REGENESIS PRACTICES GREEN CHEMISTRY

According to the United States Environmental Protection Agency (USEPA), Green chemistry consists of chemicals and chemical processes designed to reduce or eliminate negative environmental impacts. The use and production of these chemicals may involve reduced waste products, non-toxic components, and improved efficiency. Green chemistry is a highly effective approach to pollution prevention because it applies innovative scientific solutions to real-world environmental situations. The 12 Principles of Green Chemistry provide a road map for chemists to implement green chemistry and are listed below for your reference.

1. Prevent waste  
2. Design safer chemicals and products  
3. Design less hazardous chemical syntheses  
4. Use renewable feedstocks  
5. Use catalysts, not stoichiometric reagents  
6. Avoid chemical derivatives  
7. Maximize atom economy  
8. Use safer solvents and reaction conditions  
9. Increase energy efficiency  
10. Design chemicals and products to degrade after use  
11. Analyze in real time to prevent pollution  
12. Minimize the potential for accidents

For specific information about how Regenesis products align with the 12 Principles of Green Chemistry please visit our website at www.regenesis.com

MISSION

Our mission is to develop, manufacture and market advanced, innovative technologies for the restoration or remediation of natural resources such as groundwater and soil. Our efforts are driven by and focused on technology performance, customer needs and cost-effectiveness. Our technologies will be supported by the highest level of scientific research and technical support within the industry. Looking forward, we will seek out and explore new technologies for the prevention and/or remediation of a broad range of environmental concerns.

COMPANY HISTORY

Incorporated in March 1994, Regenesis was formed to develop and commercialize its first product, Oxygen Release Compound (ORC®). This unique formulation of phosphate - intercalated magnesium peroxide was the first of its kind to provide controlled-release oxygen and was specifically designed for the in-situ treatment of aerobically degradable, petroleum hydrocarbon contamination. Following extensive laboratory and field testing, ORC was successfully introduced to the groundwater remediation market in the spring of 1995. This new, low-cost and in-place treatment approach quickly expanded as a replacement technology for expensive, above-ground, mechanical pump and treat systems.

In 2000, another ground breaking technology, Hydrogen Release Compound (HRC®) was successfully brought to market. It was designed to provide a low-cost, controlled-release of hydrogen in the subsurface to support the anaerobic degradation of chlorinated contaminants. Shortly thereafter, several different versions of HRC were commercialized in response to customer need, particularly HRC-X® for extended hydrogen production and HRC Primer® for more rapid hydrogen production.

Leading up to 2004, Regenesis had been primarily in the business of providing products for the accelerated, in-situ treatment of lower concentration, dissolved-phase contaminants that could be readily degraded through aerobic or anaerobic processes. However the need for the in-situ remediation of higher concentration, source areas was growing and employing more aggressive chemical oxidation processes. In late 2004, Regenesis began laboratory then field testing of a new chemical oxidation product known today as RegenOx™. RegenOx was quickly embraced by remediation professionals as it offered a safe, effective and easy to apply alternative to other chemical oxidants.

In early 2005, Regenesis went back to the lab to re-engineer HRC. This effort was put forth in response to customer requirements for a product that could be applied in higher volumes, achieve much greater subsurface distribution, and have equal if not greater longevity than original HRC. The result was 3-D Microemulsion®, a completely new molecule that met all of our customer needs at a price point close to that of basic commodity chemicals.

Land Science Technologies, a new division of Regenesis, was formed in 2007 to support the new and growing arena of Brownfields redevelopment. This new group brought to market Geo-Seal™, an industry leading, gas vapor barrier designed to provide chemical resistance, constructability and cost-effectiveness. To date, Geo-Seal has been applied on redevelopment sites owned by Fortune 500 Companies and around the world. Visit www.landsciencetech.com for more information.

Regenesis continues to pursue its commitment to its customers and the environmental remediation industry through the development and enhancement of an entire line of remediation technologies. Looking forward, after over a decade and over 16,000 remediation project sites, Regenesis will pursue its commitment to serving our customers with state-of-the-art technologies and support services. We will continue in our leadership role developing technologies to meet the world’s growing demand for innovative environmental solutions.
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**Important Note for International Customers**

All products listed in this brochure may not be available in all countries. Please check with Regenesis or your local representative about the availability of specific products in your area or region. Visit www.regenesis.com for more information.
CHEMICAL OXIDATION

RegenOx™

RegenOx is an advanced, chemical oxidation technology designed to treat organic contaminants including high concentration source areas in the saturated and vadose zones. This product maximizes in-situ performance through the use of a simple, two-part process that produces an effective oxidation reaction without a violent exothermic reaction. It can be used on a wide range of contaminants in both soil and groundwater and is easily applied to the subsurface using readily available direct-push equipment.

ENHANCED AEROBIC BIOREMEDICATION

Oxygen Release Compound Advanced (ORC Advanced®)

This product is a patented, controlled-release, oxyhydroxide-based peroxygen product designed to deliver pure oxygen into the subsurface. In the presence of oxygen, microbes can effectively stimulate the aerobic degradation of petroleum hydrocarbons and other aerobically degradable compounds. Available as a bulk powder or in filter sock form, ORC Advanced contains 17% oxygen by weight and typically delivers oxygen to the subsurface for periods of up to 12 months.

Oxygen Release Compound (ORC®)

ORC is the original, controlled-release, magnesium-based peroxygen product designed to deliver pure oxygen into the subsurface for the purpose of stimulating the aerobic degradation of petroleum hydrocarbons and other aerobically degradable compounds. Available as a bulk powder or in filter sock form, ORC contains a minimum of 10% oxygen by weight and typically delivers oxygen to the subsurface for periods of up to 12 months.

ENHANCED ANAEROBIC BIOREMEDICATION

3-D Microemulsion (3DMe)®

3DMe sequentially releases hydrogen through the use of three types of electron donors: a) free lactate; b) tetramers of lactic acid (poly-lactate); and, c) fatty acids (primarily unsaturated C-18 fatty acids like oleic acid). The polylactate and fatty acids are esterified to a carbon backbone molecule of glycerin. As a result of this unique molecular structure (patent pending), 3DMe provides a consistent and long-lasting source of hydrogen by delivering an immediate, mid-range and long-term release of lactic and fatty acids (for periods of up to 3-5 years).

In addition, 3DMe provides enhanced subsurface distribution through the mechanism of micellar transport. Greater distribution means an increased radius of influence, maximizing contact between the material and the contaminant.

Hydrogen Release Compound (HRC®)

HRC is a patented, controlled-release, polylactate ester mixture specially formulated to slowly release lactic acid upon hydration. When placed into a contaminated aquifer, the lactic acid from HRC stimulates a multi-step process resulting in hydrogen production. The newly available hydrogen is made available for the natural process of reductive dechlorination. This microbially mediated process results in the subsequent degradation of a wide range of chlorinated contaminants (including PCE, TCE, TCA and their derivatives) as well as other anaerobically degradable compounds. HRC has been shown to produce hydrogen in groundwater for periods of up to 18 months.

Hydrogen Release Compound Extended Formula (HRC-X®)

HRC-X is an extended release formulation of the patented and widely accepted HRC product. HRC-X is a more viscous, gel-like material composed entirely of polylactate esters. Once injected into an aquifer setting, this material has been shown to produce reducing conditions for periods of at least 3 to 5 years on a single application.

METALS IMMOBILIZATION

Metals Remediation Compound (MRC®)

MRC is a controlled-release formulation designed specifically for the treatment of metals such as hexavalent chromium Cr(VI) in groundwater. It removes dissolved hex-chrome via in-situ immobilization and also provides a substrate for the biodegradation of chlorinated solvents and other anaerobically degradable compounds.

BIOAUGMENTATION

Bio-Dechlor Inoculum® Plus

Bio-Dechlor INOCULUM PLUS is an enriched microbial consortium containing species of Dehalococcoides. Originally isolated from an aquifer contaminated with chlorinated solvents, this microbial consortium has since been enriched to increase its ability to rapidly dechlorinate specific contaminants during in-situ bioremediation processes. This product offers the ability to accelerate the process of complete dechlorination at various stages of site remediation.
FREE APPLICATION DESIGNS AND COST-ESTIMATES

As part of an on-going commitment to customer service and support, Regenesis maintains a full-time technical services staff to provide free application designs and cost-estimates.

AVOID CAPITAL, DESIGN, OPERATIONS AND MAINTENANCE COSTS

Regenesis products are designed to be directly injected into the subsurface, eliminating substantial design, capital, and operations/maintenance (O&M) costs. In contrast, actively engineered systems such as pump and treat or air sparging with soil vapor extraction are expensive, obtrusive, energy dependent, time intensive and require elaborate site design.

ELIMINATE LONG-TERM MONITORING COSTS ASSOCIATED WITH NATURAL ATTENUATION

By accelerating the rate of natural attenuation, Regenesis products can decrease the time spent to reach site closure. This avoids the recurring costs of quarterly or yearly monitoring events that are required to evaluate the progress of a lengthy unassisted natural attenuation approach.

REDUCE RISK AND POTENTIAL LIABILITY

Unchecked, a migrating plume can pose significant financial and health risks. Most Regenesis products can be strategically applied to remediate contaminants in, around or downgradient of a contaminant plume using the variety of application methods cited. These products can be applied at a fraction of the cost of iron wall technologies, active pumping or sparging systems. This approach eliminates plume migration and avoids the potential liability associated with unmanaged contaminant migration and “leave alone” natural attenuation approach.

MINIMAL SITE DISTURBANCE

Regenesis products offer an in-situ treatment approach that eliminates the need for permanent, obtrusive, above-ground equipment. Thereby allowing remediation to occur without disrupting normal business or commercial activities. Applying these products to the subsurface is fast and easy, leaving no visible signs of activity.

APPLICABLE AT DIFFICULT TO MANAGE SITES

Controlled-release oxidants and reductants are ideal for sites where geological or physical conditions make active systems inappropriate. Particularly in clay soils, where pumping is difficult and sparging promotes channeling, the controlled-release of a diffusible material like oxygen from ORC and hydrogen from HRC has distinct advantages. Both products have been successfully applied into fractured bedrock aquifers where the controlled-release process facilitates remediation along the fracture planes.

SAFE APPLICATION AND TREATMENT

The controlled-release of oxygen from ORC and ORC Advanced as well as the mild exothermic reactivity of RegenOx avoids the temperature and volatility hazards associated with Fenton’s Reagent and hydrogen peroxide injections. The controlled-release of hydrogen from the HRC line of products limits the production of methane which often results from excess hydrogen formation associated with rapidly fermentable substrates.

ENVIRONMENTALLY BENIGN

Besides oxygen, the only other by-product of ORC’s reaction with water is magnesium hydroxide or Mg(OH)₂. This substance is more generally known as milk of magnesia, a common antacid. With regard to HRC, the product itself is water soluble and is completely consumed by microbes. Both products are nontoxic, food-grade materials designed with environmental safety in mind. ORC Advanced and RegenOx (Part A) are classified as 5.1 oxidizers and should be handled accordingly.

REDUCTION OF OVERALL ENVIRONMENTAL IMPACTS

Factoring in energy use and disposal issues, Regenesis products reduce impacts to air quality, wastewater discharges and hazardous material disposal. The use of these products eliminates the need for energy to sustain remediation (unlike mechanical systems). Limited energy demands minimize the potential for emissions and therefore reduce air pollution. Additionally, many of Regenesis’ products do not require the handling, transport or disposal of any hazardous liquids or solids. Overall the use of Regenesis’ products generate a substantial net environmental benefit.

A COMPLETE CHEM TO BIO STRATEGY

A well executed chemical to biological treatment approach can result in significant contaminant reductions and may also yield substantial cost savings. This can be accomplished by using Regenox to treat the higher concentration, source areas followed by enhanced bioremediation to degrade any remaining contaminants. Just ask us how, as Regenesis can customize a plan and an approach based on the specifics of your site.
Regenesis products can be applied to the subsurface through a number of different techniques including: excavation, soil mixing, direct-push injection, borehole backfill, permanent injection points and ORC filter sock applications. The most common form of product application is via direct-push injection (Figure 1). This process involves pumping the products, in their liquid form, through hollow-stem rods into the subsurface treatment area. This method is relatively simple, fast, cost-effective and applicable at most sites.

DIFFICULT TO REACH CONTAMINANTS

Regenesis products can also be applied at sites where contaminants are more difficult to reach. These include sites with fractured bedrock or with contamination beneath large structures or adjacent to buildings. These more challenging installations often require special equipment like straddle packers, horizontal wells and directional drilling rigs to effectively position/distribute the product.

FILTER SOCKS

ORC and ORC Advanced are available in filter sock form. Filter socks are typically inserted into dedicated application wells and arranged in a barrier formation to allow contaminants to flow through the oxygenated area and be degraded. Socks also allow the oxygen supply to be conveniently replenished (by removing the exhausted socks and installing replacements) to facilitate on-going aerobic degradation. Filter socks are designed to fit into 2”, 4” and 6” diameter wells respectively.

PLACEMENT STRATEGIES

There are several different product placement strategies designed to accomplish specific remediation goals and maximize material effectiveness. The most common approaches are excavations, source area treatments, migrating plume treatments and barrier installations. Each is described in brief below.
RegenOx™ maximizes performance using a solid alkaline oxidant that employs a sodium percarbonate complex with a multi-part catalytic formula. The product is delivered as two parts that are combined and injected into the subsurface using common drilling or direct-push equipment. Once in the subsurface, the combined product produces an effective oxidation reaction comparable to that of Fenton’s Reagent without a violent exothermic reaction. RegenOx safely, effectively and rapidly destroys a wide range of contaminants in both soil and groundwater (Table 1).

- Rapid and sustained oxidation of target compounds
- Easily applied with readily available equipment
- Destroys a broad range of contaminants (petroleum and chlorinated compounds)
- More efficient than other solid oxidants
- Enhances subsequent bioremediation
- Avoids detrimental impacts to groundwater aquifers

**ACHIEVES RAPID OXIDATION VIA A NUMBER OF MECHANISMS**

RegenOx directly oxidizes contaminants while its unique catalytic complex generates a suite of highly reactive free radicals that are responsible for the rapid destruction of contaminants.

- Surface-mediated oxidation – with the use of RegenOx, this process takes place in two distinct stages. First, the RegenOx activator complex forms a highly catalytic surface. Second, the RegenOx oxidizer complex and the contaminant react with the activator complex. The majority of contaminant destruction is accomplished via the process of RegenOx surface-mediated oxidation.
- Direct Oxidation:

\[
C_2Cl_4 + \frac{4}{3} Na_2CO_3 \rightarrow 2H_2O_2 + 4NaOH \rightarrow 2CO_2 + 4NaCl + 4H_2O + \frac{4}{3} Na_2CO_3
\]

- Free Radical Oxidation:
  - Perhydroxyl Radical (HO₂•)
  - Hydroxyl Radical (OH•)
  - Superoxide Radical (O₂⁻•)

**TABLE 1: OXIDANT EFFECTIVENESS VS. CONTAMINANT TYPE**

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>RegenOx™</th>
<th>Fenton’s Reagent</th>
<th>Permanganate</th>
<th>Persulfate</th>
<th>Activated Persulfate</th>
<th>Ozone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petroleum Hydrocarbons</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td>Benzene</td>
<td>A</td>
<td>A</td>
<td>D</td>
<td>B</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td>MTBE</td>
<td>A</td>
<td>B</td>
<td>B</td>
<td>C</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>Phenols</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td>Chlorinated Ethenes (PCE, TCE, DCE, VC)</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Chlorinated Ethanes (TCA, DCA)</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>C</td>
<td>B</td>
</tr>
<tr>
<td>Polycyclic Aromatic Hydrocarbons (PAHs)</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>B</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Explosives (RDX, HMX)</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
</tbody>
</table>

**OXIDANT EFFECTIVENESS KEY:**

- A = Short half-life, low free energy (most energetically favored), most complete
- B = Intermediate half-life, low free energy, intermediate degree of completion
- C = Intermediate half-life, intermediate free energy, low degree of completion
- D = Long half-life, high free energy (least favored), very low degree of completion

**Based on laboratory kinetic data, thermodynamic calculations, and literature reports.**
SAFETY:

Upon combining RegenOx Part A and Part B, a mild exothermic reaction begins. This reaction results in minimal heat and pressure generation, allowing field application of RegenOx to be accomplished safely and without the use of highly specialized equipment or specialty contractors. Through the use of widely available, direct-push equipment and an assortment of pumps, RegenOx has been designed to be as easy to install as other Regenesis products like ORC® and HRC®. As with all oxidants, proper health and safety procedures must be followed. The necessary safety guidance accompanies all shipments of RegenOx and additional resources are available on request.

PRODUCT APPLICATION MADE SAFE AND EASY:

The RegenOx mixture can be applied in a number of ways including:

- Direct-push injection (Figure 1)
- Permanent points and/or re-circulating wells
- Manual or broadcast application into open excavations/trenches
- Soil mixing (ex-situ or in-situ) (Figure 2)

Under the right conditions, in-situ or ex-situ soil mixing applications can be an effective and cost saving substitute for direct-injection.

FIGURE 2: SOIL MIXING APPLICATION

FIGURE 1: DIRECT-PUSH APPLICATION

SIGNIFICANT LONGEVITY:

RegenOx produces chemical reactions that effectively destroy contaminants for periods of up to 30 days. In addition to contaminant reduction via chemical reactivity, RegenOx also yields a significant amount of readily available oxygen that can be utilized in support of longer term aerobic biodegradation processes.

COMPATIBILITY WITH BIOREMEDIATION:

RegenOx is an effective and rapid contaminant mass reduction technology. A single injection will remove significant amounts of target contaminants from the subsurface. Strategies employing multiple RegenOx injections coupled with follow-on accelerated bioremediation can be used to treat highly contaminated sites to regulatory closure. In fact, RegenOx was designed specifically to allow for a seamless transition to low-cost accelerated bioremediation using any of Regenesis’ controlled-release compounds.
PRODUCT OVERVIEW

ORC Advanced® is the state-of-the-art technology for stimulating aerobic bioremediation. It offers unparalleled, maximum oxygen release for periods up to 12 months on a single injection and is specifically designed to minimize oxygen waste while maximizing contaminated site remediation.

ORC Advanced is a formulation of calcium oxyhydroxide which, upon hydration, releases oxygen and forms simple calcium hydroxide and water.

\[
\text{CaO(OH)}_2 + \text{H}_2\text{O} \rightarrow \frac{1}{2}\text{O}_2 + \text{Ca(OH)}_2 + \text{H}_2\text{O}
\]

PRODUCT BENEFITS

HIGHEST AVAILABLE OXYGEN CONTENT

More active oxygen (17%) plus Regenesis’ patented Controlled Release Technology (CRT™) saves time and money by increasing degradation rates and improving remediation performance by providing more oxygen on a single injection. It is particularly effective at higher demand sites where oxygen may be limited and scavenged by competing carbon sources.

PATENTED CONTROLLED-RELEASE TECHNOLOGY (CRT™)

Based on the same proven technology employed in the industry standard Oxygen Release Compound (ORC®). CRT allows for an efficient, long-term release of oxygen providing the optimal conditions for sustained aerobic biodegradation. This can save time and money by reducing the potential need for multiple applications. Also, oxygen release “lock-up” is avoided – an unfortunate problem experienced with commodity chemicals.

IN-SITU APPLICATION

Remediation with ORC Advanced is typically more cost-effective than ex-situ treatments. With the use of ORC Advanced there is minimal site disturbance with no above-ground piping or mechanical equipment, no operations and maintenance costs and no hazardous materials handling or disposal.

DEFINING THE SCIENCE BEHIND CONTROLLED-RELEASE TECHNOLOGY (CRT™)

Early on, Regenesis researchers noted that in order to optimally stimulate the natural attenuation of aerobically degradable contaminants, biologically usable oxygen was best supplied in low but constant concentrations. Big bursts of oxygen are wasteful and simply “bubble off”, often generating undesirable foaming and producing unwanted preferential flow paths in the subsurface. Regenesis sought to solve this problem by controlling the rate of oxygen release from solid oxygen sources.

The answer was provided by the development of CRT. The CRT process involves intercalating (embedding) phosphates into the crystal structure of solid peroxygen molecules. This patented feature, now available in the ORC Advanced® formulation, slows the reaction that yields oxygen within the crystal, minimizing “bubble off” which can waste the majority of oxygen available in common solid peroxygen chemicals.

CRT provides “balance” – it slows down the rate of oxygen release while at the same time preventing “lock-up”. Commodity solid peroxygen chemicals, when in contact with water, will produce an initial rapid and uncontrolled-release of oxygen. Then, as hydroxides form, a significant portion of the oxygen deeper in the crystal is made unavailable or becomes “locked-up.” This undesirable effect is inefficient and costly. CRT prevents lock-up and controls the rate of oxygen release, representing the state-of-the-art technology in passive oxygen delivery.
The original controlled-release oxygen compound, since 1994

The original Oxygen Release Compound (ORC®) is a fine, powdery material comprised of a patented formulation of phosphate-intercalated magnesium peroxide. The intercalation or embedding of phosphates within the magnesium peroxide is Regenesis’ patented, controlled-release mechanism.

Upon hydration, ORC is designed to produce a controlled-release of oxygen (10% by weight) into the subsurface in accordance with the following reaction:

\[ \text{MgO}_2 + \text{H}_2\text{O} \rightarrow \frac{1}{2} \text{O}_2 + \text{Mg(OH)}_2 \]

This process can proceed for periods of up to one year depending on site conditions. In the presence of this long-lasting oxygen source, aerobic microbes flourish - accelerating the naturally slow rates of aerobic biodegradation.

**PRODUCT BENEFITS**

By enhancing bioremediation using ORC, *in-situ* treatment of contaminants can result in an efficient, simple and cost-effective alternative to traditional technologies. With low capital costs, no operations and maintenance, minimal site disturbance and proven effectiveness, ORC can restore water quality and property values at a reasonable cost.

**MATERIAL APPLICATION**

Most contaminated sites are treated using ORC slurry which is a prescribed and easily injectable water and ORC mixture (Figure 2). The direct - injection of ORC slurry maximizes ORC and oxygen distribution in the subsurface increasing the range of enhanced biodegradation. ORC is dosed in pounds per vertical foot of material treated. The amount of ORC recommended depends greatly on various factors such as contaminant concentrations, oxygen sinks, groundwater flow rates and subsurface geology. It is recommended that a Regenesis Technical Services Representative be contacted for detailed design information.

ORC treatment approaches or designs may consist of one, or combinations of the following: Source Area Grids, Plume Area Grids or Barriers, Excavations and Biopiles.

**SUBSURFACE EMPLACEMENT**

- Direct – Push Injection
- Hollow Stem Augers
- Existing Wells
- Recirculating Wells
- Replaceable Filter Socks (existing wells)
- Excavations
- Trenches

**TREATABLE CONTAMINANTS**

ORC can treat a wide range of contaminants and most any aerobically degradable compound including: gasoline and fuel additives (BTEX and MTBE), diesel, kerosene, jet fuel, gas condensates, fuel oils, lubricants, bunker oil, PAHs, certain metals (arsenic), certain pesticides/herbicides and certain industrial solvents (alcohols and ketones).

**FIGURE 2: ORC SLURRY**
Three Stage Electron Donor Release —
Immediate, Mid-Range and Long-Term Hydrogen Production
— Provides free acid, controlled-release lactic acid and long
release fatty acids for effective hydrogen production for periods of
up to 3 to 5 years.

Low-Cost
— 3-D Microemulsion is 25¢ to 47¢ per pound as applied

Maximum and Continuous Distribution via Micellar Transport
— Unlike oil products, 3Me forms micelles which are mobile in
groundwater and significantly enhance electron donor distribution
after injection.

Wide-Area/High Volume Microemulsion Application
— High volume application increases contact with contaminants and
reduces number of injection points required for treatment —
minimizes overall project cost.

3-D Microemulsion (3Me)® is a form of HRC Advanced® and has a molecular structure specifically designed to maximize the cost-
effective anaerobic treatment of contaminants in subsurface soils and groundwater. This structure (patent pending) is composed of
free lactic acid, controlled-release lactic acid (polylactate) and certain fatty acid components which are esterified to a carbon backbone
molecule of glycerin (Figure 1).

3Me produces a sequential, staged release of its electron donor components. The immediately available free lactic acid is
fermented rapidly while the controlled-release lactic acid is metabolized at a more controlled rate. The fatty acids are converted to
hydrogen over a mid to long-range timeline giving 3Me an exceptionally long electron donor release profile (Figure 2). This staged
fermentation provides an immediate, mid-range and very long-term, controlled-release supply of hydrogen (electron donor) to fuel the
reductive dechlorination process.

Typical 3Me single application longevity is rated at periods of up to
3 to 5 years. With 5 years occurring under optimal conditions, e.g. low
permeability, low consumption

3Me applications can be configured in several different ways including:
grids, barriers and excavations. The material itself can be applied to the
subsurface through the use of direct-push injection, hollow-stem auger,
existing wells or re-injection wells.

3Me is typically applied in high-volumes as an emulsified, micellar
suspension (microemulsion). The microemulsion is easily pumped into the
subsurface and is produced on-site by mixing specified volumes of water
and delivered 3Me concentrate. Detailed preparation and installation
instructions are available at www.regenesis.com.

3Me is usually applied throughout the entire vertical thickness of the
determined treatment area. Once injected, the emulsified material moves
out into the subsurface pore spaces via micellar transport, eventually
coating most all available surfaces. Over time the released soluble
components of 3-D Microemulsion are distributed within the aquifer via
the physical process of advection and the concentration driven forces
of diffusion.
Redevelopment site subsurface contamination from a dry cleaning operation resulted in increasing PCE concentrations in groundwater and a plume with little to no measureable daughter products. 3-D Microemulsion (3DMe) was applied across the plume to enhance in-situ reductive dechlorination. Within eleven months, significant reductions in chlorinated solvent concentrations were observed and the site was recommended for closure.

**PERFORMANCE**

**Commercial Dry Cleaning Facility**

A surface spill at a dry cleaner site resulted in a chlorinated solvent groundwater plume with total chlorinated solvent concentrations as high as 8,320 ug/L (ppb). 3-D Microemulsion (3DMe) was applied near the monitoring well to treat PCE, TCE, DCE and VC. Total chlorinated solvent concentrations were reduced by 95% from 5,630 ug/L (ppb) to approximately 284 ug/L (ppb) within a year of the application.

**Redevelopment Site**

Subsurface contamination from a dry cleaning operation resulted in increasing PCE concentrations in groundwater and a plume with little to no measureable daughter products. 3-D Microemulsion (3DMe) was applied across the plume to enhance in-situ reductive dechlorination. Within eleven months, significant reductions in chlorinated solvent concentrations were observed and the site was recommended for closure.

**FIGURE 4: DRY CLEANER CONTAMINANT CONCENTRATIONS**

**FIGURE 5: REDEVELOPMENT SITE CONTAMINANT CONCENTRATIONS**
HRC® is supplied as a viscous liquid for direct injection into contaminated groundwater and saturated soils. This specially formulated product slowly releases lactic acid upon contact with water (Figures 1 & 2). This source of lactic acid is then metabolized by microbes to produce hydrogen which is then used in a natural process known as reductive dechlorination (Figure 3). Reductive dechlorination results in the step-by-step biological degradation of chlorinated contaminants. HRC can be used to degrade a range of chlorinated compounds including; degreasing agents (PCE, TCE, TCA and their breakdown products), carbon tetrachloride, chloroform, methylene chloride, certain pesticides/herbicides, perchlorate, nitrate, nitroaromatic explosives and dyes, chlorofluorocarbons, certain metals and radionuclides.

MORE ON REDUCTIVE DECHLORINATION

As discussed, reductive dechlorination is a term used to describe the mechanism by which chlorinated hydrocarbons are biologically degraded under anaerobic conditions. In this natural process, anaerobic microbes substitute hydrogen (H) for chlorine (Cl) on chlorinated contaminant molecules, thus dechlorinating the compound. Being a natural process, reductive dechlorination usually proceeds at very slow, unsustainable rates. HRC increases the rate of dechlorination up to several orders of magnitude, rapidly taking the contaminant through a step-wise dechlorination process that ultimately results in the production of non-toxic compounds such as ethene and ethane. Under the influence of HRC, this process may continue at an accelerated rate for up to 18 months.

HRC MAY FAVOR REDUCTIVE DECHLORINATION OVER COMPETING METHANOCOGENIC ACTIVITY

Within the subsurface anaerobic microbial consortium, there exist microbes that use hydrogen primarily for the production of methane (methanogens), and also present are microbes that use hydrogen primarily for dechlorination (reductive dechlorinators). Results from university studies suggest that there is competition for hydrogen between the reductive dechlorinators and methanogens. High concentrations of hydrogen favor methanogenic activity, whereas reductive dechlorinators are best supported in conditions of low hydrogen concentrations (2-10 nM). With HRC’s long-lasting, time-release feature, a more steady and low hydrogen concentration is possible which can optimize reductive dechlorination over competing methanogenic activity.
**Extended, controlled-release hydrogen for long-term contaminant reduction and residual DNAPL treatment**

**HOW IT WORKS**

HRC-X® is a special formulation of the patented and widely accepted Hydrogen Release Compound (HRC®), which has been successfully applied on hundreds of project sites worldwide for the cost-effective, in-situ treatment of groundwater contamination.

HRC-X is a viscous material, composed of glycerol polylactate, which is injected directly into the contaminated subsurface. Once in place, this compound slowly releases lactic acid for periods in excess of 3 years. This source of lactic acid is then metabolized by naturally occurring microbes producing consistent, low-level concentrations of hydrogen. This hydrogen, in turn, is used by microbes to degrade chlorinated solvent-type contaminants through a well understood process known as reductive dechlorination.

HRC-X can be used to degrade a range of contaminants including: degreasing agents (PCE, TCE, TCA and their breakdown products), carbon tetrachloride, chloroform, perchlorate, nitrate, and certain pesticides/herbicides.

**RESIDUAL DNAPL**

Residual Dense Non-Aqueous Phase Liquid (DNAPL) is often difficult to find and very costly to treat. Residual DNAPL causes a lingering and unwanted source of groundwater contamination that can represent enormous and unexpected cleanup costs. HRC-X is a proven solution to this challenging problem. Once injected into the general vicinity of the residual DNAPL, HRC-X goes to work releasing lactic acid and cost-effectively producing the desired hydrogen throughout the area. This, in turn, drives the rapid desorption, dissolution, and degradation of the bound residual DNAPL (Figures 1, 2 & 3).

Since HRC-X facilitates a microbial driven process, it can be applied without the need to identify the exact location of the residual DNAPL, avoiding costs associated with detailed site analysis. Additionally, HRC-X does not require stationary equipment, any on-going power supply, piping, long-term operations and maintenance or labor costs. These characteristics alone can significantly reduce the costs of residual DNAPL remediation.

**LONG-TERM, LOW-COST PLUME CONTROL**

When long-term plume control is required to halt the migration of groundwater contaminants, HRC-X may be one of the most cost-effective alternatives available. In the past, the only alternative in these situations was to cut-off the plume by intercepting the groundwater with very inefficient and costly pump and treat systems, or by disruptive construction of expensive sheet pile barriers and “iron filing walls.” Groundwater remediation professionals now have an effective alternative to offer their clients and to reduce their cost burden, HRC-X. When applied perpendicular to the migrating plume, HRC-X passively releases the hydrogen required to degrade the mobile contaminant flux. The HRC-X material, once installed, continues to release hydrogen, effectively “cutting off” the migrating plume for a period in excess of 3 years, while avoiding the capital costs associated with engineering, construction and O&M intensive systems.
METALS TREATMENT

GEOCHEMICAL FACTORS
Within the subsurface environment, dissolved metals are affected by a number of geochemical factors including pH, electrical potential (Eh), complexation, sorption and ion exchange. The ability to manipulate and control these factors can directly influence the physical state, mobility, and presence of metals in groundwater through processes such as precipitation, oxidation/reduction, sorption, and complexation.

THE TECHNOLOGY
MRC® removes metals such as dissolved Cr(VI) from groundwater via in-situ immobilization (precipitation and/or sorption to soil particles). MRC consists of an organosulfur compound esterified to a carbon backbone. This organosulfur ester is embedded in a polylactate matrix, making MRC a thick, viscous liquid. Upon injection into an aquifer, the organosulfur compound (the active metals immobilization agent) is released in a controlled manner when the ester bonds in MRC are cleaved via hydrolysis and microbial enzymatic action. Similar processes also cause MRC to release lactic acid which provides a carbon source for naturally-occurring bacteria and creates the optimal conditions for metals immobilization by the organosulfur compound.

IMMobilization MECHANISMS
MRC stimulates chromium immobilization using a two-part mechanism. First, the organosulfur compound in MRC is a direct chemical reductant for soluble Cr(VI) and produces insoluble trivalent chromium (Cr(III)). Secondly, MRC can stimulate Cr(VI) reduction indirectly by providing lactic acid, which is rapidly metabolized by subsurface microbes and creates reduced species, like ferrous iron and sulfide which are known to chemically reduce Cr(VI) to the insoluble Cr(III) state.

ADDED BENEFIT OF REDUCTIVE DECHLORINATION
MRC can also be used to treat sites with mixed hexavalent chromium and chlorinated hydrocarbon contamination because it provides the substrates needed to facilitate dissolved hexavalent chromium immobilization and reductive dechlorination. The dual-purpose feature allows MRC to effectively treat sites with co-mingled plumes because it eliminates the need for separate technologies to treat metals and chlorinated compounds. The organic substrate and lactate present in MRC accelerates the in-situ biodegradation rates of chlorinated hydrocarbons (CHs) via anaerobic reductive dechlorination processes. Reductive dechlorination is one of the primary attenuation mechanisms by which chlorinated solvent groundwater plumes can be stabilized and/or remediated.

IN THE LAB
MRC was tested for the immobilization of Cr(VI) in a simulated aquifer experiment.

RESULTS OF CHROMIUM TREATMENT
Over a 30 day period:
- Chromium was reduced from 15 mg/L to 0.4 mg/L
After 30 days of operation, flushing was started to assess the stability of the Cr(VI). Three pore volumes of oxygenated water were flushed through the aquifer simulation vessel (ASV) for 30 days and concentrations of dissolved Cr(VI) did not rebound or increase (Figure 1).

IN THE FIELD
SUPERFUND SITE REPLACES PUMP AND TREAT (P&T) WITH MRC
A P&T system was installed at a site in Texas to treat chromium in tight soils. After 13 years of operation, the P&T system was deemed ineffective in treating the remaining chromium and the system was shutdown. MRC was chosen to further reduce concentrations of unfiltered chromium. Figure 2 shows the reduction of unfiltered chromium as a result of MRC influence. Hexavalent and total unfiltered chromium have decreased to close to or beneath target concentrations. The use of MRC resulted in a net savings of $183,000 during the first year of treatment.
Bio-Dechlor INOCULUM® is an enriched natural microbial consortium containing species of Dehalococcoides sp. (DHC). This microbial consortium has since been enriched to increase its ability to rapidly dechlorinate contaminants during in-situ bioremediation processes. Bio-Dechlor INOCULUM has been shown to stimulate the rapid and complete dechlorination of compounds such as tetrachloroethene (PCE), trichloroethene (TCE), dichloroethene (DCE), and vinyl chloride (VC). The most current culture of Bio-Dechlor INOCULUM PLUS now contains microbes capable of dehalogenating halomethanes (e.g. carbon tetrachloride and chloroform) and haloethanes (e.g. 1,1,1-TCA and 1,1-DCA) as well as mixtures of these halogenated contaminants.

Bio-Dechlor INOCULUM PLUS is provided in a liquid form and is designed to be injected directly into the contaminated subsurface. Once in place, this microbial consortium works to accelerate the extant rate of chlorinated ethene degradation. When faced with an insufficient quantity of critical dechlorinating microbes, Bio-Dechlor INOCULUM PLUS supplies many beneficial chlorinated solvent degraders including the all important DHC required to achieve complete and rapid dechlorination.

This microbial consortium is compatible with most electron donors however it is often optimized with the addition of any of Regenesis’ Hydrogen Release Compound (HRC®) products.

Free Application and Cost-Estimate Available for All Regenesis Products.
Contact Regenesis at 949.366.8000
or visit our website www.regenesis.com
**CHEMICAL OXIDATION**

Chemical oxidation is a process that involves the injection of reactive chemical oxidants into groundwater and/or soil for the primary purpose of rapid contaminant destruction. Also known as *In-Situ* Chemical Oxidation (ISCO), this process is most often deployed at sites with high contaminant concentration source areas and downgradient plumes. Chemical oxidation is often part of a multi-step remediation approach that paves the way for more biologically mediated, less costly approaches such as accelerated bioremediation or monitored natural attenuation.

**BIOREMEDIATION**

Bioremediation is a term that describes the use of naturally occurring or cultured microorganisms to degrade and remove contaminants in groundwater and soil. The bioremediation process can be aerobic or anaerobic, requiring either oxygen or hydrogen respectively. At most sites, the subsurface is lacking in these key microbial requirements (oxygen or hydrogen) which prevents microorganisms from flourishing and completely degrading target contaminants. Regenesis provides cost-effective, proven products that enhance and complete bioremediation processes.

**NATURAL ATTENUATION**

The term “natural attenuation” has been used to describe a method of passively remediating groundwater contamination with minimal or no activity and involves a number of subsurface processes including biodegradation, dispersion, dilution and adsorption which reduce the concentrations of contaminants in the subsurface. Of these components, only biodegradation facilitated by naturally occurring or cultured microbes physically destroys the contaminants of concern. However this process can be very slow and unpredictable. In many cases, utilizing natural attenuation as a remediation option requires on-going monitoring or Monitored Natural Attenuation (MNA) which if allowed to continue for any length of time can result in significant costs. The use of Regenesis products can eliminate long-term monitoring and costs associated with MNA while expediting site recovery.

**ACCELERATED NATURAL ATTENUATION**

Accelerated natural attenuation is an approach that offers a low-cost, proven method of speeding up natural processes to decrease the time to site closure. The approach involves the addition of one or more of the following: oxygen, hydrogen, nutrients, microbes, etc. to increase the number and vitality of microorganisms performing bioremediation.

**BIAUGMENTATION**

This term is used to describe the addition of microorganisms to the subsurface that can biodegrade or transform specific groundwater contaminants. In some cases certain microorganisms are more specialized at degrading specific contaminants, e.g. some microbes can degrade PCE and TCE but not DCE and VC. As a result, remediation industry practices and recommendations are now shifting toward a more prescriptive approach to bioaugmentation at project sites.

**REDUCTIVE DECHLORINATION**

Reductive dechlorination describes the mechanism by which chlorinated hydrocarbons are biologically degraded under anaerobic conditions. In this naturally occurring process, microbes substitute carbon dioxide (C) for chlorine (Cl) on chlorinated contaminant molecules, thus dechlorinating the compound (Figure 1). Being a natural process, unamended reductive dechlorination usually proceeds at very slow and unsustainable rates.

**CONTROLLED-RELEASE TECHNOLOGY (CRT™)**

The CRT component of Oxygen Release Compound (ORC®) and ORC Advanced®, provides balance by slowing down the rate of oxygen release while also preventing “lock-up.” Commodity peroxygen chemicals, when in contact with water, will produce an initial rapid and uncontrolled burst of oxygen. Meanwhile hydroxides form and a significant portion of the oxygen deeper in the crystal is made unavailable or becomes “locked-up.” This undesirable effect is inefficient and costly. CRT prevents “lock-up” and controls the rate of oxygen release, representing the state-of-the-art technology in passive oxygen delivery.

CRT in HRC and parts of 3-D Microemulsion results from the actual molecular structure which incorporates the ester bonded components of these products. When the ester bonds are broken through chemical and/or microbial processes the material provides a moderated or gradual release rate of organic acids which then facilitate microbiologically mediated hydrocarbon production. The newly available, controlled-release hydrogen is then utilized in the natural process of reductive dechlorination.

![Figure 1: Reductive Dechlorination Process](image-url)
REGENESIS

Hours of Operation: Monday through Friday / 8:00 am to 5:00 pm / Pacific Standard Time

Website: For a comprehensive source of information on Regenesis products, available 24 hours a day, 7 days a week, visit: www.regenesis.com