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Energy infrastructure modeling for the oil sands industry: Current situation

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HIGHLIGHTS

- A simulation-based modelling of energy demands of oil sands operations is proposed.
- Aspen simulations used to simulate delayed coking-based upgrading of bitumen.
- The energy infrastructure is simulated using Aspen Plus achieving self-sufficiency.
- Various scenarios affecting energy demand intensities are investigated.
- Energy and CO_2 emission intensities of integrated SAGD/upgrading are estimated.

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ABSTRACT

In this study, the total energy requirements associated with the production of bitumen from oil sands and its upgrading to synthetic crude oil (SCO) are modeled and quantified. The production scheme considered is based on the commercially applied steam assisted gravity drainage (SAGD) for bitumen extraction and delayed coking for bitumen upgrading. In addition, the model quantifies the greenhouse gas (GHG) emissions associated with the production of energy required for these operations from technologies utilized in the currently existing oil sands energy infrastructure. The model is based on fundamental engineering principles, and Aspen HYSYS and Aspen Plus simulations. The energy demand results are expressed in terms of heat, power, hydrogen, and process fuel consumption rates for SAGD extraction and bitumen upgrading. Based on the model's output, a range of overall energy and emission intensity factors are estimated for a bitumen production rate of 112,500 BPD (or 93,272 BPD of SCO), which were determined to be 262.5–368.5 MJ/GJ_{SCO} and 14.17–19.84 gCO_2/MJ_{SCO}, respectively. The results of the model indicate that the majority of GHG emissions are generated during SAGD extraction (up to 60% of total emissions) due to the combustion of natural gas for steam production, and the steam-to-oil ratio is a major parameter affecting total GHG emissions. The developed model can be utilized as a tool to predict the energy demand requirements for integrated SAGD/upgrading projects under different operating conditions, and provides guidance on the feasibility of lowering GHG emissions associated with their operation.

1. Introduction

The worldwide oil demand is on the rise and is expected to reach levels of 105 million barrels per day by 2030, and with the limited conventional oil resources, focus has shifted towards unconventional oil resources, such as the oil sands in western Canada. Unconventional oil resources (i.e. extra heavy oil and bitumen) account for approximately one third of the world's oil reserves. The Canadian Oil Sands is the third largest crude oil proven reserves in the world, which amount to proven reserves of about 168 billion barrels constituting approximately 97% of Canada's total oil reserves [1]. As of 2012, Alberta produced 1.9 million barrels per day of raw bitumen, which is projected to increase to 3.8 million barrels per day by 2022 [2]. Given the vast size of oil sands resources in Alberta, it is considered to be one of the leading sources of fossil energy for North American markets.

The oil sands are a mixture of bitumen, sand, clay and water, from which bitumen is extracted. The bitumen extracted is diluted by solvents to reduce its viscosity for further transportation, which

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is then sold as commercial bitumen or sent to upgrading facilities to produce refinable crude (i.e. SCO). Upgrading reduces the carbon-to-hydrogen ratio of the bitumen and removes undesirable compounds from the hydrocarbons, such as sulphur, nitrogen, and heavy metals. Upgrading operations can be integrated with bitumen extraction processes, and they are typically comprised of hydrogen-based or/and thermal-based cracking processes. The two prominent bitumen extraction processes are mining and in-situ, with the latter being more economically and environmentally preferable and will account to approximately two-thirds of future oil sands production capacity. In-situ methods are employed for extracting deep bitumen deposits, which account to approximately 70% of the available bitumen resources. In-situ methods, such as SAGD, rely on the use of steam, solvents or thermal energy to enhance the flow of the viscous bitumen, which is then pumped to the surface. In 2012, SAGD production exceeded surface mining, becoming the market leader in Alberta's oil sands production. Because of the reliability and the maturity of the SAGD technology, this percentage is expected to grow in the future.

Being characterized as heavy and viscous crude, bitumen requires significant amounts of energy for its extraction, upgrading and transportation. The energy consumed is in the form of steam, hydrogen, electricity, and process fuel, which is almost entirely produced from fossil fuels, particularly natural gas (i.e. combined heat and power, once-through steam generators (OTSGs), and steam methane reforming). This as a results causes the generation of significant GHG emissions, which led to making the oil sands industry the largest contributor to the growth of GHG emissions in Canada [3]. In 2007, the government of Alberta introduced reduction objectives of 12% on CO_2 emissions for all plants emitting more than 0.1 Mt CO_2/year. New plants have a reduction target of 2% from the fourth year of operation, which increases by 2% annually up to 12%. The facilities can improve their performance or can pay carbon taxes for emissions beyond the imposed target [4]. This, along with the low price of natural gas, motivated energy producers to explore lower carbon fuels, such as natural gas, and carbon mitigation options.

Carbon Capture and Storage (CCS) is a viable strategy to mitigate GHG emissions, and is receiving increasing attention by the scientific community and governments. It has significant potential in reducing the CO_2 mitigation costs when integrated with large fossil fuel based energy producers. Further benefits can be observed from utilizing the CO_2-concenrated streams, for example, in enhanced oil or coal bed methane natural gas recovery. This is particularly true for the province of Alberta, including the Western Canadian Sedimentary Basement where the majority of oil sands are located, as its geological formations are suitable for these value-added applications and underground storage sinks. Moreover, based on the Alberta Geological Survey major oil sands producers and CO_2 emitters in the province are located in close proximity to the available CO_2 sinks, which is a major factor that contributes to the favorability of utilizing CCS. Despite the operational start of some large scale CCS projects in Alberta [5,6], there is currently some concerns regarding the economic effectiveness of this technology [7].

The further development of GHG mitigation strategies that are based on CCS technologies for oil sands operations requires adequate tools to estimate their total energy demand requirements and the associated GHG emissions. Moreover, these tools can be of assistance to industries and policy makers in the energy planning required to achieve higher levels of SCO and bitumen production. The demand for energy commodities (i.e. electricity, steam, heat and hydrogen) is tied to the forecasted increase expected for bitumen and SCO production, and the increase for their requirements will require the establishment and commissioning of additional energy production units in order to sustain the required bitumen and SCO production levels. The development of the energy infrastructure of the oil sands industry must take into account the increasingly CO_2-contrained environment, which requires a quantification of the magnitude of emissions associated with energy production.

Several studies in the literature have been proposed for the modeling of the energy demands and their associated GHG emissions for oil sands operations, as well as studies that utilize these estimates of energy demands for the energy design planning for oil sands operations [8–22]. Charpentier et al. [8] developed a life cycle-based model, referred to as the GHOST model, which estimates the life cycle (total direct and indirect) emissions of multiple oil sands producers for the production of bitumen and SCO. Their model was utilized to estimate a range of emission intensity factors based on confidential operating data of existing oil sands projects. Ordorica Garcia et al. [9] developed a mathematical model to estimate the energy demands of integrated SAGD/upgrading and mining/upgrading operations based on yield data available from industrial reports of currently operating facilities. Betancourt et al. [10] later developed a mathematical optimization model that uses the energy demand estimates provided by Ordorica Garcia et al. [9] in order to determine the optimal oil sands production routes and their corresponding energy infrastructure with the goal of minimizing total costs subject to CO_2 emission constraints. Giacchetta et al. [11] utilize energy demand assessment and GHG intensity data to conduct economic and environmental evaluation and optimization of industrial scale SAGD projects. Similarly, several studies [12–16] have utilized models that assess energy requirements of oil sands operations in order to investigate the feasibility of incorporating alternative energy production technologies and carbon mitigation options, such as nuclear energy, gasification of alternative fuels (e.g. coal, petroleum coke, bitumen, etc.), and production technologies integrated with carbon capture and sequestration.

Nimana et al. developed a model, which is referred to as the fundamental engineering principles based model for the estimation of greenhouse gases in the oil sands (FUNNEL-GHG-OS), for the estimation of the energy demand requirements and GHG life cycle emissions associated with bitumen extraction [17], upgrading and refining [18], and for the life cycle assessment of bitumen derived transportation fuels (i.e. gasoline, diesel and jet fuel) [19]. The spreadsheet model allows the user to change default parameters to input user data in order to estimate the energy demand requirements of project-specific operations. Two studies [20,21] prepared for the Alberta Energy Research Institute analyze the GHG emissions specific to crude oil production operations in North America, including the oil sands industry. A lot of different petroleum types, extraction technologies and reservoir locations are analyzed and compared. The GREET model developed by Argonne National laboratory [22] calculates the emissions associated with a variety of processes, including bitumen extraction and upgrading to SCO. The model's output results are expressed in terms of specific emissions (i.e. amount of CO_2/MJ of SCO produced). The methodology and various parameters used in the estimation of energy demands and GHG emissions are not disclosed.

Within the above context it can be realized that the development of models for the estimation of energy demands and GHG emissions of oil sands operations is important for future planning in the industry. The models developed so far in the literature can provide adequate estimates of these parameters. Even though it is possible to construct several oil sands production pathways using these models, most of them do not provide a specific methodology to estimate the specific energy consumption of bitumen extraction and upgrading operations. Therefore, it is not possible to estimate the energy consumption and GHG emissions for a specific project, as they cannot be modified to accommodate differ-