Bioaugmented Phytoremediation to Treat 1,4-Dioxane Contaminated Groundwater

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Background/Objectives. 1,4-Dioxane (dioxane) is a probable carcinogen and persistent groundwater pollutant often found comingled with chlorinated solvents (e.g., trichloroethylene, dichloroethylene, and trichloroethane). Because of dioxane's high mobility in groundwater, dioxane plumes tend to be large and dilute. EPA risk guidelines for dioxane in drinking water are as low as 0.35 µg/L. Reaching this low clean-up guideline through remediation has proven to be particularly difficult and costly. Utilizing aggressive pump-and-treat and *ex-situ* technologies such as advanced oxidation (AO) on dilute dioxane plumes is often prohibitively expensive. Alternatively, phytoremediation using poplar trees has been proposed as a cost-effective clean-up strategy. However, questions remain if this technology can alone remediate dioxane, especially from deep groundwater plumes. Another promising solution is to pump the contaminated water onto plantations of trees and to bioaugment the poplar rhizosphere with dioxane-degrading bacteria to speed remediation. In prior laboratory studies, we evaluated metabolic dioxane degraders *Pseudonocardia dioxanivorans* CB1190 and *Mycobacterium sp.* PH-06 as bioaugmentation candidates to speed the degradation rate of dioxane by hybrid poplar (*Populus deltoides* x *nigra*, DN34) via bioaugmentation. However, these strains are often ineffective at relatively low dioxane concentrations (<100 µg/L) commonly encountered in the field. In addition, chlorinated solvents have been shown to inhibit dioxane degradation by CB1190. In our recent work, we have identified *Rhodococcus ruber* 219 as a strong alternative candidate for field bioaugmentation. With the addition of B-vitamins, the strain can sustain metabolic degradation in dilute dioxane concentrations (<100 µg/L) and degrade dioxane to below health advisory levels (<0.35 µg/L). In the current research, we evaluate bioaugmented phytoremediation with *R. ruber* 219 to treat dioxane-contaminated groundwater.

Approach/Activities. In this research, we conducted bench-scale flow-through experiments to evaluate dioxane degradation by hybrid poplar bioaugmented with either *R. ruber* 219 or CB1190. Using quantitative PCR, we also assessed strain colonization and washout post-bioaugmentation. We also evaluated the performance of an in-series arrangement to maximize treatment capacity. Finally, we have initialized a pilot-scale demonstration at the former Twin Cities Army Ammunition Plant (TCAAP) in Arden Hills, Minnesota. In this demonstration, we will utilize above-ground Phyto Attached Growth Reactors (PhAGRs®) developed by Ecolotree, Inc. These PhAGRs are planted with poplar or willow trees and bioaugmented with *R. ruber* 219 or CB1190 to treat irrigated groundwater contaminated with dioxane and chlorinated solvents.

Results/Lessons Learned. In our findings, we report that bioaugmented phytoremediation with *R. ruber* 219 can degrade >90% of influent dioxane (<100 µg/L) in bench-scale experiments. Furthermore, based on quantitative PCR results, we report strain colonization and washout in planted versus unplanted systems. We also report that in-series flow-through systems bioaugmented with *R. ruber* 219 can sustain >50% degradation for up to 40 days without rebioaugmentation. Finally, we report progress from our pilot-scale demonstration at TCAAP. Overall, this research demonstrates that bioaugmented phytoremediation is an attractive strategy to treat dilute dioxane-contaminated groundwater to low risk-based concentrations (<0.35 µg/L).