E-REDOX® (R)

TECHNICAL FACT SHEET

ISOTEC REMEDIATION TECHNOLOGIES

AET

Technology Overview

E-Redox® (R) [previously known as E-Redox ® (I)] is an engineered electrochemical-redox technology that establishes low-redox, electron-rich conditions in the subsurface to accelerate abiotic and biologically mediated contaminant degradation. By applying a low-voltage direct-current (DC) field between subsurface electrodes and throughout the surrounding formation, E-Redox® (R) mobilizes and delivers electrons through the soil matrix, promoting reduction-dominated degradation of chlorinated solvents, metals, nitrate, and other oxidized contaminants. The system operates at extremely low energy input and can be powered by solar or conventional utility sources.

The "static" electrochemical field enhances desorption of contaminant mass from solids into groundwater. It also initiates and maintains stable reducing conditions (low ORP) without the need for liquid or solid chemical amendments.

Key Benefits

- Establishes uniform reducing conditions and facilitates electron movement within the matrix using only low-voltage electric fields.
- Enhances both abiotic and biologically mediated reduction-dominated redox reactions.
- Effective in both "conventional" and low-permeability formations (clays, silts, fractured rock) where hydraulic conductivity limits reagent delivery.
- Compatible with existing wells or installed as a standalone system. Configurable for solar, grid, or battery operation with minimal above-ground infrastructure.
- Low power demand (<50W per unit) with minimal maintenance requirements.

Best Suited For

E-Redox® (R) is optimized to treat a broad range of reducible contaminants:

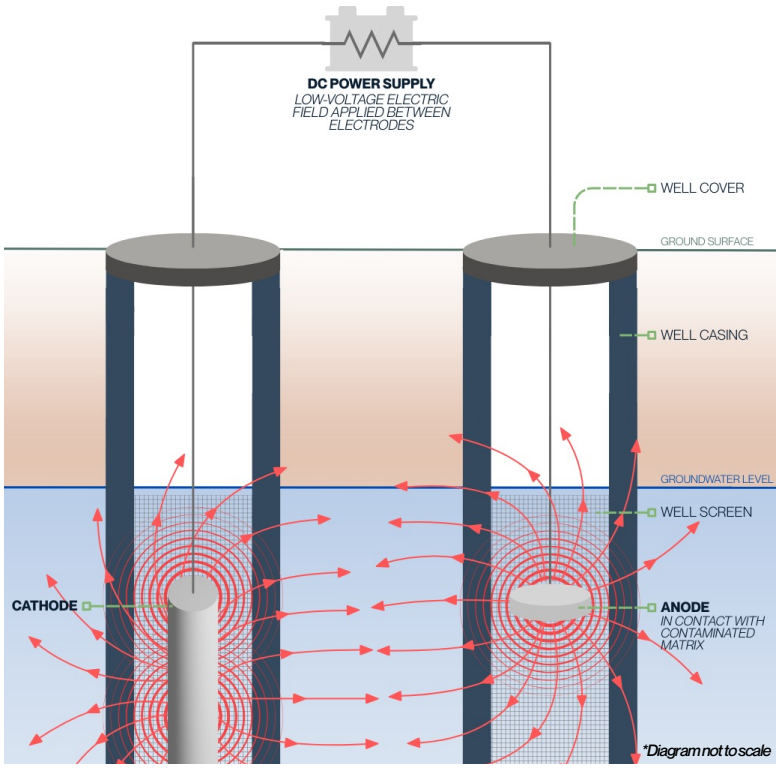
- Chlorinated solvents (PCE, TCE, DCE, VC).
- Hexavalent chromium (Cr^{6+}) and other redox-sensitive metals.
- Nitrate, nitrite, perchlorate, and other oxyanions.
- PFAS and persistent organic compounds.

This technology is designed for both source zones and plume treatment and is particularly effective where traditional injection-based remedies underperform due to limited permeability or rebound effects.

Treatment Timeline

Observed field performance demonstrates significant contaminant reduction within the first several months of operation. At CVOC-impacted sites, concentration declines of 60–90% within 3 to 9 months are commonly observed, with complete dechlorination achieved at some sites within one year. For nitrate and metal treatment, measurable ORP decreases are typically observed within days, and reduction to regulatory endpoints (e.g., Nitrate <10 mg N/L, Cr^{6+} <10 µg/L) can occur within 3 to 6 months depending on mass loading.

Treatment duration depends on lithology, groundwater flow, and contaminant mass. Once optimal redox potential is achieved, the electrochemical field remains stable for extended durations and requires minimal intervention for long-term maintenance; installations have operated continuously for 18 to 24 months with minimal current decay.



E-Redox® (R) system drives abiotic and biological reduction by supplying electrons to the subsurface and enhancing desorption through soil-particle polarization. In-well voltage and ORP measurements serve as a real-time indicator of reducing conditions.

Mechanism of Action

The E-Redox® (R) system consists of paired electrodes installed in wells or direct-push borings to generate a low-intensity electrochemical field across the target interval. Within this field, soil and sediment particles polarize and function as micro-conductors and micro-capacitors, transferring electrons through the saturated matrix and establishing sustained reducing conditions:

- Electrons flow from the cathodic region into the contaminated matrix, stimulating abiotic β-elimination and hydrogenotrophic dechlorination pathways that reduce oxidized species to stable end products.
- Trace hydrogen generated at mineral interfaces supports hydrogenotrophic microorganisms, enhancing reductive dechlorination and denitrification under the imposed low-redox conditions.
- Polarization disturbs the solid-water interface and releases sorbed contaminant mass from low-permeability zones, increasing contaminant availability for transformation to the aqueous phase.
- Soil-particle charge cycling creates repeated micro-capacitor discharge events that enhance mass transfer and sustain reducing conditions throughout the treatment zone.
- In areas with zero-valent iron or other reductants, cathodic polarization rejuvenates passivated surfaces and extends reactive longevity.
- Optional polarity sequencing alternates brief desorption and reduction phases, accelerating cleanup and minimizing diffusion-limited rebound.

Voltage and oxidation-reduction potential (ORP) measurements collected in-well provide real-time confirmation of field strength and system performance throughout treatment.

E-Redox® technology is developed and patented by AET. ISOTEC is an approved specialist remediation contractor authorized by AET to install E-Redox® systems.

System Design

- Each E-Redox® (R) installation is a modular system consisting of paired or multi-node electrodes, low-resistance cabling, and a programmable DC power controller.
- Proprietary electrodes are titanium-based alloys coated with noble metals to enable rapid exchange of electrons between the electrode surface and the matrix. They are corrosion resistant and are housed within perforated PVC casings.
- The system operates continuously once energized. Power can be supplied from on-site utility service, solar panels, or battery banks. Programmable timers enable polarity sequencing and voltage pulsing.
- Routine performance monitoring includes measurement of voltage, current, and in-well ORP.
- Periodic maintenance may include inspection of surface connections and polarity sequencing adjustments to optimize field performance.

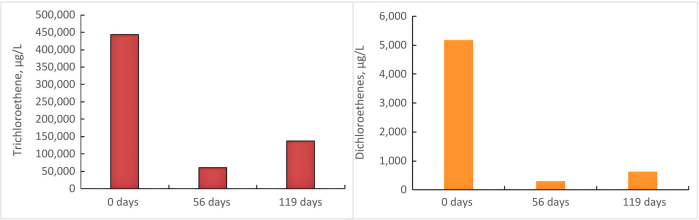
Capabilities & Advantages

- Operates effectively within saturated, low-permeability, or fractured formations where injection efficiency is limited.
- Can form a "virtual reactive barrier" for the in-situ treatment of migrating plumes.
- Provides treatment coverage independent of groundwater flow, enabling effective mass reduction in hydraulically stagnant or diffusion-limited zones.
- Radius of influence (ROI) typically ranges from 25 to 50 feet depending on lithology and conductivity.
- Synergistic with in-situ chemical reduction (ISCR), zero-valent iron (ZVI), and electron donor-based bioremediation technologies.
- Rapidly establishes and maintains stable low-redox conditions over extended durations.
- Can be paired with dual-phase or multiphase extraction systems to enhance desorption and mass recovery.
- No consumable reagents, waste generation, or complex above-ground infrastructure required.

Design Considerations

- Systems can be configured using existing remediation or monitoring wells (≥2-inch ID) or by installing dedicated borings in a grid or line configuration.
- The following parameters are recommended to evaluate and optimize the performance of the E-Redox® (R) system: groundwater conductivity, baseline ORP, total organic carbon (TOC), total iron, and nitrate/nitrite concentrations. Continuous monitoring of these parameters can guide field adjustments to ensure reducing conditions are maintained.
- Performance may be limited by extremely low conductivity (<100 µS/cm) or the presence of large metallic utilities that disrupt uniform current flow. Conductivity and redox profiling should be performed prior to installation to refine electrode spacing and configuration.
- E-Redox® (R) may be combined with organic donor injection or carbon substrates where additional electron sources are beneficial for long-term biological activity.

Chlorinated Solvent Reduction with E-Redox® (R)



Chlorinated ethene concentrations from the primary monitoring well.

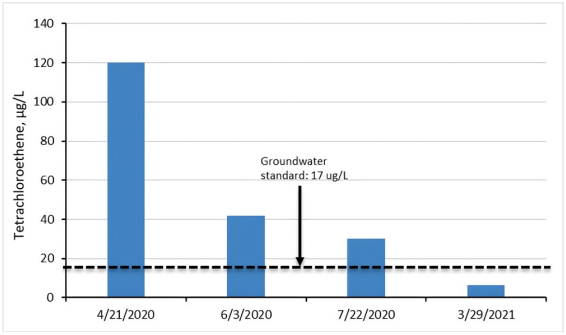
Location: HVAC Manufacturing Facility in Colorado
Contaminants of Concern: TCE, DCE, VC
Contaminated Matrix: Saturated Matrix
Impacted Lithology: Silty Clay

Treatment & Results: E-Redox® (R) was implemented at an active HVAC manufacturing facility to address persistent chlorinated solvent impacts in a low-permeability, clayey formation. E-Redox® (R) units were installed across the source zone and downgradient plume and operated at low power for 56 days. During this period, total chlorinated ethenes decreased by 86 to 97%, with TCE concentrations reduced from 443,000 µg/L to 60,500 µg/L (approximately 86% reduction); ethane production confirmed complete dechlorination.

Source Zone Stabilization in Clays with E-Redox® (R)

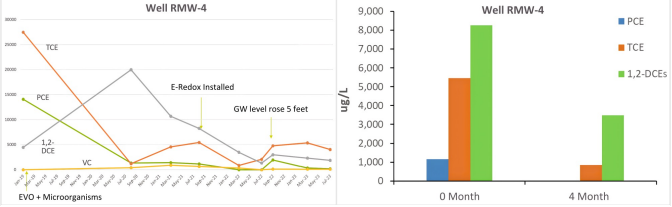
Location: Former Shopping Center in Colorado
Contaminants of Concern: PCE
Contaminated Matrix: Groundwater & Saturated Soil
Impacted Lithology: Alluvial Clay with Bedrock Channels

Treatment & Results: E-Redox® (R) was applied to address persistent PCE impacts in low-permeability clays, where prior injection-based remedies were ineffective due to limited permeability and PCE mass presumed to be trapped within bedrock fractures and depressions. A three-well E-Redox® (R) array reduced PCE concentrations from 120 µg/L to 6.5 µg/L (approximately 95% reduction) within 11 months of operation. No rebound was observed during post-treatment monitoring, confirming durable redox stability in tight formations.



PCE concentrations in the primary well within the E-Redox® treatment area.

Post-EVO Urban Redevelopment with E-Redox® (R)



PCE, DCE, and 1,2-DCE concentrations from an on-site monitoring well.

Location: Redeveloped Retail Site/Former Dry Cleaner in Colorado
Contaminants of Concern: PCE, TCE, 1,2-DCEs
Contaminated Matrix: Groundwater
Impacted Lithology: Clayey Formation

Treatment & Results: E-Redox® (R) was applied at a former dry-cleaner site to address persistent chlorinated solvent impacts in groundwater. Prior donor-based remediation reduced PCE but resulted in residual TCE and 1,2-DCE concentrations. E-Redox® (R) units were installed within the former building footprint and along an adjacent sidewalk; within four months of operation, concentrations of chlorinated ethenes decreased by approximately 58 to 100% across the monitored wells.

E-Redox® technology is developed and patented by AET. ISOTEC is an approved specialist remediation contractor authorized by AET to install E-Redox® systems.