Costs and GHGs impact of emerging oil sands technologies

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ABSTRACT

The vast oil sands resources in Western Canada provide significant economic and societal benefits for Canada. However, the extraction and processing of oil sands is not only capital intensive but also results in high energy use and greenhouse gas (GHG) emissions impacts. Reduction of the associated production costs and GHG emissions impacts are two important challenges facing the oil sands industry. Consequently, numerous research and development (R&D) projects are being undertaken. However, what is missing from the research is an evaluation of environmental in conjunction with economic impacts of these R&D projects. This study bridges this gap through a detailed techno-environomic assessment of the potential of the emerging *in situ* technologies to reduce supply cost and GHG emissions in the short and long runs. Major technologies that could be commercially deployed in *in situ* process-based projects are covered. Results show that opportunities exist to significantly reduce costs and emissions using reservoir and steam generation technologies. The cumulative effect of some of the new technologies can achieve potential reduction of bitumen supply cost by 34-40 percent as well as reduce fuel-derived emissions from *in situ* oil sands production by 80 percent, and consequently delay the time until the emissions cap is reached. Findings in this study provide insights into the capability of emerging technologies to address the pressing cost and GHG emission challenges facing the Alberta oil sands industry.

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INTRODUCTION

The objective of this study is to explore how innovation and technology development efforts in the oil sands industry can lead to costs and emissions reduction in bitumen extraction and processing. We identify new technologies and processes that can be deployed in the oil sands industry within the next 5-7 years and how these options can reduce fuel-based emissions and supply costs. The supply cost of bitumen captures the minimum constant dollar price needed to recover all capital expenditures, operating costs, royalties and taxes and earn a specified return on investment.

This study focuses on *in situ* bitumen extraction and processing technologies because future of oil sands developments is expected to be predominantly *in situ*-based due to resource deposition characteristics in Alberta. This is because more than 70% of the recoverable bitumen is too deep to be mined. *In situ* bitumen extraction includes steam-assisted gravity drainage (SAGD) and cyclic steam stimulation (CSS) approaches. These *in situ* methods have similar characteristics as they involve injection of high pressure and high temperature steam into oil sands reservoirs to reduce bitumen viscosity, mobilize and recover bitumen. Once the product has been recovered at the surface, a central processing facility is used to purify the bitumen product prior to sales.

METHODS

A conventional SAGD facility with steam-oil ratio (SOR) of 3 m^3/m^3 and 30,000 barrels per day (bbl/day) production capacity is set as the baseline. SOR is the volume of steam (cubic meter cold water equivalents) injected into the reservoir to produce a cubic meter of bitumen. The SOR is used to measure the efficiency of an *in situ* bitumen extraction process – the lower the SOR, the more efficient the process is. The bitumen production and processing facilities are sub-divided into segments that constitute the oil sands process chain. These segments include Water and Waste Treatment (*WWT*), Steam Generation (*SG*), Wells and wellpads (*WWP*), Reservoirs (*RES*), and

Business Management and Data Analytics (*BM*). These technologies and processes are assessed to determine their potential contribution to reduction of supply costs and process fuel-derived GHG emissions in bitumen production and processing.

With various technologies identified and assessed for their cost and emissions reduction potential, six optimal technology paths (five for greenfield projects and one for brownfield), as shown in Table 1, were determined. These technology paths were constructed in a way that allows for a combination of complementary processes and technologies in the bitumen extraction and processing chain to be combined to reduce supply costs and GHG emissions. Detailed explanations of the technologies highlighted in Table 1 can be found in Nduagu et al. (2017).

Table 1. Optimal technology configurations for Brown- and Greenfield

<table>
<tr><th rowspan="2">Technology configurations</th><th colspan="6">Compatible processes and technologies</th></tr>
<tr><th colspan="2">BM</th><th>WWP</th><th>RES</th><th>WWT</th><th>SG</th></tr>
<tr><td colspan="7">Brownfield development</td></tr>
<tr><td>Steam solvent</td><td></td><td>Steam flood management</td><td></td><td>Steam Solvent</td><td>Magox precipitation and CO_2 conversion</td><td>OTSG</td></tr>
<tr><td colspan="7">Greenfield development</td></tr>
<tr><td>Steam with CO_2 co-injection</td><td rowspan="5">Digitalization of EPC</td><td rowspan="5">Steam flood management</td><td rowspan="5">Wellpad standardization</td><td>Steam/CO_2 co-injection</td><td rowspan="2">Evaporator</td><td>DCSG</td></tr>
<tr><td>Steam with CoGen</td><td>Steam</td><td>SOFC</td></tr>
<tr><td>Steam-solvent</td><td rowspan="2">Steam Solvent</td><td rowspan="2">Chemical water treatment</td><td>RT-OTSG</td></tr>
<tr><td>Steam-solvent Cogen</td><td>SOFC</td></tr>
<tr><td>Pure Solvent</td><td>Pure Solvent</td><td></td><td></td></tr>
</table>

Key: OTSG – once-through steam generation boiler; RT-OTSG – Riffle tube once-through steam generation boiler; Magox – Magnesium oxide; DCSG – Direct contact steam generation and SOFC – Solid oxide fuel cell

The optimal technology configurations could be classified either as applicable to Brownfield or Greenfield or both depending on where the configuration can be applied suitably. Technologies that can be easily retrofitted into existing SAGD infrastructure with modest capital expenditures are considered as Brownfield whereas those that require an almost complete change of the existing infrastructure are Green field. Greenfield configurations will be uneconomic as retrofits.

RESULTS

The economics and emissions reduction potentials of various technology segments are assessed and the results are presented in this section.

GHG Emissions Reduction from New Technologies. The ranges of process fuel –derived GHG emissions obtained under the various segments are shown in Figure 1. Whereas all the technology segments can reduce process fuel–derived GHG emissions of the *SAGD Base* case (60.4 kgCO_2eq./bbl bitumen shown with a dash line in Figure 1), two technology segments (the RES and SG) show the greatest potential for emissions reduction. The RES and SG segments can independently reduce direct fuel-derived GHG emissions of the *SAGD Base* case by 70-75%. This is achieved by the pure solvent-based extraction and direct contact steam generation (DCSG) technologies. The DCSG case assumes that 30%-60% of the CO_2 generated from oxy-fired natural gas combustion is sequestered in the oil sands reservoir during the bitumen extraction process. The process descriptions of these technologies are presented elsewhere (Nduagu et al., 2017). In terms of GHG reductions, electromagnetic heating, which is among the RES technologies reduces emissions quite significantly (55% less than SAGD baseline when natural gas combined cycle is used). However, electromagnetic heating technology uses more electricity than other RES technologies, and when emissions from electricity generation are included, its emissions reduction potential is reduced dramatically.

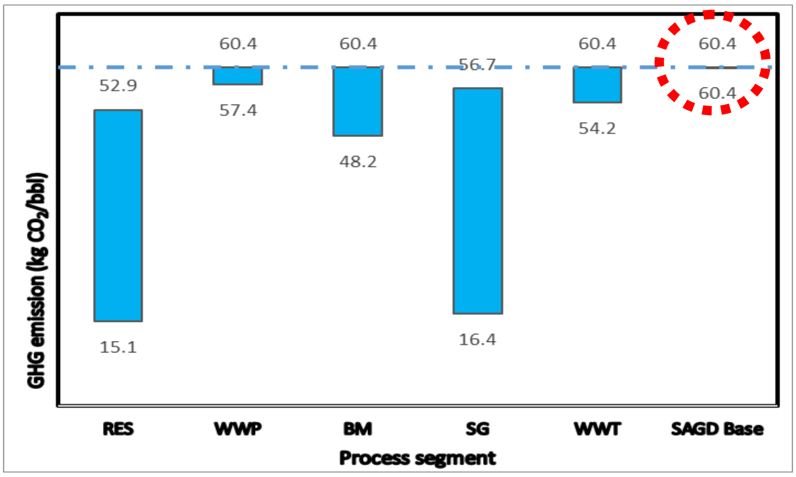

Figure 1. Range of direct GHG emissions for various bitumen extraction process segments. Key: *RES* – Reservoirs; WWP - Wells and wellpads; *BM* - Business Management and Data Analytics; SG - Steam Generation; *WWT* -Water and Waste Treatment and *SAGD Base* – conventional *SAGD* process used as basis for comparison.

Cost Reduction from New Technologies. Supply cost results in Figure 2 show that only the RES segment constitutes emerging technologies that can dramatically reduce SAGD bitumen supply costs and may even increase the cost significantly. The supply costs under the RES segment is between C$29.6/bbl and C$64.1/bbl bitumen (as against C$43.3/bbl bitumen for the *SAGD Base*) if steam-solvent technologies are deployed in a Greenfield facility.

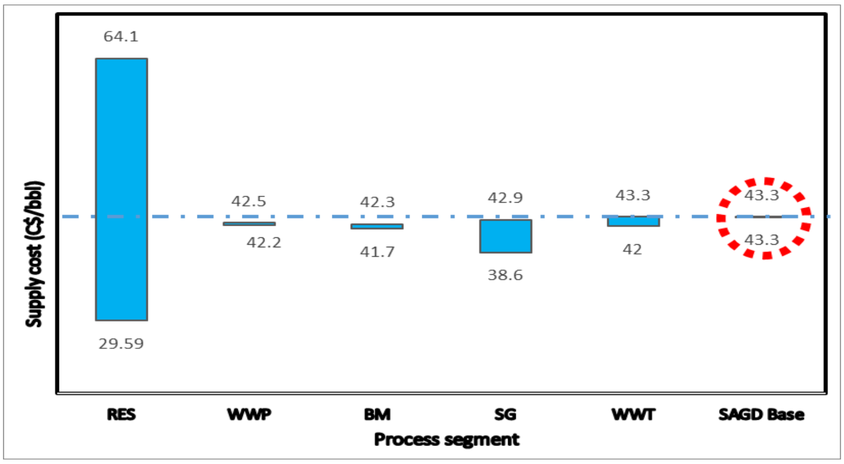

Figure 2. Range of supply costs for various bitumen extraction process segments. Key: RES – Reservoirs; WWP - Wells and wellpads; BM - Business Management and Data Analytics; SG - Steam Generation; WWT -Water and Waste Treatment and *SAGD Base* – conventional SAGD process used as basis for comparison.

Under *RES* segment, the steam-solvent extraction processes show the greatest potential for cost reduction. The lowest cost value (C$29.6/bbl) represents high performance steam-solvent processes that can reduce the SOR of the SAGD (3 m^3/m^3) base case by 35% and produce a bitumen production uplift of 38% over the *SAGD Base* case. If a lower range of 10.5% production uplift is applied, the supply cost of the steam-solvent process becomes C$0.50/bbl less than that of the *SAGD Base* case. It can then be deduced that *SOR* reduction and production uplifts are key factors that influence the economics of the steam-solvent process.

Other technologies with moderate cost reduction potentials within the supply costs range for the RES segment are the *Pure solvent* (C$39.9/bbl bitumen) and the *Steam-surfactant* (C$41.8/bbl bitumen) processes. However, these technologies produce partially upgraded bitumen products. For example, a *Pure Solvent* process such as *NSOLV* uses propane or butane as solvent for bitumen extraction and produces a lower viscosity bitumen product with an API gravity of 13-14 as against raw bitumen's API gravity of 8. Consequently, a diluent cost of C$4/bbl can be avoided in supply cost of SAGD bitumen on a Western Canadian Select equivalent (WCS eq.) basis. Diluent reduction also frees up pipeline volume allowing more bitumen to be transported. Though water consumption footprint is not covered in this study, it is worth mentioning that the solvent processes have the potential to reduce water use in oil sands extraction to zero, and thus, reducing the requirements for water treatment facilities. However, the solvent-based processes face concerns of loss of solvent and uncertainties about the long-term fate of the unrecovered solvent in the reservoir.

The upper range of the *RES* segment represents maximum supply costs for the electromagnetic heating technologies. With electromagnetic heating, a range of supply costs of bitumen (C$48.7/bbl to C$64.1/bbl) is obtained depending on the number of wells and durability (lifespan) of the heating antennas. This technology also uses pure solvent but is heated electromagnetically. Similar benefits of partial upgrading and zero water use footprints are expected, but the supply costs are prohibitively high.

The BM segment achieves notable economic and environmental performance, particularly in the application of data analytics in steam flood optimization, which results in considerable emissions reduction and higher return on investment (low adoption cost but relatively high performance).

Performance Improvements from Technology Configurations. Considering both cost and GHG emissions minimization objectives, an optimal process was observed to be the *Steam Solvent CoGen* configuration (Figure 3).

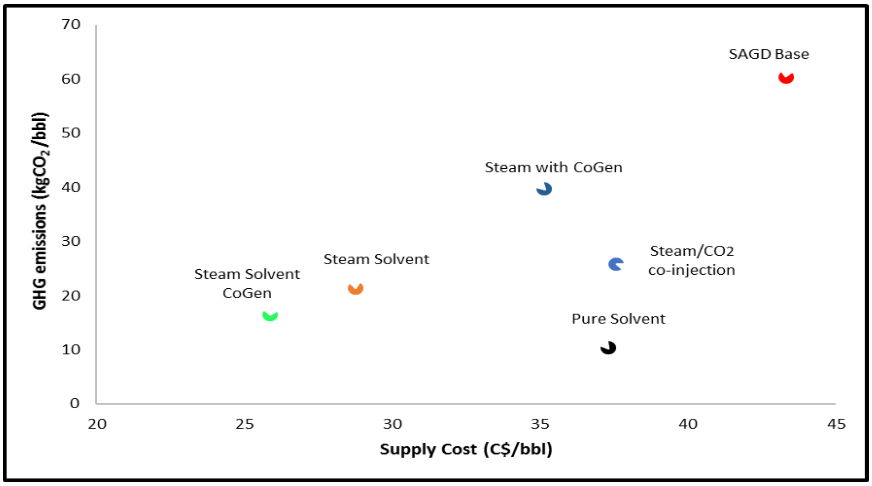

Figure 3. Combined impact of technologies under different cost and GHG emissions scenarios

This process uses solid oxide fuel cells (*SOFC*) for steam and electricity generation and has the potential to reduce costs and GHG emissions of the *SAGD Base* by 40% and 73%, respectively. However, this technology still needs further development and may face significant technical maturity and economic issues if implemented in an oil sands facility. Another near optimal technology configuration is the *Steam Solvent* configuration with most of its process components almost commercial. Thus, this configuration seems more feasible than the *Steam Solvent CoGen* configuration.

On the other hand, the *Pure Solvent* technology configuration has the potential to achieve the highest emissions reduction, an 83% reduction of fuel-based GHG emissions of the *SAGD Base*. This is a configuration of choice if the objective is to reduce fuel-derived emissions of oil sand to near zero. Only the *Steam Solvent* technology configuration is applicable to the Brownfield. This configuration requires minimal retrofits and uses data analytic-based steam flood management to optimize steam injection and bitumen mobilization.

Oil Sands Emissions Profile and the 100 MtCO$_2$eq. Cap. Using production projections (Millington, 2017) and fuel-derived and fugitive emissions intensities of mining, *in situ* production, primary production, enhanced oil recovery, and upgrading, annual emissions profile of the Alberta oil sands industry are assessed (Figure 4). Recently, the Alberta Government introduced a 100 MtCO$_2$ eq./year emissions cap regulation aimed to limit oil sands emissions (Government of Alberta, 2016a). The cap is shown in Figure 4 as a horizontal red line. The profile "*Total Direct Emissions with CH4 Policy*" is the business as usual case where no new technologies are used and the Alberta methane policy (Government of Alberta, 2016b) of achieving 45% reduction of methane emissions from oil and gas industry against 2014 levels is implemented. The methane policy will result in an emissions reduction of less than 2 megatons CO$_2$ equivalents per year (Mt CO$_2$/year) which will, however, be dwarfed by emissions growth associated with increasing bitumen production.

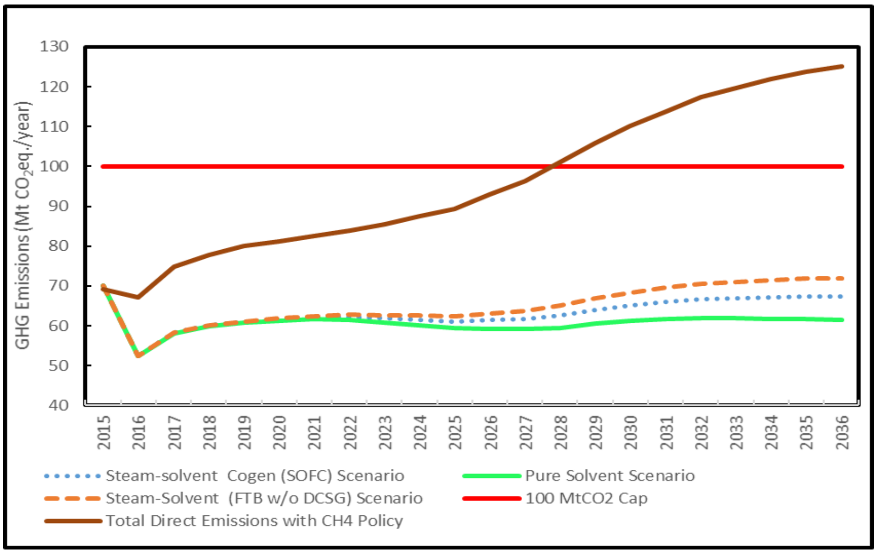

Figure 4. Combined impact of technologies under different cost and GHG emissions

The optimal cost and emissions technology configuration profiles (Fig. 4) are the "*Steam-solvent Cogen (SOFC) Scenario*" and the "*Steam-Solvent (FTB w/o DSCG) Scenario*"; however, the later seems to be plausible given its level of technical maturity. The "*Pure Solvent Scenario*" is the profile for minimum emissions. The emissions profiles are a product of the emissions intensity (including fuel-derived, flaring and fugitive emissions) and the bitumen production expressed in Mt CO$_2$e/year.

The observed deviation in the emission profile in Fig. 4 can be explained by the downturn due to global oil glut and Alberta wildfires in 2016. Our results indicate that the "*Total Direct Emissions with CH4 Policy*", which indicates the business as usual case, would reach the 100 Mt CO$_2$/year cap by 2026 whereas under the alternative scenarios, the industrial emissions cap is not reached over the 20 years' production window considered.

CONCLUSIONS

New technologies that are deployable for *in situ* bitumen extraction and processing show potential to reduce supply costs and emissions impacts significantly. Our optimal technology configurations can reduce costs and fuel-based GHG emissions by up to 34-40% and more than 80%, respectively. However, realization of these potentials will depend largely on technical progress and funding towards commercialization of these technologies.

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