International Conference on Applied Energy 2019
Aug 12-15, 2019, Västerås, Sweden
Paper ID: 1007

MODELING OIL SANDS PRODUCTION IN AN INTEGRATED ASSESSMENT MODEL: ENERGY CONSUMPTION AND CO_2 EMISSIONS

Rui Xing[1*], Christopher Roney [2], Diego V Chiappori [1], Matthew T Binsted [2], Evan Arbuckle [1], Evan G R Davies [1]

1 Department of Civil and Environmental Engineering, University of Alberta, Edmonton, Alberta, Canada
2 Joint Global Change Research Institute, Pacific Northwest National Laboratory, College Park, MD

ABSTRACT

In the past four decades, oil sands production in Canada has increased dramatically. More recently, Canada has developed carbon emission reduction targets to meet its Nationally Determined Contributions and Mid-Century Strategy to reduce GHG emissions. Quantification and assessment of GHG emissions from the oil sands industry – a high emitter – is necessary to track progress toward meeting emissions reduction and technology development. This study uses GCAM, an integrated assessment model, to examine the energy consumption of oil sands extraction and upgrading. Five traditional and cogeneration extraction technologies are compared in model simulations for energy cost and non-energy (operating) cost. Results show that energy consumed by oil sands production will triple by 2050 because of the expected increase in oil sands production. Cogeneration technologies result in reduced CO_2 emissions.

Keywords: integrated assessment model, energy system for oil sands, industry energy consumption, CO_2 emission projection

NONMENCLATURE

Abbreviations	
bpd	Barrels per day
BTU	Bitumen
DCK_C	Delayed coking, cogeneration
DCK_NOC	Delayed coking, no cogeneration
GCAM	Global Change Assessment Model
HDC_C	Hydroconversion, cogeneration
HDC_NOC	Hydroconversion, no cogeneration
MIN_GTC	Surface mining, gas turbine cogeneration
MIN_NOC	Surface mining, no cogeneration
MIN_STC	Surface mining, steam turbine cogeneration
SAGD	Steam assisted gravity drainage
SAGD_GTC	SAGD, steam turbine cogeneration
SAGD_NOC	SAGD, no cogeneration

1. INTRODUCTION

Canada's oil sands are one of the largest unconventional fossil fuel reserves in the world. The oil sands of northern Alberta contain 10% of discovered global reserves [1]. Crude bitumen production in Canada has increased from 47.4 thousand bpd in 1975 to 2.53 million bpd in 2015, while in-situ production has increased about 400-fold during this time period [2]. The production is expected to reach 5 million bpd by 2030, which will supply 16% of North America's oil demand [3]. Although oil sands development brings significant economic benefits, it has significant environmental impacts, including fossil fuel energy consumption and associated greenhouse gas (GHG) emissions. Oil sands require more energy for recovery, extraction, and upgrading into refined products than conventional oil resources [4], because of their viscous nature. Canada has recently developed a set of Nationally Determined Contributions intended to reduce its GHG emissions by 30% below 2005 levels by 2030 [5] and its Mid-Century Strategy proposes reductions of as much as 80% by 2050 [6]. As energy systems transition from fossil fuels to renewables, it is important to reduce the GHG emissions of fossil fuel production in the meantime and understand the role of particular technologies in this process.

Implementing technologies that minimize fossil fuel consumption in oil sands production are a crucial step in the reduction of demand for fossil fuel production itself. Quantification and assessment of GHG emissions from the oil sands industry is necessary to track progress toward meeting emissions reduction targets and the associated technological developments that may improve energy efficiency. This study uses and expands the capability of the integrated assessment model, GCAM, to examine the technology profile of oil sands extraction and upgrading, and estimates CO_2 emissions through 2050.

2. METHOD

2.1 GCAM-Canada

To simulate future emission pathways, we use GCAM [7], an integrated assessment model that links socioeconomics, energy systems, land-use changes, climate, and water resources. In each simulation run, GCAM takes input in the form of scenario assumptions to produce outputs in terms of prices, energy production and transformations, as well as commodity and other flows across regions and time in 5-year intervals. Supply and demand for primary and secondary energy forms are simulated, as are emissions of greenhouse gases and other pollutants. Recently, many model improvements have been made to better align GCAM with Canadian energy consumption profiles – the improved model will henceforth be referred to as GCAM-Canada. The oil sands module with increased technology details and an off-road vehicle sector have been implemented for GCAM-Canada by the authors. Energy balances in the base year were also adjusted to match Canada's observed data. GCAM-Canada resolves supplies and demands in all markets of energy resource on 5-year time steps from 2015 through 2050. Figure 1 illustrates the general model structure of GCAM with concentrations on the newly improved oil sands module.

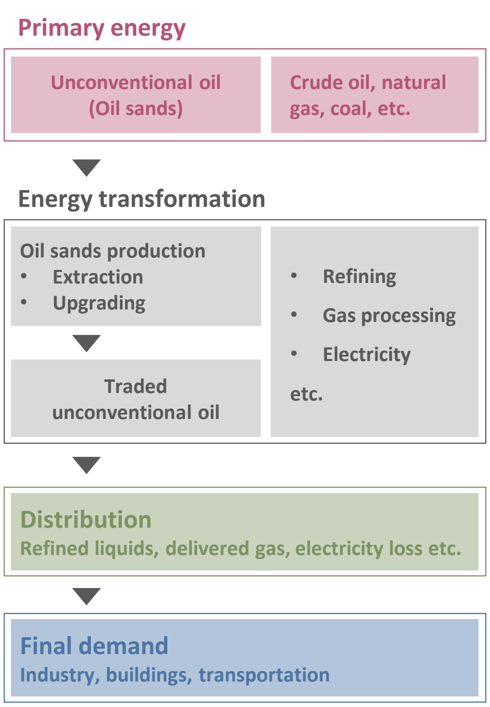

Fig 1 GCAM model structure

2.2 Modeling energy system of oil sands industry

In energy system modeling, the energy flow of oil sands production is divided into two processes: extraction and upgrading. Extraction processes include surface mining and SAGD, with surface mining defined as the extraction of ore from an open pit, and thermal in-situ processes called steam-assisted gravity drainage (SAGD). The primary energy input for surface mining is natural gas, which is required to heat water and generate electricity to operate pumps and flotation vessels. All existing oil sands mines have been equipped with cogeneration facilities because of high demands for steam and electricity. Mining without cogeneration is considered traditional and less efficient, and imports electricity from the local grid. In GCAM-Canada, one traditional technology and two cogeneration technologies (gas turbine and steam turbine) are included to explore alternative energy pathways. Compared to the two cogeneration technologies, the net electricity input in mining without cogeneration is much higher.

Although surface mining was initially the only path to extract bitumen from the oil sands, deeper oil sands can now be accessed by using applied thermal in-situ techniques - about 80% of Alberta's reserves can only be extracted economically using in-situ techniques. The two common in-situ techniques use either a single wellbore for steam injection and oil production called Cyclic Steam Stimulation (CSS) or two wellbores for continuous steam injection and bitumen production, called SAGD. SAGD has become more popular in the oil sands industry and is gradually replacing CSS. Therefore, this study only investigates SAGD technologies (one traditional and one cogeneration). In total, therefore, five extraction technologies compete in model simulations over energy cost and non-energy (operating) cost.

Two upgrading technologies are widely used in the oil sands industry to increase the hydrogen to carbon ratio in the produced synthetic crude oil (SCO): delayed coking (rejecting carbon) and hydroconversion (adding

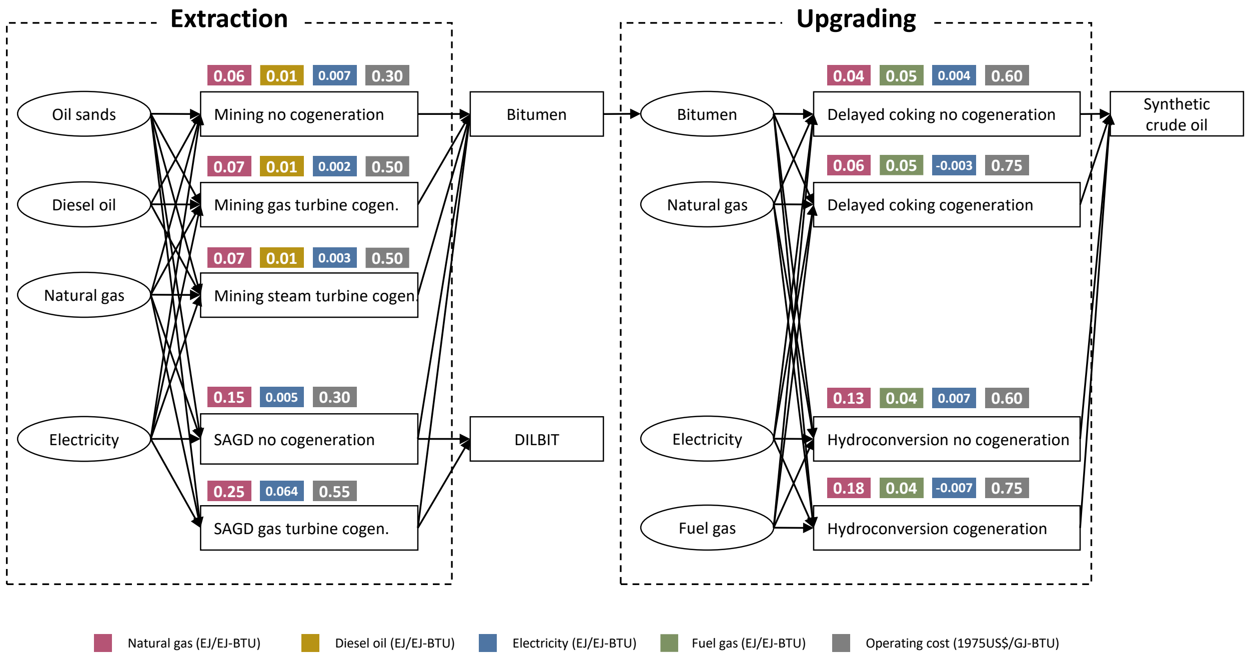

Fig 2 Energy demand and operating cost in the oil sands industry

hydrogen). Hydroconversion requires higher energy input but yields higher SCO production. Both delayed coking and hydroconversion combine one traditional technology with one cogeneration technology; therefore, four upgrading technologies are simulated in total. The energy demand and operating cost of each technology for the base year (2015) are taken from existing literature [8-9]. Taking technology improvement into consideration, modest energy efficiency improvement of 1.01 per year is assumed through 2050, while operating costs are held constant throughout the estimation period. Figure 2 summarizes the demand of each energy input and the operating cost of each technology. Electricity inputs for cogeneration technologies are net values that incorporate both total demand and surplus power. For extraction technologies, total electricity demand cannot be fully satisfied by cogenerated power. For upgrading, surplus power generated on-site can be exported to the local grid. The negative electricity input denotes the export of excess electricity.

3. RESULTS

3.1 Model validation

Figure 3 compares observed data [2] and model estimates of oil sands production in Canada from 1990 to 2015. Overall model estimates align well with the statistics, but a considerable increase in oil sands production occurred in 2015. Future work should be carried out to improve model estimates and capture the production increase in 2015.

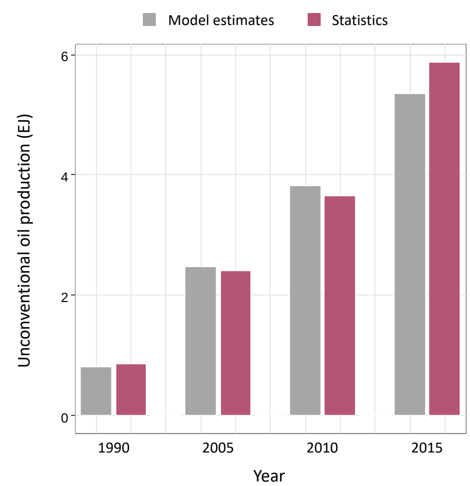

Fig 3 Comparison of statistics and model estimates

3.2 Energy consumption

Figure 4a shows the estimated energy consumption for oil sands extraction and upgrading. Energy inputs of both processes are expected to triple by 2050 with projected increases in oil sands production. For extraction, natural gas is a major energy input for open pit mining and its consumption will increase from less than 0.2 EJ/yr in 2015 to around 0.6 EJ/yr by 2050. For upgrading, natural gas consumption is at the same level as extraction; however the fuel gas consumption is much higher than the diesel oil consumption required for extraction.

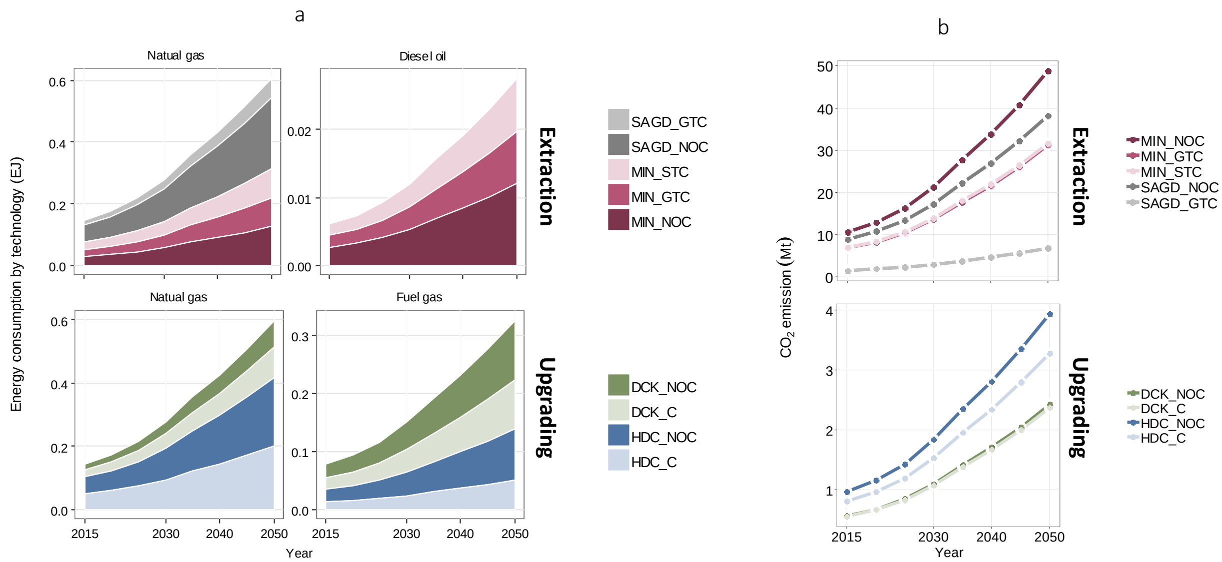

Fig 4 Estimated energy consumption (a) and CO_2 emissions (b)

3.3 *CO_2 emissions*

Figure 4b shows the estimated CO_2 emission pathways of five extraction and four upgrading technologies. Extraction is responsible for the bulk of the CO_2 emissions, possibly because of diesel combustion used for surface mining. Mitigation measures such as the adoption of electric mining trucks can reduce diesel oil consumption and hence improve emission pathways of oil sands extraction. Emissions from upgrading are approximately 10% of the extraction emissions. Between surface mining and SAGD, the latter has relatively lower emission pathways. Further, cogeneration technologies result in much lower CO_2 emissions because of low-emission electricity generated on-site.

The limitations of this study include uncertainties of socioeconomic assumptions and technology boundaries. First, the estimates of oil sands production in Fig. 3 are based on the assumption of a "business-as-usual" world where the typical trends of recent decades continue. Second, energy inputs and operating costs are limited to the technologies described in Fig. 2.

ACKNOWLEDGEMENT

This research was supported by Future Energy Systems of Canada First Research Excellence fund.

REFERENCE

[1] Natural Resources Canada, "Crude oil facts" 2018. [Online]. Available: https://www.nrcan.gc.ca/energy-facts/crude-oil-facts/20064. [Accessed: 03-Jul-2019].

[2] CAPP, "Statistics - Canadian Association of Petroleum Producers," *Canadian Association of Petroleum Producers*, 2019. [Online]. Available: https://www.capp.ca/publications-and-statistics/statistics. [Accessed: 21-May-2019].

[3] ACR, *Oil Sands Technology Roadmap: Unlocking the Potential - Alberta Chamber of Resources - Google Books*. 2004.

[4] A. R. Brandt, J. Englander, and S. Bharadwaj, "The energy efficiency of oil sands extraction: Energy return ratios from 1970 to 2010," *Energy*, vol. 55, pp. 693–702, 2013.

[5] UNFCCC, "Canada's Nationally Determined Contributions to the United Nations Framework Convention on Climate Change," 2017. [Online]. Available: https://unfccc.int/process/the-paris-agreement/nationally-determined-contributions/ndc-registry. [Accessed: 21-May-2019].

[6] G. of Canada, "Canada's Mid-century Long-term Low-greenhouse Gas Development Strategy, Environment and Climate Change Canada," 2017.

[7] JGCRI, "GCAM v5.1 Documentation: GCAM Model Overview," 2019. [Online]. Available: http://jgcri.github.io/gcam-doc/overview.html. [Accessed: 28-May-2019].

[8] B. Nimana, C. Canter, and A. Kumar, "Energy consumption and greenhouse gas emissions in the recovery and extraction of crude bitumen from Canada's oil sands," *Appl. Energy*, vol. 143, pp. 189–199, 2015.

[9] B. Nimana, C. Canter, and A. Kumar, "Energy consumption and greenhouse gas emissions in upgrading and refining of Canada's oil sands products," *Energy*, vol. 83, pp. 65–79, 2015.