specifications  
Bid Package Solicitation & Evaluation  
RA Startup Report (Includes As-Builts)  
Permitting & Mobilization  
Professional Surveying  
Oversight

The system O&M costs will consist of

Analytical costs  
Quarterly Monitoring Reports  
System checks – 2 times first month and then monthly  
Gas usage and tank rental  
Quarterly Sampling Visit

### **References and Suggested Reading**

The following publications are suggested as references and informative reading for the remediation specialist.

Sutherson, Suthan S. Remediation Engineering; Design Concepts. New York: CRC Lewis Publishers, 1997.

*Principles and Practices of Enhanced Anaerobic Bioremediation of Chlorinated Solvents*  
Prepared by the Air Force Center for Environmental Excellence (AFCEE), 2004  
<http://www.afcee.brooks.af.mil/products/techtrans/Bioremediation/BIOREMresources.asp>

**[www.isocinfo.com](http://www.isocinfo.com)**