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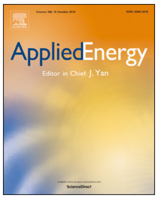

The development of a techno-economic model for the extraction, transportation, upgrading, and shipping of Canadian oil sands products to the Asia-Pacific region

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HIGHLIGHTS

- Development of techno-economic models to estimate the delivery costs of dilbit/SCO.
- Four pathways of Canadian oil sands products are compared.
- Shipping costs of seven scenarios are evaluated.
- Sensitivity of key parameters on each stage of operation costs is evaluated.

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ABSTRACT

The diversification of Canadian oil sands markets is imperative for the long-term economic growth of oil sands products. To ensure a competitive place in the global market, supply chain costs of oil sands must be as low as possible. This study conducts a comparative techno-economic analysis of potential pathways for the transportation of Canadian oil sands products (synthetic crude oil and diluted bitumen) to seaport destinations in the Asia-Pacific region. We developed data-intensive techno-economic models to estimate total supply chain costs from the production site in Alberta to ports in China, Japan, and India. Four pathways were developed using production (steam assisted gravity drainage), transportation (production-upgrader-port in Vancouver), upgrading, and shipping operations. A sensitivity analysis was conducted to identify cost ranges with their occurrence probability measures and evaluate the effect of key parameters for each stage of operation. Supply chain costs (C$ per barrel of bitumen) to China, Japan, and India are from 61–87, 60–86, and 62–90, respectively. Overall supply chain costs of dilbit (a blend of bitumen and diluent) and synthetic crude oil (SCO) are affected most by production and upgrading costs. The production and upgrading costs are influenced by capital cost, while pipeline lifetime and capacity highly impact transportation (pipeline) and shipping costs, respectively. The developed models can be used to predict total supply chain costs of different pathways in Canadian oil sand markets.

1. Introduction

Canada's oil sands are the third largest oil reserves in the world, after those in Venezuela and Saudi Arabia [1]. Most of Canada's reserves (166 billion barrels) are in the province of Alberta [1]. These oil reserves, along with Canada's substantial oil production, have led to significant overseas interest, particularly from Asian countries [2], including the heavy financing of Canada's oil sands sector by Chinese companies [3] (see Table S2 in the supplementary information section [SI]). In addition to investments from China, there has been significant involvement from Korean and Thai oil and gas companies [3]. However, the Canadian oil sands products have for long relied solely on the United States for its supply. This poses an economic risk. There is the need to explore the benefits associated with the diversification of the oil sands products for improved, competitive, and long-term economic growth. For these reasons, the potential demand, particularly to the Asia pacific region, as well as the supply chain costs of the Canadian oil sands products are key factors to consider.

There is a high demand and limited supply of oil in the Asia-Pacific region. In order to meet demand, refinery capacities in the Asia-Pacific

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Nomenclature

Acronyms

ADU	atmospheric distillation unit
API	American Petroleum Institute
AR	atmospheric residue
Bbl	barrel
C	Canadian
CAPP	Canadian Association of Petroleum Producers
CERI	Canadian Energy Research Institute
CNOOC	China National Offshore Oil Company
CNPC	China National Petroleum Company
CPF	central processing facility
cSt	centistoke
DCFA	discounted cash flow analysis
DCU	delayed coking upgrader
DH	diesel hydrotreater
EIA	U.S. Energy Information Administration
ESP	electric submersible pump
GH	gas hydrotreater
HCU	hydroconversion upgrader
HFO	heavy fuel oil
HRSG	heat recovery steam generator
HVGO	heavy vacuum gas oil
IGF	induced gas flotation
iSOR	instantaneous steam-oil ratio
kbd	thousands barrel per day
kg/d	kilogram per day
km	kilometer
kPa	kilopascal
kWh	kilowatt hour
LNG	liquefied natural gas
LVGO	light vacuum gas oil
MC$	million Canadian dollar
MDO	marine diesel oil
MMBtu	million metric British thermal unit
MW	megawatt
NEB	National Energy Board
NG	natural gas
NH	naphtha hydrotreating
O&M	operating and maintenance
ORF	oil removal filter
PADD	Petroleum Administration for Defense District
SAGD	steam assisted gravity drainage
SCO	synthetic crude oil
SFC	specific fuel consumption
SMR	steam methane reforming
SYPC	Shaanxi Yanchang Petroleum Company
VDU	vacuum distillation unit
VR	vacuum residue
WCS	Western Canadian Select
yr.	year

Abbreviations

C_t	total annual cost, $/year
C_{tf}	total fuel cost, $/year
C_{OM}	total operating and maintenance cost, $/year
OI	operating income of the unit, $/year
R_t	total revenue, $/year
NI	net income of the unit, $/year
C_c	capital cost of unit, million dollar
I	discount rate, %
K	considered year
ID	internal diameter, m
ΔP	differential pressure, bar
P_E	towing power
P_B	brake power
η_H	hull efficiency
η_o	open water propeller efficiency
η_R	relative rotative efficiency
η_s	shaft efficiency

SCO and dilbit carrier specifications

V_c	cargo volume
Δ	displacement of the SCO/dilbit carrier, tons
L_{OA}	overall length, meters
L_{PP}	length between perpendiculars, meters
L_{wl}	length on waterline, meters
L_D	light displacement, tons
B	breadth, meters
D_{design}	design draft, meters
V	sailing speed, m/s
T	depth, meters
A	air draft, meters
l_{cb}	longitudinal center of buoyancy, meters
dwt	dead weight tonnage, tons

Coefficients

C_b	block coefficient
C_m	midship section coefficient
C_w	water plane coefficient
C_p	prismatic coefficient based on length on waterline

Engine fuel consumption

SFO_m	main engine specific fuel consumption, g/kWh
SFO_{aux}	auxiliary engine specific fuel consumption, g/kWh

are increasing [4], which in turn provides opportunities to expand the future market of Canadian oil sands products. Eastern Asia, particularly China, India, and Japan, have the largest number of refineries [4]. Apart from product demand, the attractiveness of heavy crude oil to refiners in the Pacific Basin is driven by other factors such as refinery configuration, shipping consideration, and refining capacity [4]. The fast-growing economy of China alone is a substantial market for Canada. China's installed crude refining capacity reached nearly 14.2 million bbl/d in 2015, about 680,000 bbl/d higher than in 2013 [5]. These refineries are able to handle the crude with American Petroleum Institute (API) range from 31.5 to 33.2, which are within synthetic crude oil (SCO) ranges obtained after upgrading Canadian oil sands products; thus these products can be supplied to China in the form of SCO [6] (see Table S4 in SI). Refinery use in China has been between 82 and 86% since 2009 [7]. However, according to the EIA 2015 [5], use is falling below these rates, which suggests that there are potential markets for Canadian oil sands products in China.

According to the Canadian Associated of Petroleum Products (CAPP), as of 2014, oil sands production was 2.2 million bbl/day, of which 1.2 million bbl/day were recovered from in situ and 0.9 million bbl/day from surface mining. Oil sands production is projected to increase to 3.1 million bbl/day by 2020 [8]. However, Canada's oil refinery capacity is expected to remain fairly constant at around 600,000 bbl/day to 2020 [9]. The surplus oil sands products need a