# Heat-enhanced Bioremediation and Destruction

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## Introduction

*In situ* thermal treatment through Electrical Resistance Heating (ERH) is a proven robust technology for the treatment of volatile organic compound (VOC) source zones. ERH effectively treats the subsurface by volatilizing dense non-aqueous phase liquid (DNAPL) and VOCs, recovering the vapor, and treating the vapor by conventional technologies such as granular activated carbon or thermal oxidation.

In addition to volatilization and recovery of VOCs, *in situ* contaminant destruction also occurs at many ERH sites and can play an important role in the overall contaminant source reduction.

## Field Study

TRS has completed a field study that increased the understanding of the benefits of *in situ* destruction mechanisms. The U.S. Environmental Security Technology Certification Program (ESTCP) funded the study that was performed at the Fort Lewis Army Base south of Seattle, WA. The overall goal of the study was to demonstrate the use of ERH to heat the treatment zone to moderate temperatures of 30°-70°C and quantify the increased efficiency of biotic and abiotic *in situ* degradation reactions. More specifically, the *in situ* destruction mechanisms were evaluated as outlined in the ESTCP submittal:

- Validate the increased rate and extent of contaminant degradation during thermally enhanced *in situ* bioremediation (ISB) at a temperature of approximately 35°C compared to ISB at ambient temperature
- Validate the increased rate and extent of contaminant degradation during thermally enhanced iron-based reduction at a temperature of approximately 55°C compared to ambient temperature
- Determine the relative contributions of *in situ* biotic and abiotic degradation at different temperatures in order to optimize each
- Collect data from a controlled field demonstration at a Department of Defense site to develop cost and performance data for the combined remedies

## Results

Data from the ESTCP demonstration suggest that thermally enhanced dechlorination activity can be sustained for 6 to 12 months after zero-valent iron injection. The average trichloroethene (TCE) dechlorination rate was 0.14 to 0.24 grams-TCE/day per $m^3$ (about 0.12 mg/kg/day). Heating increased both desorption/dissolution and dechlorination of TCE. The dechlorination rate exceeded the desorption/dissolution rate up to temperatures of 45-50°C.

The biotic portion of the study included multiple injections of donor amendments and resulted in similar conclusions. Temperature increases both kinetics and efficiency of dechlorination reactions. TCE dechlorinated to *cis* 1,2-dichloroethene during the ambient baseline test. During heating, increases in vinyl chloride and ethene along with dramatic increases in *Dehalococcoides* were observed. Desorption/dissolution rates increased with temperature with the most significant effects at locations with the highest concentrations of residual mass.

ERH, ISB, and zero-valent iron are relatively mature technologies; however, there are various benefits of combining these technologies. The overall cost for a combined system will be significantly lower than the cost for standard ERH because a low-energy system would be utilized. The low-energy ERH system would have 50-75% lower capital equipment and operating costs, largely by eliminating vapor and steam recovery and aboveground treatment. Additionally, combining technologies can make *in situ* contaminant destruction reactions more effective for source area treatment.

At some sites where both DNAPL and dissolved phase VOCs are present, ERH can be used as a rapid source reduction technology. The remaining dissolved phase plume could then be treated using the combined remedies discussed and eliminate expensive above grade treatment equipment, significantly reducing the overall cost of the remediation. Figure 1 conceptually shows the cost benefit of the combined *in situ* remedies.

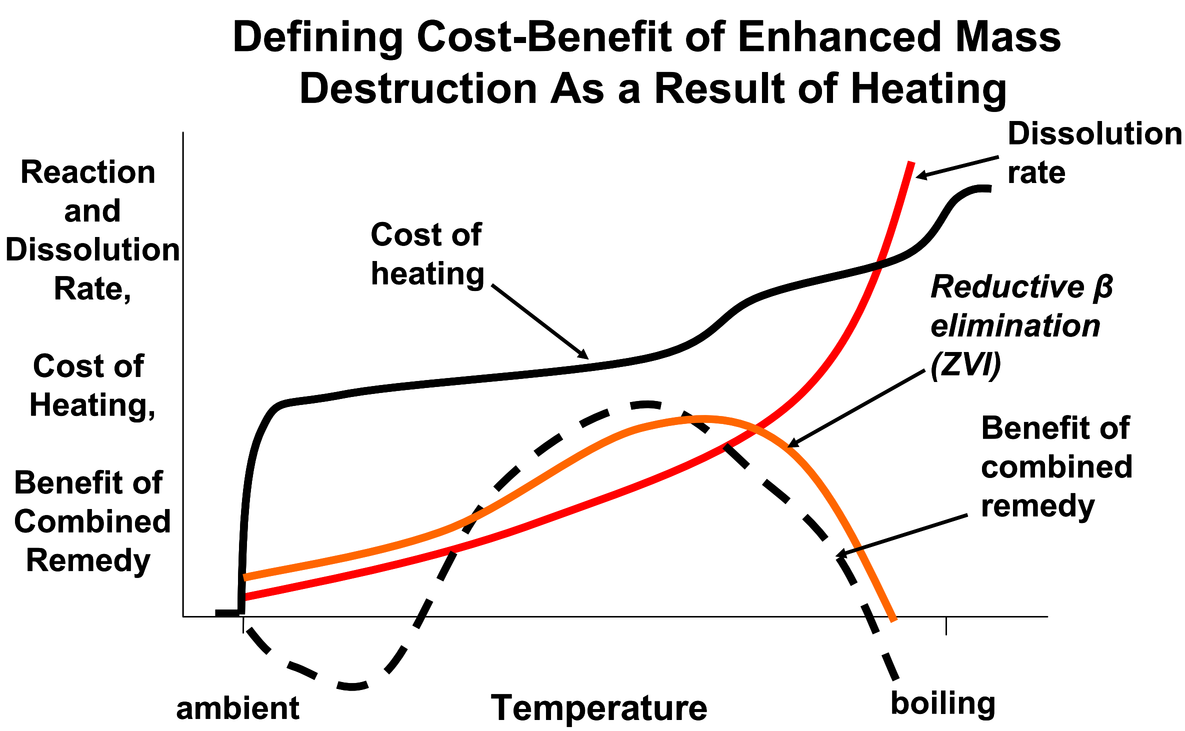


**Figure 1.** Cost Benefit Analysis for Combined Remedies (courtesy of CDM Smith)

Full-temperature remediation using ERH requires vapor control and treatment at the surface. While full-temperature ERH is very effective for source zone treatment, sites that are able to accept longer treatment durations could benefit from a less aggressive, less capital-intensive combination of ERH by relying on heat enhanced biotic or abiotic *in situ* contaminant degradation to achieve remedial objectives.