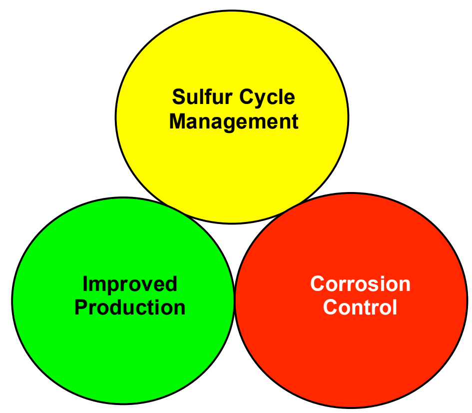
NSERC Industrial Research Chair in Petroleum Microbiology Program Description/Rationale

One of the biggest challenges facing society today is how to chart the best course towards our energy future (1). Our society currently depends greatly on fossil fuels (40% oil, 24% gas, 22% coal) with smaller contributions from nuclear energy (6%) and renewables (8%). The environmental consequences of this heavy reliance on fossil fuels are well known and include significant increases of CO_2 in the Earth's atmosphere contributing to global warming. Hence, governments are under significant pressure to act to halt or reverse environmental consequences of our reliance on fossil fuels. Key steps towards a sustainable energy future will be to:

(i) reduce per capita energy consumption
(ii) have renewables contribute a larger fraction of our energy supply and
(iii) to make extraction and use of fossil fuels as efficient and "green" as possible.

Research on step (iii) is somewhat ignored but is especially important, because it is expected that fossil fuels will remain the main component of our energy supply for many years to come. The problems associated with the production of sufficient fossil fuel to meet the world's growing demand should not be underestimated. New, out-of-the-box technologies are required to reduce the environmental impact of production and use, to extend the life span of existing conventional oil and gas reservoirs, to improve recovery of heavy oil and bitumen.



Microbiology is one of the disciplines that can offer novel solutions. Although its potential has been recognized for over 50 years, the role that microorganisms have played in shaping the oil-component of our fossil fuel energy resource is only now becoming understood and reliable technologies involving microbes are only now being implemented. This proposal aims to establish a critical mass of expertise in petroleum microbiology at the University of Calgary (UofC) focussing on the three indicated, interconnected areas. Completion of the intended program will offer improved ways to reduce souring and corrosion, allowing the oil and gas industry to reduce costs and safely extend the life of conventional production in Western Canada, Canadian offshore fields and elsewhere in the world. The program also aims to develop biotechnologies for the oil sands that improve water recycling and current production strategies. This will allow greater recovery and more efficient production of oil sands deposits with reduced environmental consequences. Given the size and importance of these resources the benefits attainable by even very modest improvements in the target areas are economically enormous. Expanding knowledge and applications of Petroleum Microbiology will be the main benefits to the scientific and engineering discipline. Benefits to the University of Calgary include increasing its research capacity and ability to teach students in Petroleum Microbiology, an area of growing importance to ensuring our energy supply.

The rationale for and scientific and technical objectives of each of the three areas are as follows:

<u>2.1.1 Sulfur cycle management</u>.

<u>Rationale:</u> Oil production by water injection often results in increased sulfide levels (souring), because sulfate-reducing bacteria (SRB) couple the oxidation of degradable oil organics to the reduction of sulfate to sulfide. High levels of sulfide represent increased toxicity and corrosion risk. Souring also negatively affects the quality of gas stored in subsurface reservoirs, because the H_2S must be removed

prior to distribution to consumers! Souring can be prevented or reversed by the periodic, batchwise application of biocides or by the continuous, field-wide injection of nitrate. The latter method stimulates two groups of beneficial subsurface bacteria. Nitrate-reducing, sulfide-oxidizing bacteria (NR-SOB) remove sulfide and heterotrophic nitrate-reducing bacteria (hNRB) remove degradable oil organics, which would otherwise be used by SRB. Because nitrate is converted to chemically inert nitrogen or ammonia, nitrate injection is an environmentally friendly, "green" method of sulfide removal and its continuous, field-wide use is now commonly practiced in older offshore operations in the North Sea and is steeply on the rise elsewhere. One outcome of this program will be the transfer and successful application of this technology to oil and gas operations in Canada and elsewhere in the world. Application of nitrate to contain souring has been especially successful for seawater injection in offshore operations. However, its use in onshore reservoirs subjected to produced water reinjection (PWRI) is less well understood and will be of particular interest.

<u>Scientific and technical objectives are as follows</u>:

Microbial populations, as well as concentrations of sulfate, sulfide, sulfur and degradable oil organics will be determined in produced and injection waters from different fields. Those subjected to produced water reinjection (PWRI) will also be included. Determining the kinetics and extent of reduction of nitrate added directly to these produced waters will indicate the need for additional nutrients and the possible presence of inhibitors. Determining the rate of oxidation of oil-dissolved sulfur will be a novel feature of these studies. Input of the data obtained into a STARS-based multifactor souring model will allow an estimate of the required dose, as well as simulated visualization of souring reduction as nitrate injection progresses. The results will be used to select fields most suited for long-term nitrate injection trials. Up-flow packed-bed bioreactor studies, under PWRI conditions if relevant, will be conducted for these to simulate reservoir conditions more closely. Concentrations of microbes and metabolites will be monitored during the long-term nitrate field trials. The data will be incorporated into the STARS reservoir simulation tool. Better understanding of the reliability of souring control by long-term nitrate treatment will be the main deliverable of this part of the study

<u>2.1.2 Corrosion control</u>.

<u>Rationale:</u> Corrosion risk is determined by multiple physical, chemical and microbial factors. Localized bacterial growth on the steel surface of oil and gas production facilities increases surface heterogeneity and, thereby, the risk of pitting corrosion. This risk can be lowered by application of corrosion inhibitors and/or biocides. High sulfide concentrations also enhance corrosion risk. Hence, removing sulfide by oxidation with nitrate may be beneficial, provided that formation of partially oxidized forms (sulfur) is avoided. Nitrite formed by partial reduction of nitrate (or added directly) is a strong SRB inhibitor. However, it also reacts chemically with sulfide to form sulfur and polysulfides. Nitrite and biocides have been shown to be strongly synergistic in inhibiting SRB activity. The use of biocide, of biocide/nitrite or of nitrate are very different strategies. Biocide or biocide/nitrite application reduces microbial numbers, whereas nitrate application increases these, while shifting the population from SRB to NRB. Correct use of these options will lower corrosion rates and the chance of hydrogen-driven cracking problems in oilfield production facilities. This can extend the lifespan of wells, pipes and pumping equipment, improving safety, avoiding the environmental impact of leaks and ruptures and lowering replacement costs.

<u>Scientific and technical objectives are as follows:</u>

Determination whether partial souring control, resulting in production of sulfur/polysulfide, increases corrosion risk. Characterization of the chemical reaction between nitrite and sulfide to determine the potential for corrosion enhancement by this key reaction. The potentially enhancing role of sulfur/polysulfide in SRB-mediated corrosion of steel will also be determined. These studies will give new insights on how potentially negative aspects of nitrate injection technology can be limited.

Synergy of nitrite and biocides to further reduce corrosion risk in pipelines and topsides facilities will be exploited. Compatibility of these topsides treatments with nitrate injection technology will be assessed in order to prevent failed nitrate treatments in PWRI situations due to the presence of remaining biocides. The effects of long-term nitrate injection in field trials on corrosion will also be monitored. Objectives of this work are thus to identify how nitrate injection technology impacts and is impacted by other control strategies that may be in place. The results will allow appropriate modification of technologies-in-place to obtain optimal benefits from nitrate injection.

2.1.3 Improved production.

Rationale: Continuous injection of nitrate or oxygen has been reported to result in microbially enhanced oil recovery (MEOR) by *in situ* production of biosurfactants or of partially reduced, highly reactive intermediates (HRI), or by removal of oil-dissolved sulfur by resident bacteria. Understanding this MEOR mechanism is critical, not only for improving conventional oil production, but also for the Alberta Oil Sands, the largest remaining hydrocarbon reservoir in North America, containing heavily biodegraded oil. Light components have been removed over geological time by anaerobic microbial consortia, which crack hydrocarbons to methane and CO_2. Production of the remaining highly viscous bitumen from shallow zones by surface mining involves separation of bitumen, clay and sand from aqueous mixtures. Slow settling of separated particulates in tailings ponds compromises water reuse and gives significant microbial emissions of methane, a potent green house gas. Production from deep zones requires viscosity reduction by steam injection (requiring considerable energy input), organic solvent injection or combinations of the two. Biotechnologies for the oil sands should aim to improve existing technologies by decreasing their environmental impact and required energy input. Even incremental improvements are valuable in view of the vast scale of oil sands operations!

Scientific and technical objectives are as follows;

We will determine whether continuous nitrate treatment of oil results in increased biosurfactant production, and whether exposure of oil to HRI or removal of oil-dissolved sulfur reduces viscosity. The results will indicate whether MEOR, resulting from injection of nitrate or oxygen in conventional production, depends on any or all of these factors. Conducting similar studies with oil sands or oil sands fractions will indicate the extent to which biosurfactants or HRI can contribute to viscosity reduction. Comparison of the composition of aliphatic and aromatic fractions of oil sands and heavy oils can indicate which components in the latter may be converted into methane *en route* to an inceasingly viscous tar sands-like oil. Oil sands components, which can be converted into methane, can be identified by monitoring more rapid methanogenesis under thermophilic conditions. Results from large metagenomics project will uncover the microbial diversity in Alberta Oil Sands tailings ponds, deep anaerobic zones and air-exposed surface sites and will thoroughly characterize genes for enzymes and microorganisms active in anaerobic methane formation in tailings ponds and deep anaerobic zones, and in degradation of recalcitrant bitumen fractions at air-exposed surface sites. The results may allow design of microbial biotechnology processes that improve tailings pond water recycling with reduced methane emissions, that reduce viscosity allowing reduced energy input for bitumen production, or that allow *in situ* microbial conversion to methane as an alternate way of producing the resource.

1. Hall, C., P. Tharakan, J. Hallock, C. Cleveland and M. Jefferson. 2003. Hydrocarbons and the evolution of human culture. Nature 426: 318-322.