## EXECUTIVE SUMMARY

In Canada, contaminated site stakeholders have favoured excavation and landfilling practices for source removal due to the speed and perceived cost-effectiveness of this method for 'remediating' hydrocarbon contaminated sites. However, landfill disposal is not a substantial treatment method due to potential environmental liabilities associated with the landfilled soil material for secondary contamination such as groundwater impacts by leachate and landfill gas migration towards off site. Internationally, conventional thermal desorption (i.e. low temperature incineration) and/or soil washing have been widely used for heavily contaminated soil and/or source material. However, with an ever increasing emphasis on sustainable remediation practices, contaminated site stakeholders are under increasing pressure to select more sustainable and innovative solutions minimizing environmental footprints caused by massive soil excavation, disposal at landfill and backfill with imported soils, and there is a demand for the evolution of a diverse number of in-situ and ex-situ remediation approaches. Furthermore, the developed and improved remediation technologies over the last few decades are still not cost-effective and potentially cause secondary contamination (e.g. GHG emissions, chemical residues, etc.).

In the first year (2018-2019) of the subject project, the research team successfully developed multi-functional stimulators using nanomaterials with technical and economic benefits, which utilize the advantages of thermal and chemical treatments for hydrocarbon impacted soil. A series of lab scale in-situ feasibility tests proved that the stimulators effectively generated heat and other remediation mechanisms through their activation thereby reducing concentrations of F2 and F3 hydrocarbons up to 93% in soils contaminated with 100,000 mg/kg diesel. Although the stimulator assisted in-situ remediation has shown significant removal of hydrocarbons, an additional remediation was required to meet the Alberta Tier 1 Soil and Groundwater Remediation Guidelines. It was confirmed that a lab-scale in-situ eletrokinetic/electrochemical (EK/EC) treatment as a subsequent remediation method further reduced residual hydrocarbons up to 50% in total hydrocarbons after 4 weeks of the onset of direct electric current application.

In the second year (2019-2020), further lab-scale tests were performed to improve the developed stimulator assisted in-situ application by identifying followings: (1) the impact of coating material dose in stimulator composition for various soil textures; (2) feasibility of a lab-scale integrated in-situ remediation system in hydrocarbon removal; (3) radius of influence (ROI) and depth of influence (DOI) for activated stimulators; (4) impact of multiple stimulator layers on hydrocarbon remediation; and (5) produced heat propagation in soils through modeling and simulation.

The lab-scale test results for the impact of coating material dose in the stimulator composition were inconsistent with our initial postulation that increase of field soil amount (i.e. increase of clay content) would reduce amount of coating material required for protecting spontaneous activation of stimulators and being activated by heat supply under the tested soil moisture conditions. In a specific range of coating material dose, its impact was negligible on the stimulator activation in the tested soils with over 25% of field soil, which implies that there may exist a critical soil composition to be considered for determination of the coating material dose. Soil that contains lower clay content than the critical composition may demand more coating material to protect stimulators from spontaneous activation without heat supply.

The lab-scale integrated in-situ remediation system was developed and its feasibility tests showed that the exothermic chain reactions of the stimulators were ideally propagated from the original heat source. In addition, the maximum temperature at all locations were not significantly different which indicates feasibility of Phase 1 treatment (stimulator-assisted thermal treatment) of the integrated in-situ remediation system for hydrocarbon removal. The subsequent Phase 2 treatment (EK/EC treatment) reduced up to 15% of hydrocarbons over the period of direct electric current application (4 weeks). However, further investigation is required as varying concentration reduction was observed over the length of the tested soil and majority of the concentration decline stopped or rebounded after 3 of the 4 weeks.

The radius of influence (ROI) tests concluded that stimulators immediately activate with onset of heat supply and that the ROI of activated stimulators can be expanded as wide as stimulator exists. However, analytical results presented only 33.3% of hydrocarbon removal, but this was likely due to reduced stimulator dose applied in the ROI tests. The depth of influence (DOI) test results showed that heat penetration did not effectively reach distances greater than 1 cm above and below the layer of stimulators. Due to the findings on DOI tests with a single layer of stimulators, multiple stimulator layers were evaluated to identify the synergistic impact in temperature increase and hydrocarbon remediation. However, no noticeable synergy impact was observed from the multiple stimulator layers. Finally, modeling and simulations were performed to identify influence of soil type on propagation of heat produced from the exothermic chemical reactions and compare the simulation results with experimental observations. The simulation results showed that impact of soil type and water content is limited for the heat propagation, presenting not significantly different temperature distribution in soils under different conditions.