# Success Stories at Low-Permeability Sites: Field Demonstrations of Electrokinetic-Enhanced Amendment Delivery for In Situ Remediation

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**Background/Objectives.** A common challenge to achieving remediation goals at sites with complex geology is contaminant mass stored in low-permeability (low-K) materials acting as long-term sources. One critical limitation of applying enhanced in situ remediation in a low-K zone is the inability of conventional hydraulic-based techniques to effectively deliver the required amendments to a target area. This presentation will discuss field-scale demonstrations of electrokinetic-enhanced (EK enhanced) in situ remediation technology that represents a fundamentally improved solution for this vexing problem. The mechanism of EK transport of ionic compounds is relatively independent of the hydraulic property of geologic matrix, and, thus, can achieve effective and uniform amendment delivery throughout a target area in low-K formations. Successful field demonstrations of EK enhanced in situ bioremediation (EK-BIO) at multiple sites specifically targeting chlorinated solvent sources in low-K zones will be presented.

**Approach/Activities.** Tetrachloroethene (PCE) from a primary source area at Naval Air Station Jacksonville (NAS JAX) in Florida had migrated vertically across a shallow sandy unit into the underlying clay unit. An EK-BIO demonstration was implemented using a network of 9 electrode wells in a treatment area (approximately 35 ft by 35 ft) targeting the contaminant mass in clay at depths of approximately 19 to 24 ft. A control system was installed and operated to provide a constant direct current (DC) to electrodes and supply amendments (lactate and carbonate buffer solutions) to the treatment area. Bioaugmentation using reductive dechlorination cultures was also performed in this demonstration. The demonstration was completed with two stages of active operation (5 months each) and a rigorous performance monitoring program. Another successful EK-BIO implementation was a full-scale remediation at a site in Denmark targeting a PCE source in a glacial till formation. The remedy involved a network of 15 electrode wells and was completed through several stages of active operation over a period of 3 years to distribute lactate amendment and sustain reductive dechlorination treatment in the target low-K zone.

**Results/Lessons Learned.** Both EK-BIO systems operated in these projects required fairly low electrical energy (~30V) to supply target constant currents (~8A) to the electrodes reflecting the energy efficient nature of this technology. At NAS JAX, performance monitoring data indicated attainment of the demonstration objective criteria: >80% of PCE concentration decrease in groundwater with substantial increase of dissolved ethene; >1000x increase of *Dehalococcoides* and *vinyl chloride reductase* (*vcrA*) genes; and >78% decrease of PCE concentration in clay soil. These performances were further supported by microbial community analysis via next generation sequencing showing enhanced microbial diversity within the treatment zone, and a mass flux assessment showing >95% reduction of PCE and TCE at the sand/clay interface downgradient of the source area, demonstrating the beneficial effects of remediating contaminant sources in low-K materials. As another successful remedy implementation, Danish regulators for the full-scale EK-BIO project agreed that remediation goals for the target area had been achieved. Complete dechlorination of PCE to ethene leading to PCE mass reduction in clay was verified by soil sampling results. Molecular biomarker analyses confirmed the sustained development of active reductive dechlorination microbial populations within the treatment area. These field-scale EK-BIO success stories offer a solution for overcoming the challenges at low-K sites.