EXECUTIVE SUMMARY

Contamination of soil and groundwater has increased by not only the extensive oil and gas developments in Canada over the past few decades but oil spills through leakages from underground storage tanks and pipelines. Cost reduction and efficiency enhancement have been always pursed in environmental remediation. It was reported that thermal treatments result in relatively higher remediation efficiency compared to other treatments such as bioremediation, chemical oxidation/reduction, and electrokinetic remediation. However, current thermal treatments and incineration requires high temperature heat (400~1,200 °C), consequently demanding high operating costs and producing greenhouse gases (GHG). To utilize the advantages of thermal treatment but reduce operating cost and energy consumption, the proprietary multi-functional stimulators for ex-situ remediation have been developed by the current research team using nanomaterials. Through a series of lab-scale testing, the developed stimulators have proven both technical and economic potential with outperformed technical results that can be summarized as 99% hydrocarbon removal and 82% DNAPL (diesel and tar) removal of soils contaminated with 100,000 mg/kg concentrations.

In this project, based on the outperformed technical results in petroleum hydrocarbon contaminated soil by ex-situ application of the stimulators, (1) multi-functional stimulators for in-situ application were developed, (2) the developed stimulators and their application method were evaluated in the aspects of heat generation as well as hydrocarbon remediation efficiency, and (3) the specially designed ex-situ prototype for application of the proprietary stimulators (T-Rex®) was validated in remediation of heavy hydrocarbons (crude oil) in soil.

To develop the multi-functional stimulators for in-situ application, various compositions of the candidate constituents were evaluated in the aspects of energy consumption and lag time for their activation, temperature generated by their activation, and controllability. One of the select constituents was emulsified with water-resistant material to delay its activation in the presence of soil moisture due to its high reactivity with water. The developed stimulators were successfully activated at low heat temperature (< 150 °C) and effectively generated additional heat through their exothermic chemical reactions in the lab-scale in-situ application, resulting in maximum soil temperatures in a range of 280 °C to 670 °C depending on soil conditions. In a separate test, it was confirmed that the developed stimulators were stable in the presence of soil moisture until they received proper heat temperature.

A series of lab-scale in-situ feasibility tests has proven that the generated heat and other mechanisms through the chemical reactions effectively degraded hydrocarbons in soil, resulting in remediation efficiency of 88 – 93 % in F2 and F3 hydrocarbons under 5 % hydrocarbon contamination and 10 – 12 % soil moisture conditions. However, it also has been confirmed that heat generation and remediation efficiency via exothermic chemical reactions of the stimulators are significantly influenced by soil characteristics that influence available oxygen content in soil pores. Although considerable removal of hydrocarbons (> 88 %) have been confirmed through the feasibility tests of the in-situ application, approximately 10,000 – 15,000 mg/kg of hydrocarbons still remained in the treated soil, which indicates that further reduction of hydrocarbon concentration is necessary to meet the Alberta Tier 1 Soil and Groundwater Remediation Guidelines which require concentrations less than 260 mg/kg for F2 and 2,500 mg/kg for F3 for the commercial land use. The lab-scale in-situ electrokinetic/electrochemical (EK/EC) treatment that was employed as the subsequent remediation method to further reduce the residual hydrocarbons after the stimulator assisted in-situ application, resulted in 47 – 50 % removal of

total hydrocarbons (C10 – C34) 4 weeks after the onset of the direct electric current application. This result indicates that the integrated in-situ remediation system comprising the stimulator assisted thermal treatment and the subsequent EK/EC treatment will greatly enhance the remediation efficiency with low energy consumption.

Based on the outperformed technical results of the stimulators assisted ex-situ prototype in remediating petroleum hydrocarbons (diesel and artificial creosote), lab-scale tests using the proprietary stimulators (T-REX®) and their ex-situ application prototype were performed to evaluate treatability for heavy hydrocarbons (crude oil) in soil. The effectiveness of the proprietary stimulators (T-Rex®) and the specially designed ex-situ prototype for their application was successfully validated to reduce heavy hydrocarbons in soil. The treatability test results have confirmed that the ex-situ remediation system was effective in extracting heavy hydrocarbons (F2 - F4+) present in soil and recovering light hydrocarbons (F2 – F3), which indicates that activation of the stimulators can crack the chemical bonds of the long-chained hydrocarbons. Both qualitative and quantitative results indicate that heat temperature over 400 °C is demanded to remediate relatively heavier hydrocarbons (> F3) and to enhance recovery of light hydrocarbons.