Evaluating Oil Sands Technologies Using Life Cycle Analysis (LCA) and Optimization

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Overview

Alberta's oil sands reserves supply stable and reliable energy to the world and play an important role in the Canadian economy[1]. Oil sands operations are energy intensive and costly compared to conventional oil production and generally generate higher greenhouse gas (GHG) emissions than conventional oil[2]. Considering the recent decline in oil prices, and more stringent environmental regulations that have threatened the contribution of oil sands products to the global oil market[3,4], oil sands operators and policy makers seek technological improvements to enhance the performance of oil sands operations by reducing cost, energy consumption and GHG emissions of the operations[5]. This can be achieved by replacing existing technologies with new and more efficient technologies[5]. This study intends to provide a framework for evaluating the implications of adopting new technologies in oil sands operations and investigating the performance of these new technologies under various economic and policy conditions when the entire supply chain is considered.

Many technologies have been developed and employed for oil sands extraction and processing in the past five decades to keep oil sands products economically competitive in the global oil market[7]. Emerging technologies such as partial upgrading technologies[6] and solvent-assisted extraction and recovery[7] that are focused on improving the economic and environmental performance of oil sands operations are being considered for deployment in oil sands operations but have not yet been deployed at commercial scale[8]. The framework proposed in this study is used to evaluate these technologies and to explore the conditions under which the emerging technologies can become competitive with the existing technologies.

There are several factors that affect the comparison between life cycle impacts of emerging and existing oil sands technologies[9]. Performance characteristics of the technologies (e.g., energy consumption intensity) and external market parameters (e.g., natural has (NG) price and carbon price) are among the main factors that influence this comparison. For example, low natural gas prices discourage investments in solvent-assisted technology because of narrow economic benefits. Therefore, selecting the optimal "technology pathway" (a combination of technologies for 1. extraction and recovery of bitumen, 2. bitumen dilution/upgrading and 3. refining to produce final oil sands products) with respect to economic and environmental objectives is complicated by a large number of input parameters in the system and requires a comprehensive techno-economic framework that considers all technological and economic input parameters that affect the performance of the entire system in terms of total cost, total energy consumption, and GHG emissions. No study in the literature has investigated the set of conditions that change the competitiveness of emerging technologies against current technology pathways from full life cycle and multi attribute perspectives (economic and environmental perspectives), that is therefore, the goal of this study.

Methods

A mathematical model is developed in this study to represent all possible technology pathways for oil sands production, including existing and emerging technology options, and to estimate GHG emissions and costs associated with all possible pathways from bitumen extraction and recovery to combustion of refinery products using a life cycle analysis (LCA) approach. GHG emissions estimates are obtained using existing LCA models that have previously been developed to estimate GHG emissions in different stages of oil sands production. These models include GHOST[10], OSTUM[11], PRELIM[12] and COPTEM[13]. Existing infrastructure and capacity for refining and pipeline transportation of oil sands products are considered in the model. In addition to that, uncertainties associated with input parameters including market parameters (e.g., NG price) and technology performance parameters (e.g., energy consumption intensity) are incorporated in the model. The mathematical model is used to find the optimal technology pathway (or optimal combination of technology pathways) with respect to total cost and total GHG emissions of the pathway. Trade-offs between total cost and total GHG emissions of different pathways are explored under various scenarios for NG price, carbon price, source of electricity generation, etc. using multi-objective optimization.

Results

Preliminary results of this study identify the conditions under which emerging technologies become competitive alternatives in oil sands production. For example, the results show that solvent assisted extraction leads to higher profit values compared to conventional extraction methods under most conditions. In the next stage of the study, capacity constraints for existing oil sands facilities as well as the effect of increased demand of raw material such as solvent and diluent on the price of these commodities are considered and the effects of including these additional constraints on the selection of optimal pathway is investigated.

Conclusions

This study aims to inform oil sands operators about the technology alternatives that can potentially increase the competitiveness of oil sands products in the global oil market by reducing the supply chain cost and life cycle GHG emissions of oil sands operations. Results of this analysis can help oil sands producers to better understand the long-term effects associated with the use of existing and emerging oil sands technologies. The mathematical model developed in this thesis combines life cycle and optimization techniques and is used to create a tool that can evaluate the performance of emerging technologies in various industries with respect to economic and environmental criteria.

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