UNIVERSITY OF CALGARY

# SAGD Emissions Intensity

by

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A RESEARCH PROJECT SUBMITTED

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER OF SCIENCE

GRADUATE PROGRAM IN SUSTAINABLE ENERGY DEVELOPMENT

CALGARY, ALBERTA

AUGUST, 2017

## Abstract

Steam assisted gravity drainage (SAGD) is a technique used to produce significant volumes of bitumen from Alberta's oil sands. The generation of steam from natural gas combustion generates greenhouse gas (GHG) emissions. There is increased concern about climate change associated with increasing GHGs and a desire for action to reduce GHGs through initiatives such as the Alberta Climate Leadership Plan (CLP). One CLP aspect restricts oil sands GHG emissions at 100 megatonnes per year. An advisory body, the Oil Sands Advisory Group, drafted recommendations for managing the emissions limit in 2017 that are currently under government review. Use of modified SAGD technologies, such as solvent assisted processes, can reduce the GHG intensity for bitumen production. Economic success of such processes depends upon the amount of solvent that can be recovered from the reservoir. Effective implementation of the emissions limit will be key to continued oil sands production in Alberta.

## Acknowledgements

My participation in the Sustainable Energy Development (SEDV) program at the University of Calgary has been an interesting journey. It was prompted by an unexpected job loss after over twenty years in the upstream oil and gas industry. It was a challenge to enter the academy after an almost twenty-four-year absence. I believe that I have grown a great deal and this M.Sc. program has, I believe, positioned me well for the future.

During my time in the SEDV program, I have gained employment at the Alberta Energy Regulator (AER). I would like to thank the AER for being supportive of my completion of the SEDV program while working. I also want to emphasize that this research reflects my analysis and perspective and not those of the AER.

Most importantly, I would like to thank my wife, Andrea Newberry-Koroluk, for her support and encouragement through this program. She was instrumental in getting this journey started for me for which I am very appreciative.

I would also like to thank my classmates for welcoming a more mature student into their ranks and to all the faculty in the SEDV program for their support of me.

I have a long list of people to whom I owe thanks for helping me in completing this research. I apologise for any that I may overlook in this list. I would like to thank: Dr. Anil Mehrotra, my supervisor for this project (and also my supervisor when I worked for him as an undergraduate engineering student back in 1990) for his guidance and advice; Dr. Irene Herremans who assisted in navigating through the complexities of conducting a research project; Dr. Amos Ben-Zvi of Cenovus for his industry perspective on this work; Dr. Joule Bergerson, for her advice and information on understanding of emissions intensities; Dr. Brij Maini, for his understanding of aspects of SAGD performance and Rhiannon Jones who provided useful research hints including use of the Mendeley research tool. I also want to thank people from the Alberta Climate Change Office (ACCO) who assisted me with my understanding of the role of the Oil Sands Advisory Group (OSAG), this was made more difficult since the work that OSAG was doing was confidential during part of the time when I was conducting this research project. From ACCO I would like to thank: Patrick Forseth; Andrea Orellana Abreu; Michael Fulsom and Kirk Heuser. As I mentioned, I'm now working at the AER and I would like to thank my supervisor, Nadia Haider for her understanding of my need for some flexibility in work hours to allow my completion of the SEDV program. I would also like to thank two AER colleagues – Albert Liu and Ken Yap – who were also understanding of my situation. Numerous AER employees were helpful to me regarding this project, they were willing to talk with me about my research and give their perspectives on the issues at hand. These people at the AER include: Mussie Yemane; Shamus Hardie; Rick Nutbrown; Glen Tsui; Syed Ayub; Cailee Ellis; Laura Johnson, Jon Keeler, Andrew MacPherson, Mark Taylor and Alex Bolton. I would like to thank Steven Johnson of June Warren Nickle's group and the AER in providing me with some access to the CanOils database which was instrumental in the aspects of this project concerning economics and aspects of emissions intensity. I would also like to thank Michael Benson, my mentor from the Haskayne Mentorship program, for his advice and suggestions concerning my research project. Thanks also to Dave Murray (my mentor from the University of Calgary's Graduate Student Association Mentorship Program), Mohsen Keshavarz of Suncor (for information on solvent assisted schemes), Johan Van Dorp (an SPE Distinguished Lecturer on heavy oil) and Experience Nduagu (for a discussion of CERI's research). Also thanks to Milt Fischbein, Leanne Dick, Catherine Stowe, Margaret Fath and Ian O'Connell from my former employer. They were willing to support me and assist with my transition and my project. Finally, I would also like to thank my friends and family for supporting me through this journey.

*I would like to dedicate this project to all of those who have worked in Canada's oil sands industry, from policy makers, researchers, academics and everyone else who has been involved in this sector. The bitumen resource is a challenging one and Canadians have shown how, through innovation and perseverance, this resource can be developed for the benefit of Canadians. There will be future challenges of developing this resource in a more sustainable manner, but, based on history, this is a challenge that I think Canadians will be able to embrace. I'm confident that the oil sands sector can become a responsible part of Canada's energy future through increased innovation and cooperation.*

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| | |
|---|---|
| ACCO | Alberta Climate Change Office |
| AEP | Alberta Environment and Parks |
| AER | Alberta Energy Regulator |
| AMD | Air Monitoring Directive |
| AOSP | Athabasca Oil Sands Project |
| API | American Petroleum Institute |
| B&F | Reference to a paper by Brandt & Farrell (Brandt & Farrell, 2007) |
| BATEA | Best Available Technology Economically Achievable |
| bbl | barrel |
| CAD | Canadian Dollars |
| CAPP | Canadian Association of Petroleum Producers |
| CCAP | Climate Change Advisory Panel |
| CCME | Canadian Council for Ministers of the Environment |
| CEAA | Canadian Environmental Assessment Act |
| CEMS | Continuous Emissions Monitoring System |
| Cenovus | A Canadian energy company involved in oil sands extraction |
| CEO | Chief Executive Officer |
| cEOR | Cumulative energy injected to cumulative oil production |
| CEPA | Canadian Environmental Protection Act |
| CHOPS | Cold Heavy Oil Production with Sand |
| CLA | Climate Leadership Act |
| CLP | Climate Leadership Plan |

| | |
|---|---|
| CLR | Climate Leadership Regulation |
| $CO_{2e}$ | carbon dioxide equivalent |
| ConocoPhillips | The Canadian affiliate of a multinational oil and gas corporation |
| CPCSI | Cyclic Production with Continuous Solvent Injection |
| CPF | Central Processing Facility |
| CSA | Canadian Standards Association |
| CSI | Cyclic Solvent Injection |
| cSOR | cumulative Steam Oil Ratio |
| CSS | Cyclic Steam Stimulation |
| CTL | Coal-to-Liquids |
| DC | Delayed Coking |
| DD | Discussion Document |
| Devon | The Canadian affiliate of a multinational oil and gas corporation |
| DW | Deep Water |
| ECCC | Environment and Climate Change Canada |
| EDF | Environmental Defence Fund |
| EG | Energy Gain |
| EIA | Energy Information Administration (United States) |
| eMSAGP | enhanced Modified Steam and Gas Push |
| ENGOs | Environmental and Non-Governmental Organizations |
| EOR | Enhanced Oil Recovery |
| EPA | Environmental Protection Agency (United Sates) |
| EPEA | Environmental Protection and Enhancement Act (Alberta) |

| | |
|---|---|
| e-SAGD | enhanced Steam Assisted Gravity Drainage |
| ESEIEH | Enhanced Solvent Extraction Incorporating Electromagnetic Heating |
| ES-SAGD | Expanding Solvent Steam Assisted Gravity Drainage |
| EU | European Union |
| F&D | Finding and Development (cost) |
| FC | Fluid Coking |
| FC&H | Fluid Coking and Hydrotreating |
| FCCC | Framework Convention on Climate Change (United Nations) |
| FID | Final Investment Decision |
| FSU | Former Soviet Union |
| GHG | Greenhouse Gas |
| GHGenius | A model of lifecycle assessment of transportation fuels |
| GJ | gigajoule |
| GoA | Government of Alberta |
| GOM | Gulf of Mexico |
| GREET | Greenhouse gases, Regulated Emissions and Energy use in Transportation Model |
| GTL | Gas-to-Liquids |
| Harris | A corporation involved in the development of ESEIEH technology |
| HRSG | Heat Recovery Steam Generator |
| IEA | International Energy Agency |
| IEO | International Energy Outlook |
| Imperial Oil | The Canadian affiliate of a multinational oil and gas corporation |

| | |
|---|---|
| JPM | J.P. Morgan |
| LASER | Liquid Addition to Steam for Enhancing Recovery |
| LATAM | Other Latin America |
| LCA | Life Cycle Assessment |
| LCF | LC Fining (upgrading process) |
| LRS | Liquid Rich Shale |
| MEG Energy | A Canadian energy company involved in oil sands extraction |
| MJ | megajoule |
| MLA | Member of Legislative Assembly |
| NAGD | Naphtha Assisted Gravity Drainage |
| NCG | Non-Condensable Gas |
| NDP | New Democratic Party |
| Nexen CNOOC | The Canadian affiliate of a multinational oil and gas corporation |
| NGO | Non-Governmental Organization |
| NIST | National Institute of Standards and Technology, part of the US Department of Commerce |
| Nsolv | A Canadian company involved in warm solvent based oil sands extraction |
| O-G | Reference to a paper by G. Ordorica-Garcia (Ordorica-Garcia & Croiset, 2007) |
| OCI | Oil Climate Index |
| OECD | Organization for Economic Cooperation and Development |
| OPEC | Oil Producing and Exporting Countries |
| OPEM | Oil Products Emissions Module |

| | |
|---|---|
| OPGEE | Oil Production Greenhouse Gas Emissions Estimator |
| OSAG | Oil Sands Advisory Group |
| OSELIR | Oil Sands Emission Limit Implementation Regulation |
| OTSG | Once Through Steam Generator |
| PIA | Term used by AER for approval numbers |
| PP-CSI | Pressure Pulsing Cyclic Solvent Injection |
| ppmv | parts per million by volume |
| PRELIM | Petroleum Refinery Life-Cycle Inventory Model |
| SAGD | Steam Assisted Gravity Drainage |
| SAP | Solvent Aided Process |
| SAS | Steam Alternating Solvent |
| SA-SAGD | Solvent Assisted Steam Assisted Gravity Drainage |
| SBH | Steam Butane Hybrid |
| SC-SAGD | Solvent Cyclic Steam Assisted Gravity Drainage |
| SEDV | Sustainable Energy Development (program at University of Calgary) |
| SEDV 625 | Research project course in SEDV program |
| SG&A | Selling, General and Administrative Expense |
| SGER | Specific Gas Emitters Regulation |
| SOR | Steam Oil Ratio |
| SPE | Society of Petroleum Engineers |
| Suncor | A Canadian energy company involved in oil sands extraction |
| US | United States |
| USD | United States Dollars |

| | |
|---|---|
| VAPEX | Vapour Extraction (bitumen recovery process) |
| VSD | Vertical Steam Drive |
| WACC | Weighted Average Cost of Capital |
| WCSB | Western Canada Sedimentary Basin |
| WTI | West Texas Intermediate |

# Chapter One: Introduction

## 1.1. Overview

In-situ bitumen production in Alberta, predominantly from Steam Assisted Gravity Drainage (SAGD), is increasing. SAGD results in increased greenhouse gas emissions (GHGs) that impact the global climate. Governments, both provincial and federal, are committed to addressing the impacts of climate change and are developing policies to address GHG emissions. In addition, there are international agreements on the reduction of GHGs (United Nations FCCC, 2016). Industry is working on improvements in SAGD technology that may reduce the intensity of the GHG emissions per volume of bitumen produced.

Understanding how GHG emissions intensity from SAGD can be improved is important to meet ongoing demands for liquid hydrocarbons while improving environmental performance. Continuing with the current methods of SAGD extraction could make compliance with Alberta's and Canada's environmental goals more difficult. A lower emissions intensity will allow for the production of a greater quantity of bitumen than could be realized with current approaches. Employing alternative technology could therefore result in improved environmental performance and maximizing the economic value to companies, governments and citizens of Alberta's bitumen resource.

## 1.2. Research Question

I have investigated how the Alberta Climate Leadership Plan (CLP) and recent technological innovations in SAGD impact the GHG intensity per volume of bitumen produced. My research addressed the emerging regulatory impacts of the CLP on how the overall cap on GHG emissions from the oil sands will be managed. A high-level discussion of differences in emissions intensity and associated economic impacts is presented.

### 1.2.1. Research Dimensions.

Three dimensions related to SAGD emissions intensity are addressed in my research; these are energy, the environment and policy.

#### 1.2.1.1. *Energy.*

The differences in the energy intensity (i.e. energy to generate steam) employed in the extraction of bitumen with different types of injection are explored and reviewed. I utilized data from a review of the literature to understand emissions intensity associated with different technologies. I had discussions with Cenovus Energy to obtain an understanding of the performance of their Solvent Aided Process (SAP) for SAGD (Cenovus Energy, n.d.). The strategy employed was to utilize information from the literature on SAP and from research information on other solvent based co-injection technologies to show differences in emission intensity.

The continued need for liquid hydrocarbon based fuels into the future and Alberta's position in the supply of such fuels is reviewed and discussed.

#### 1.2.1.2. *Environment.*

A quantification of the impacts on GHG intensity with the different SAGD schemes is discussed. A high-level review of literature was conducted with an evaluation of climate change and how SAGD fits into GHG emissions.

#### 1.2.1.3. *Policy.*

My research also discusses how different SAGD techniques could impact production considering recent emissions related aspects of the CLP. The mechanics of how the overall emissions cap from the oil sands are proposed to be managed and regulated is addressed.

# Chapter Two: Background

Bitumen produced by SAGD (Steam Assisted Gravity Drainage) is an important component of the hydrocarbons developed in the province of Alberta.

## 2.1. Energy Demand

The worldwide demand for liquid fuels, predominantly hydrocarbons, is forecast to increase. The Energy Information Administration (U.S. Energy Information Administration, 2016) forecasts that the demand for liquid hydrocarbon fuels will increase through its forecasting period. Figure 1 shows the anticipated demand for OECD (Organization for Economic Cooperation and Development) and non-OECD countries for liquid hydrocarbon fuels consumption. The International Energy Agency (International Energy Agency, 2016) also forecasts an increase in energy demand. The world oil demand from the International Energy Agency (IEA) forecasts can be found in Figure 2. Hydrocarbon production is anticipated to increase in this timeline to meet the increased demand (U.S. Energy Information Administration, 2016) as shown in Figure 3. These forecasts indicate that liquid hydrocarbon fuels will be a part of the energy mix for the foreseeable future.

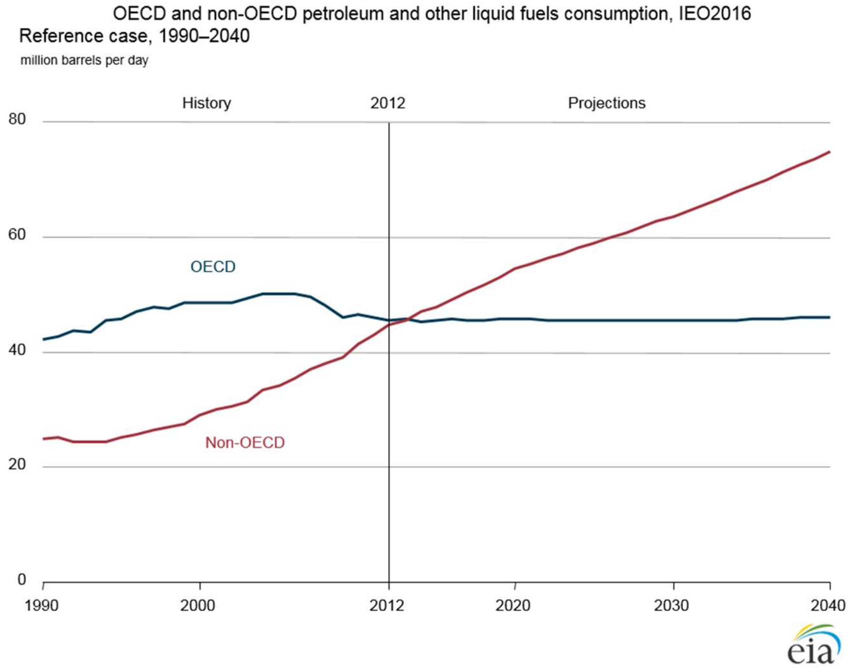
## 2.2. Liquid Hydrocarbons in Alberta

The province of Alberta has significant hydrocarbon resources. Historically, the bulk of production was from conventional oil sources. Currently, bitumen produced from oil sands comprises most production from Alberta.

### 2.2.1. Conventional Oil

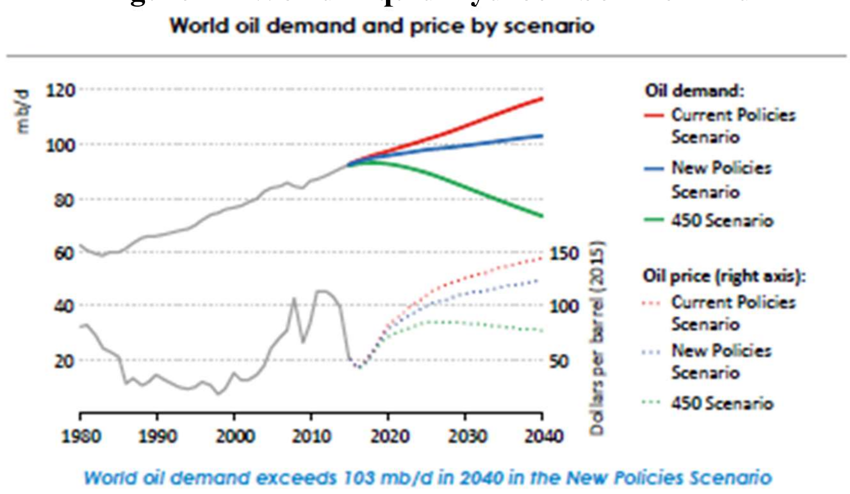
Alberta had significant quantities of conventional oil, however most of these have been produced and there are limited reserves remaining. Of the 82.9 billion barrels of conventional oil originally in place, only 1.8 billion barrels remain (Alberta Energy, 2015).

**Figure 1 – Liquid Hydrocarbon Demand Forecast**



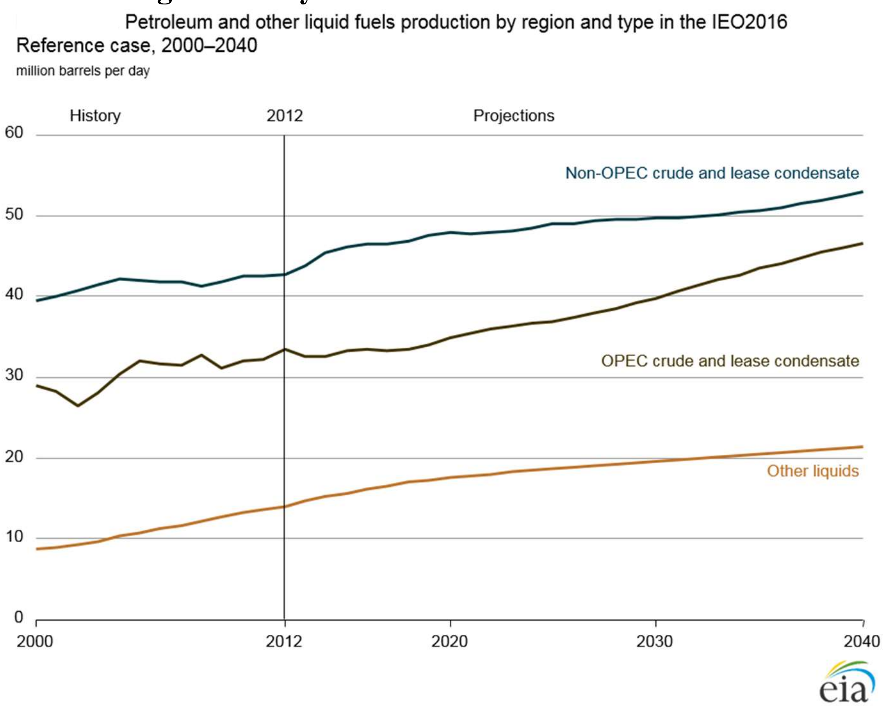

(U.S. Energy Information Administration, 2016, p. 24)

**Figure 2 – World Liquid Hydrocarbon Demand**




(International Energy Agency, 2016, p. 110)

**Figure 3 – Hydrocarbon Production Forecast**




(U.S. Energy Information Administration, 2016, p. 27)

### 2.2.2. Bitumen.

There are significant reserves of bitumen in Alberta in the oil sands. These reserves total 177 billion barrels and of these 165 billion barrels remain (Alberta Energy Regulator, 2016c). Given the large amount of remaining bitumen resources, the bulk of Alberta's production will come from bitumen in the future.

#### 2.2.2.1. *Surface mining.*

For the oil sands deposits that are closer to the surface, recovery is possible by surface mining. Surface mining is possible for deposits less than 75 m from the surface; these deposits comprise about 20% of the reserves base (Alberta Energy, n.d.).

#### 2.2.2.2. *In-situ.*

The production of most of the bitumen from the oil sands employs in-situ techniques. In-situ techniques are used for deeper deposits of oil sands. About 80% of the reserves can be recovered by in-situ means (Alberta Energy, n.d.).

There are numerous means of in-situ recovery of bitumen. Roger Butler, who pioneered the development of SAGD (Lowey, 2006), discussed other techniques including Cyclic Steam Stimulation (CSS), and in-situ combustion (Butler, 1997). SAGD accounted for about 60% of bitumen production in 2015 and is the most commonly used bitumen production technique (Alberta Energy Regulator, 2016c).

### 2.3. SAGD

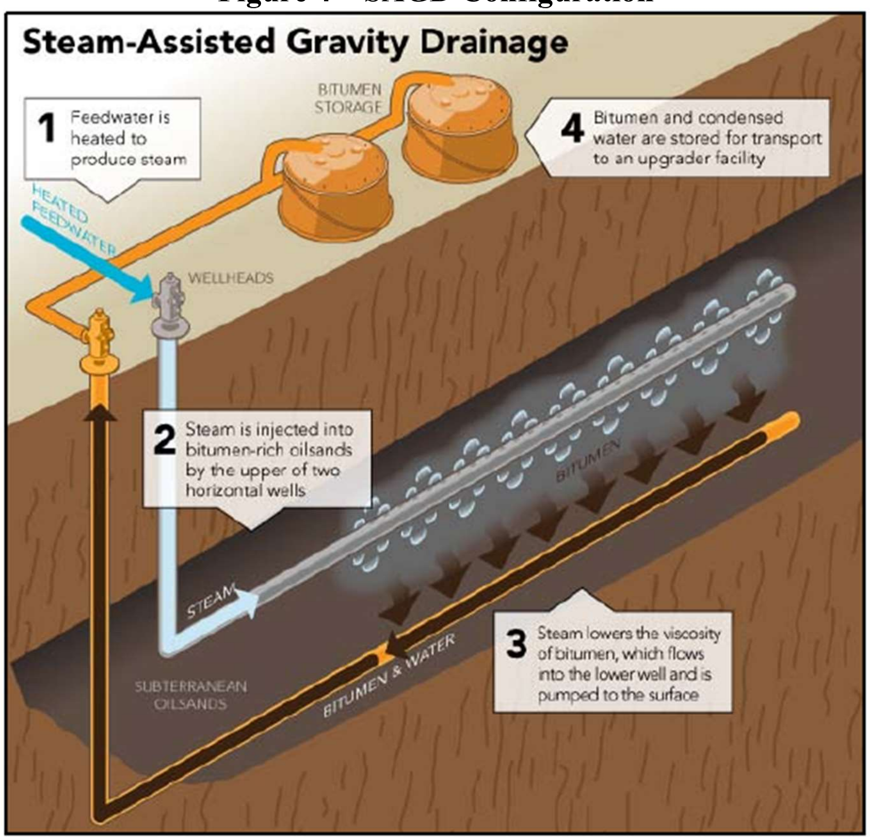
The SAGD technique involves producing the bitumen through a well pair. Horizontal wells are used which allows for the drilling of multiple well pairs from a single wellpad. The upper horizontal well is the injection well; about 5 m below this well the production well is drilled. Steam is injected via the injection well which creates a steam chamber in the reservoir. The heat imparted by the steam reduces the viscosity of the bitumen which results in flow by gravity to the producing well (Government of Alberta, 2013). The bitumen is produced from the producing well via artificial lift, typically by gas lift or the use of electric submersible pumps. Figure 4 shows the configuration employed in SAGD production.

A key parameter in SAGD production is the Steam to Oil Ratio (SOR). The higher the SOR, the greater the quantity of steam required for production. In SAGD operations, steam is typically generated by Once Through Steam Generators (OTSGs) or Heat Recovery Steam Generators (HRSGs) that burn natural gas. The combustion of natural gas results in the production of carbon dioxide, a greenhouse gas (GHG). Reducing SOR is a means to reduce the GHG intensity of SAGD production.

There are a few techniques, in various stages of development, to produce bitumen at a lower GHG intensity. These include (Yeung, 2017):

- Use of wedge wells and infill wells
- Use of solvents in conjunction with steam
- Purely solvent based processes
- Electric heating of bitumen

**Figure 4 – SAGD Configuration**




(Government of Alberta, 2013)

# Chapter Three: Literature Review

There has been work done in industry and academia concerning the emissions intensity of SAGD. Other elements of my research include the environment and policy on GHG emissions; these have also been addressed in the literature.

## 3.1. Energy

As discussed, bitumen production will be an important part of the liquid hydrocarbons produced from Alberta now and into the future. There is a demand for hydrocarbon resources that will continue. Regarding SAGD specifically, there has been corporate research on new technologies and there has been work in academia on new approaches to SAGD.

### 3.1.1. Corporate centred research.

#### *3.1.1.1. Cenovus*

Cenovus has developed a Solvent Aided Process (SAP) for SAGD. The process is predicted to use about 30% less steam than conventional SAGD (Cenovus Energy, n.d.). Conventional SAGD uses the heat from the steam to reduce the viscosity and increase the mobility of the bitumen. In the SAP process, solvent (butane) is also used to assist in reducing the viscosity (Gupta & Gittins, 2006). A pilot project at the Senlac field in Alberta showed an improvement in oil production rate of about 50%, a decrease in bitumen of one degree API and recovery of 70% of the solvent (Gupta & Gittins, 2006). Based on the results at Senlac, another pilot was conducted at Christina Lake. The initial results of this pilot showed a decrease in SOR from 5.0 to 1.6 (Gupta & Gittins, 2006). This reduction in SOR means the use of less steam and lower GHG emissions. Reservoir simulation work showed that for an injection of 15% (by weight) of solvent, the energy intensity for the SAP process was in the range of 0.7 to 0.9 GJ/bbl as opposed to 1.1 GJ/bbl for conventional SAGD (Subodh Gupta, Gittins, & Picherack, 2003).

#### *3.1.1.2. ConocoPhillips.*

ConocoPhillips has done pilot work at their Surmont joint venture on their e-SAGD process. This process uses a steam and light hydrocarbon mixture. They have indicated an anticipated reduction in GHGs of 15 to 35% per barrel produced along with a reduction in water use (ConocoPhillips Canada, n.d.). In their reporting to the Alberta Energy Regulatory (AER) for 2014, ConocoPhillips noted a 36% increase in bitumen production and recovery of almost 40% of the solvent (ConocoPhillips Canada, 2015).

#### *3.1.1.3. Imperial Oil.*

Imperial Oil has operated a Solvent Assisted SAGD (SA-SAGD) pilot at its Cold Lake field since 2010. They claim a reduction in GHG intensity of 25% while claiming similar reduction in water use (Imperial Oil, n.d.).

Imperial Oil's SA-SAGD approach has been discussed more extensively in the literature. The design approach for the Cold Lake area pilot was outlined initially in a paper from 2011 (Dickson et al., 2011). A pilot was deemed necessary to validate the earlier laboratory and simulation work. A key consideration for the selecting the pilot location was to avoid an area that would be influenced by Cyclic Steam Stimulation (CSS) based production that was occurring in the area. The pilot was initially operated in a fashion consistent with conventional SAGD operations starting with a warm-up phase and a steam injection phase (Dickson et al., 2011).

Initial SA-SAGD performance results from the pilot were discussed in 2013 based on employing up to 20% (by volume) of solvent injection (Dittaro, Jaafar, Perlau, Boone, & Yerian, 2013). The pilot showed an increase in production from 40 $m^3/d$ to 75 $m^3/d$ while maintaining a constant instantaneous SOR (Dittaro et al., 2013) with solvent recoveries more than 75%.

The environmental focus of GHGs associated with SAGD is discussed as a motivating factor for SA-SAGD (Dickson, Dittaro, & Thomas, 2013). The addition of solvent results in a lower viscosity than just by adding steam. “Solvent-assisted processes require less injected steam in order to recover the same amount of oil” (Dickson et al., 2013, p. 2). Such an approach will result in a lower GHG emission intensity.

Further evaluation of the SA-SAGD process found that there is a reduced energy requirement for SA-SAGD (Khaledi, Boone, Motahhari, & Subramanian, 2015). Their research “concluded that the reduced energy requirement is due to reductions in the stored energy in front of the steam interface and lost to over/under-burden” (Khaledi et al., 2015, p. 16).

***3.1.1.4. Suncor.***

Suncor has tested some alternative SAGD technologies as well. Suncor employed naphtha as solvent in an Expanding Solvent SAGD (ES-SAGD) pilot and no increase in production rate was noted (Orr, 2009). This was believed to be due to the fact that naphtha is a heavier solvent and that the naphtha condensed before the steam (Bayestehparvin, Ali, & Abedi, 2016).

Suncor has been involved in other work related to enhancing SAGD operation and reducing GHG intensity. Suncor has been involved in pilot work of Nsolv’s technology. Nsolv’s process involves the injection of warm solvent at about 50 ºC and does not use any water (“Nsolv - Using the downturn as a catalyst,” 2015). Nsolv’s CEO, Joe Kuhach, says that “we have very low GHG emissions, about an 80% reduction in GHG compared with the existing technologies today” (“Nsolv - Using the downturn as a catalyst,” 2015, p. 25). The Suncor pilot has produced over 100,000 barrels (Jaremko, 2016), however additional information on the Nsolv process is considered proprietary. I contacted an engineer at Nsolv who indicated that information is confidential and that information on parameters such as energy intensity could not be made available.

Suncor also is also involved in a partnership with Nexen CNOOC and Devon to test the Harris Corporation's electrically based heating technology for in-situ bitumen recovery called Enhanced Solvent Extraction Incorporating Electromagnetic Heating (ESEIEH) ("With Few New Projects Breaking Ground, Work Continues to Enhance or Replace SAGD," 2016). This technology uses radio frequency energy to heat the reservoir and also involves the injection of solvent to recover bitumen (Harris Corporation, n.d.-a). The Harris technology, the 'Heatwave System', claims "dramatically lower energy requirements, greenhouse gas emissions, and capital requirements, with lower subsurface operating pressures" (Harris Corporation, n.d.-b, p. 1).

#### *3.1.1.5. MEG Energy.*

MEG Energy is employing an approach that injects a small amount of non-condensable gas with steam ("With Few New Projects Breaking Ground, Work Continues to Enhance or Replace SAGD," 2016). MEG has adapted this Steam and Gas Push (SAGP) process by initiating it earlier in the production timeline and in combination with infill wells. MEG Energy is claiming an SOR for their enhanced Modified Steam And Gas Push (eMSAGP) process that is 30% lower than others in industry with the same reduction in GHG intensities ("With Few New Projects Breaking Ground, Work Continues to Enhance or Replace SAGD," 2016).

#### *3.1.1.6. Nexen CNOOC.*

Nexen CNOOC's Long Lake project combines upgrading with SAGD. Nexen CNOOC had plans (Orr, 2009) to pilot ES-SAGD in their Long Lake field. Some pilot work was done at their Pad 13, however the results were inconclusive due to facility operational problems (Nexen CNOOC, 2016). Also, Nexen CNOOC used solvent to assist in the start-up of some of their

SAGD well pads. This approach showed improved circulation performance and a faster ramp-up to production (Ahmadloo & Yang, 2014).

### 3.1.2. Academic research.

Much of the academic research has related to the industry related projects already discussed. There has been research concerning reservoir performance and mechanics associated with solvent injection, however this is beyond the scope of this project.

There are many approaches to employing solvents with steam (Bayestehparvin et al., 2016). Using solvents in bitumen recovery is advantageous as it requires lower energy input; for example the VAPEX process has an energy consumption that "is 3% of the energy requirement for SAGD for the same production rate in terms of latent heat of vapourization of water and the solvents" (Bayestehparvin et al., 2016, p. 6). Figure 5 shows the different types of processes for heavy oil recovery that involve solvent.

Academic research has also addressed the energy intensity associated with SAGD and how the application of new technology could be used to improve environmental performance. The need for new processing techniques to reduce carbon intensity is required as current GHG intensity is high (Gates & Larter, 2014). The impact of SOR on GHG intensity is significant as can be seen in Figure 6.

Research has also been conducted using a Life Cycle Assessment (LCA) approach for GHG intensity for SAGD. A hypothetical SAGD facility model (Giacchetta, Leporini, & Marchetti, 2015) was created to determine the GHG emissions. Based on this model, GHG intensities ranging between 8.71 g $CO_{2e}$ / MJ bitumen to 13.6 g $CO_{2e}$ / MJ bitumen were reported for SAGD. This was contrasted with values between 4.4 and 4.7 g $CO_{2e}$ / MJ bitumen (Giacchetta et al., 2015) for more conventional crude oils. These values may not consider all the actual operational parameters of SAGD as the model is hypothetical. Also, the influence of solvents on reducing the GHG intensity is not addressed in this hypothetical model.

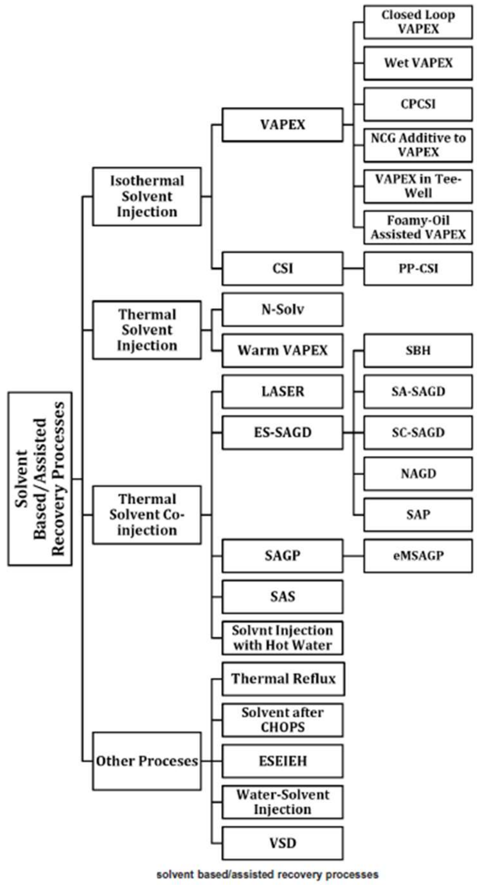
A similar modeling approach for GHG intensity in oil sands resulted in different values (Nimana, Canter, & Kumar, 2015). This approach addressed differences between surface mining and SAGD. Considerations for natural gas consumption and the potential offset from electricity cogeneration were also considered. The intensities reported (Nimana et al., 2015) were:

- 4.4 to 7.4 g $CO_{2e}$ / MJ bitumen for surface mining
- 8.0 to 34.0 g $CO_{2e}$ / MJ bitumen for SAGD

The addition of electrical cogeneration facilities significantly reduced GHG intensity. The potential application of solvent to reduce intensity was highlighted as a future opportunity to improve performance (Nimana et al., 2015).

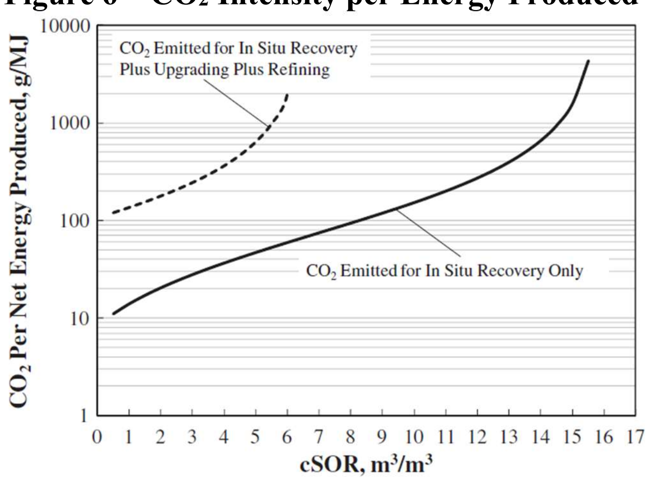
Reservoir simulation work (Alharthy, Kazemi, Graves, & Akinboyewa, 2010) illustrated different ways of increasing energy efficiency. This simulation study involved an Energy Gain (EG) parameter which is the useful energy produced (i.e. bitumen) divided by the energy consumed in production of the bitumen. Scenarios investigated included the application of non-condensable gases. The highest EG was found for the case where there was six months of preheating, five years of steam and 4.5 years of carbon dioxide injection. Overall recovery was slightly lower for this case than others investigated and the impacts of solvents were not considered in this research.

**Figure 5 – Processes Involving Solvents**




(Bayestehparvin et al., 2016, p. 3)

**Figure 6 – $CO_2$ Intensity per Energy Produced**




$CO_2$ emitted per unit net energy generated (100% steam quality generated with efficiency of the steam generator equal to 0.75) from steam-based recovery process operating at 2100 kPa.

(Gates & Larter, 2014, p. 712)

### 3.2. Environment

The use of fossil fuels by humanity since the industrial revolution has caused an increase in carbon dioxide ($CO_2$) in the atmosphere. Levels of $CO_2$ have increased from 280 ppmv in the 1700s to over 400 ppmv today (US Environmental Protection Agency, n.d.). This is significant as scientific work has shown that when $CO_2$ levels are low, the earth tends to be cooler whereas when $CO_2$ levels are high, the earth tends to be warmer (Sachs, 2015). Carbon dioxide levels have not been this high in the last 3 million years (Sachs, 2015).

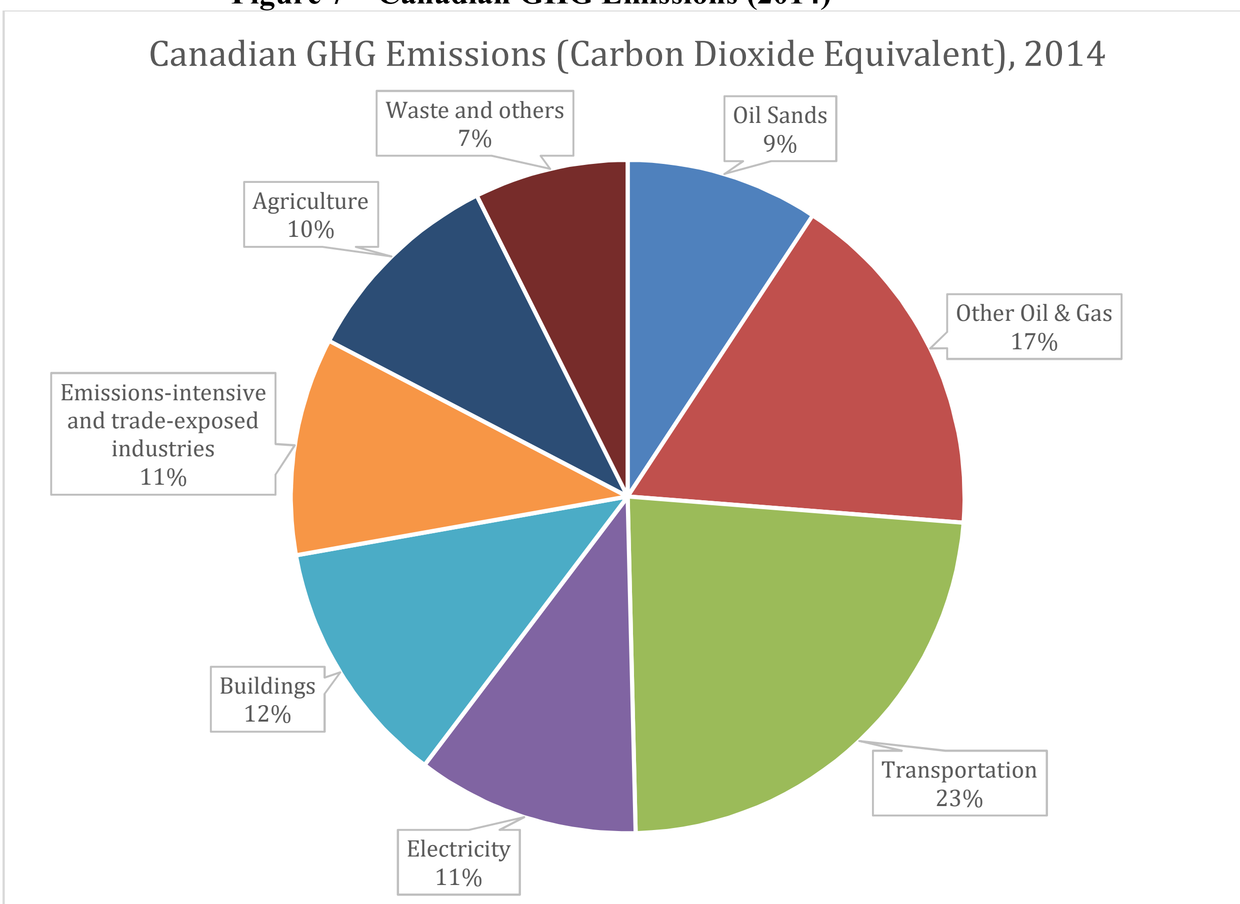
The impact of carbon dioxide is that it contributes to the greenhouse effect. The greenhouse effect occurs when certain atmospheric gases, called greenhouse gases or GHGs (including $CO_2$, $N_2O$ and $CH_4$), prevent the re-radiation of energy to space (US Environmental Protection Agency, n.d.). There is recognition that the global temperature rise that is occurring due to GHGs needs to be reduced to limit the extent of climate change (Anderson, Hawkins, & Jones, 2016). The United Nations Conference of Parties (COP) in 2015 reached agreement in Paris with the aim to hold "the increase in global average temperature to well below 2 $^{o}$C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 $^{o}$C above pre-industrial levels" (United Nations FCCC, 2016, p. 22).

The oil sands are a contributor to GHGs, in particular to $CO_2$, in Canada (Figure 7). In 2014, oil sands GHG emissions were about 9% of the total Canadian GHG emissions (Environment and Climate Change Canada, 2016). Globally, GHG emissions from the oil sands constituted 0.13% of total emissions (Canada's Oil Sands, n.d.; Canadian Association of Petroleum Producers, n.d.).

The oil sands are attracting world wide attention on their perceived impact towards climate change (Biello, 2013; Greenpeace, n.d.). This prompted a review by the European Union

(EU) of oil sands based fuels which could have impacted the ability to sell such products into the EU. After review, the EU developed their fuel quality directive which ended up placing oil sands based products in a similar position to other hydrocarbons (Canadian Association of Petroleum Producers, 2015). Given the concern about oil sands based GHGs, Canadian governments have had to react.

**Figure 7 – Canadian GHG Emissions (2014)**




(Environment and Climate Change Canada, 2016)

## 3.3. Policy

### 3.3.1. Alberta government policy.

The Alberta government became concerned about the impacts of climate change and in 2015 a panel was struck to develop an Alberta Climate Leadership Plan (CLP). The panel produced a report in 2015 that made recommendations to reposition Alberta to address climate change and future climate policies (Leach, Adams, Cairns, Coady, & Lambert, 2016). The recommendations included:

- Regulation concerning carbon competitiveness
- Phasing out coal based electricity and replacing with renewable based sources
- Reducing methane emissions
- Promoting energy efficiency and resiliency
- Promoting technology and innovation regarding emissions
- Ensuring that Indigenous peoples are fully included in the process

The recommendations from the panel were implemented by the Alberta Government in the Alberta Climate Leadership Plan (Alberta Government, 2017d). Key elements of the CLP are:

- Implementing a price for carbon on greenhouse gas emissions
- Ending coal based electricity generation by 2030
- Increasing development of renewable energy
- Capping emissions of GHGs from the oil sands at 100 megatonnes per year
- Reducing methane emissions by 45% by 2025

SAGD based oil sands production will be impacted by the emissions cap from the oil sands. If SAGD production can be done at a lower intensity, potentially using the alternative technologies discussed earlier, greater volumes of bitumen could be produced under the cap. The Alberta government has implemented into law the cap on oil sands emissions (Province of Alberta, 2016c).

The policy activity that is still underway is how the emissions cap will be managed. There is concern about how the cap will be allocated (Cattaneo, 2017a) and whether existing producers will be favoured over new entrants to the oil sands. The Alberta government believes that implementation of the cap will encourage technological innovation (M2 Presswire, 2016). There is also disagreement over the impact of the cap; the Fraser Institute believes that the 100 megatonne limit could be reached by 2025 and cost the Canadian economy $250 billion over 15 years (The Oil Daily, 2016). Another report shows that if existing technology is used the emissions cap will be reached by 2026, but if new technology is employed, the cap may not be reached until 2036 (Southwick, 2017). Both the Alberta Climate Change Office (Forseth, 2017) and the Alberta Energy Regulator (Bolton, 2017) will be involved in the management of emissions under the cap.

#### 3.3.2. Federal government policy.

The Government of Canada is committed to act to address climate change. "The Government of Canada will provide national leadership and join with the provinces and territories to take action on climate change, put a price on carbon, and reduce carbon pollution" (Government of Canada, 2016, para. 3). In December 2015, the federal government and a group of provincial premiers committed to reducing Canadian GHGs by 30% below 2005 levels (Boothe, 2016). Boothe (2016) believes that this reduction will be challenging and require a transformation of the Canadian economy.

The Canada West foundation reviewed policy alternatives for Canada related to Climate Change (McLeod, 2016). The work done by McLeod (2016) indicates that there has been a poor record on countries meeting their climate change targets, but that Canada appears more committed to meeting goals in its adoption of the Paris agreement. McLeod (2016) believes that the premiers, in particular Western Canadian premiers, need to work with the federal government to develop policies to proactively address climate change.

# Chapter Four: Methodology

## 4.1. Data Collection and Research Plan

My project employed different techniques to address the three dimensions of energy, environment and policy. Data collection involved a review of the literature to quantify the emissions intensity difference between conventional SAGD and solvent-assisted SAGD, and included discussions on recent developments of GHG related policy.

### 4.1.1. Energy.

Data collection for the energy dimension of my research involved different approaches including:

- Literature review

  A review of the current understanding of energy is needed to address:

  - Demand for liquid hydrocarbon fuels into the future
  - Alberta's role in supplying these hydrocarbon fuels
  - The current energy intensity of SAGD operations
  - Potentials for reduction in energy intensity by employing alternative SAGD technology

- Consultation with operators and suppliers

  Interviews and discussions with an operating company – Cenovus – and suppliers were conducted to understand energy changes in the extraction of bitumen via SAGD

### 4.1.2. Environment.

Data collection for the environmental dimension of my research primarily involved a review of the literature. This literature review included a high-level background discussion on the mechanics of climate change and how GHGs contribute to it. The literature review also comprised a review of the environmental perception of the oil sands with discussion on some efforts conducted to date to address some of the negative perceptions about the industry and its environmental performance.

#### 4.1.3. Policy.

The focus of the policy dimension was on policies of the Government of Alberta. The reason for the focus on Alberta is that natural resource extraction is primarily the domain of provincial governments in Canada. The Canadian Constitution Act, 1867 was framed where "jurisdiction over natural resources" was "to the level of government that controlled the territory in which they were located" (Hessing, Howlett, & Summerville, 2014, p. 60).

The plan for data collection to address the policy dimension included:

- Literature review

  The focus of the literature review was on information that is currently available on aspects of the Alberta CLP that concern the emissions cap from the oil sands.

- Interviews with key players in the policy development concerning the emissions cap from the oil sands were conducted; this included discussions with:
  - Staff at the Alberta Climate Change Office (ACCO)
  - Staff at the Alberta Energy Regulator (AER) who will ultimately be implementing enforcement of the oil sands emissions cap

### 4.2. The Policy Dimension and Transition Theory

A key element of understanding SAGD emissions intensity and its impacts on bitumen production is the evolution of policy, in particular that addressing the overall GHG emissions cap for production from the oil sands. The information gathered on policy will be reviewed and tested to see how the planned activities fit into the concepts of transition management and transition theory. Specifically, the policy initiatives will be reviewed against two papers on these theories (Frantzeskaki & de Haan, 2009; Rotmans, 2005).

## Chapter Five: Timeline

This research project commenced in December 2016 with a timeline developed to meet the required completion date at the end of August 2017. A high-level summary of the timeline is presented below.

### 5.1. Progress Reports

Short progress reports were prepared as outlined in the schedule for the SEDV 625 (Research Project) course. These reports were provided monthly starting at the end of March 2017 through to the end of June 2017.

### 5.2. Activities

Activities completed included:

- March 2017
  - Developed final proposal
  - Continued literature review which had started in December 2016
  - Initiated and conducted discussions with ACCO and the AER
- April 2017
  - Finalized proposal by obtaining feedback from the project supervisor, Dr. Anil Mehrotra and Dr. Amos Ben-Zvi of Cenovus Energy
- May 2017
  - Started development of plan to use literature based data to evaluate GHG intensity for different SAGD configurations
  - Conducted further discussions with AER on bitumen economics and role of AER regarding climate change policy

- June 2017
    - Attended Technical Briefing that presented initial recommendations of the Oil Sands Advisory Group
    - Worked with June Warren Nickle's group contacts to get access to CanOils, a database with economic information
- July 2017
    - Finalized HYSYS and economic models
    - Completed draft report
- August 2017
    - Completed oral presentation of research project
    - Finalize final report
    - Submit final project

### 5.3. Key Deliverables

Key deliverables and documents related to the project include:

- Finalized legal agreements
- Progress reports
- Presentation
- Final report

# Chapter Six: Policy Development – Alberta Climate Leadership Plan

## 6.1. Policy Background and Development

The election of a majority provincial government with New Democratic Party (NDP) Members of the Legislative Assembly (MLAs) in 2015 was a major change in Alberta politics (CBC News, 2015). The new Government of Alberta (GoA) embarked in a different direction on environmental policy, one focused on increased management of, and reductions to, greenhouse gas emissions in Alberta. The NDP government's plan included "a phaseout of coal-fired power in the next 15 years, a 10-year goal to nearly halve methane emissions, as well as incentives for renewable energy" (Giovannetti & Jones, 2015, para. 6).

To guide policy changes related to climate change, the Alberta government formed a *Climate Change Advisory Panel* (CCAP) in the summer of 2015 (Alberta Government, 2017c). This panel had responsibility to develop "a new climate change strategy for Albertans" (Alberta Government, 2017c, para. 1).

### 6.1.1. Discussion Document

To guide the policy discussions, the Minister of Alberta Environment and Parks (AEP), Shannon Phillips, produced a Discussion Document (DD) (Alberta Government, 2015c). This document outlined key messages from the minister along with actions taken to date and planned activities. At the time of the DD, the NDP government had updated carbon emission regulations that were about to expire and announced the formation of CCAP (Alberta Government, 2015c). The DD described the government's goal for a lower carbon future while ensuring long term economic success for Alberta.

The document outlined the planned consultation approach. It also addressed:

- Climate change impacts

- Alberta’s vision
- Alberta’s challenge
- Current emissions profile
- Next steps

The timeline for the work was outlined including for CCAP to provide advice to the Minister of AEP.

To facilitate the development of the new policy, the DD discussed many different policy approaches for consideration. These included (Alberta Government, 2015c):

- Carbon Policy – including carbon taxes, cap and trade systems and/or performance standards
- Oil and Gas sector – carbon pricing, technology incentives, performance / technology / fuel standards and/or sector limits
- Electricity sector – feed-in-tariffs, tax credits, carbon offsets, renewable performance standards and/or emissions performance standards
- Transportation sector – carbon taxes, infrastructure investment, technology standards and/or education and outreach
- Buildings and homes sector – incentive programs, carbon pricing and/or building code and performance requirements
- Industrial and agriculture sectors – similar approaches to the other sectors discussed

### 6.1.2. Climate Change Advisory Panel

To focus the policy discussion, the CCAP panel was struck that helped to represent different perspectives on issues concerning climate change. The panel members included representatives from academia, industry, NGOs, and Indigenous groups.

### 6.1.3. Consultation Approach of the Climate Change Advisory Panel

CCAP used different techniques to obtain input into policy questions that they were investigating (Alberta Government, 2015e). These included public engagement in open houses, use of online surveys, technical engagement with industry, Indigenous engagement and the use of online submissions as means to obtain input.

***Public Open Houses***

Two open houses were held in 2015 in Calgary and Edmonton to gather input on proposed policy changes. "The open houses offered the general public the opportunity to informally interact in person with panel members and subject matter specialists, and to:

- Share opinions on values, priorities, and outcomes to guide government actions to address climate change
- Share input on what they are willing to do to address climate change, based on their values and priorities
- Raise awareness about climate change" (Alberta Government, 2015d, p. 1)

Over 900 people attended the open houses and the participants provided more than 4000 written comments for consideration by the panel (Alberta Government, 2015d).

### *Online Survey*

To ensure there was representation of views from all over Alberta and from those who could not attend the open houses, an online survey was included as part of the consultation. The survey included twenty-three questions, some of which were open ended questions. There were over 25,000 completed surveys, but it is worth noting that there were only 16,000 unique computer addresses for these submissions (Alberta Government, 2015b). Also, a targeted group of almost 2,000 participants was selected by a research firm to complete the survey. The targeted group was tested to ensure that it adequately represented Alberta's demographics (Alberta Government, 2015b).

### *Technical Sessions*

Targeted stakeholders were the focus of the technical engagement portion of the panel's work. There were approximately 350 diverse stakeholders invited to panel sessions (Alberta Government, 2015f). The "sessions were designed to provide stakeholders with an opportunity to share their perspectives on key areas including: buildings and houses; electricity; oil and gas; industrial emitters; agriculture and forestry; transportation and the role of municipalities; electricity; innovation and technology; and economy-wide approaches for greenhouse gas reductions" (Alberta Government, 2015f, p. 1).

### *Aboriginal Sessions*

To ensure that Indigenous voices were heard, forty-seven Indigenous individuals participated in engagement sessions in Calgary, Edmonton and Fort McMurray (Alberta Government, 2015a).

*Submission Library*

The panel also invited submissions for consideration from interested stakeholders including the public, industry, academic experts and NGOs. About 60% of the submissions were from the public, 20% from industry, 18% from NGOs and remainder from other stakeholders (Alberta Government, 2017c).

### 6.2. Report from Climate Change Advisory Panel

After the consultation process was complete and the responses compiled, CCAP prepared its report to the Minister of AEP (Leach et al., 2016). The Executive Summary (Alberta Government, 2015e) highlighted how the process included consultations with members of the Alberta Public Service throughout development of the report. The panel also indicated how many of their members engaged with members of the government, and “with other members of the legislative assembly, members of parliament and representatives of the federal government” (Alberta Government, 2015e, p. 7). The panel also believed that they were involved in a more iterative policy development process than typical for such policy engagement. “The government provided us with a unique opportunity to provide on-going feedback and advice, rather than a typical panel report to which a government would then respond” (Alberta Government, 2015e, p. 7).

The panel’s report made recommendations in two specific areas:

- Carbon competitiveness regulation
- Complementary policies

#### 6.2.1. Carbon Competitiveness Regulation

The panel recommended implementation of some form of carbon pricing. There were four specific recommendations in this regard (Alberta Government, 2015e):

- Carbon price be applied to industrial emissions to replace the existing Specific Gas Emitters Regulation (SGER)
- Carbon price be applied for end-use emissions (such as transportation and heating fuels)
- A ceiling on the carbon price, but one that can increase over time
- Defined purpose for the revenues from the carbon pricing scheme

### 6.2.2. Complementary Policies

The panel recommended five complimentary policies to be considered (Alberta Government, 2015e):

- Electricity – phasing out of coal and introduction of renewables
- Oil and gas initiatives:
  - Pricing carbon
  - Reducing methane emissions
- Promote energy efficiency and energy-resilient communities in Alberta
- Promote technology and innovation
- Fully include Indigenous people in climate change activities

## 6.3. Alberta Climate Leadership Plan

The government reviewed the panel's recommendations and in November 2016, the Alberta CLP was finalized. The plan was communicated worldwide (Alberta Government, 2016b) and in a series of telephone town halls (Alberta Government, 2016c) to update Albertans on the plan.

The key aspects of the plan generally aligned with CCAP recommendations. The key aspects of the plan are:

- "implementing a new carbon price on greenhouse gas emissions
- ending pollution from coal-generated electricity by 2030
- developing more renewable energy
- capping oil sands emissions to 100 megatonnes per year
- reducing methane emissions by 45% by 2025" (Alberta Government, 2017d, para. 4)

# Chapter Seven: Policy Implementation

## 7.1. Aspect in Place – Carbon Pricing

The implementation of different aspects of the Alberta CLP involves many different stakeholders including government departments, regulatory agencies, industry advisory groups and industry experts. Due to the number of different aspects of the Alberta CLP – the key aspects discussed previously – implementation will occur at different times.

The first portion of the Alberta CLP that was implemented surrounded the carbon price on greenhouse gas (GHG) emissions. The carbon price came into effect on January 1, 2017 and started at a level of $20.00 per tonne of carbon dioxide rising to $30.00 per tonne in 2018 (Key Energy News, 2017).

## 7.2. Aspect in Progress – Methane Reduction

The implementation of measures is further advanced for other aspects of the CLP, such as methane emissions, than for the 100 megatonne oil sands emission cap. The progress on methane is discussed as it indicates a possible path for the implementation of the oil sands emission cap. Based on CCAP recommendations, the Alberta CLP was structured to ensure that methane emissions from the upstream oil and gas sector are reduced by 45% by 2025 (Alberta Government, 2017d). The finalized Alberta CLP includes more details on the plans to reduce methane emissions and atmospheric methane impacts. While methane is a valuable hydrocarbon as it a key constituent of natural gas, fugitive emissions of methane are associated with the production of coal, bitumen and oil and gas. The GHG impact of methane is twenty-five times greater than that of carbon dioxide over 100 years (US Environmental Protection Agency, 2017). Because of methane's higher impact, the GoA believes that reducing methane emissions is the most cost-effective way of reducing provincial GHG emissions (Alberta Government, 2017b).

To achieve the 45% reduction, the GoA plans the following (Alberta Government, 2017b):

- Apply new design standards for new Alberta facilities to reduce methane emissions
- Improve the reporting and measurement of methane emissions; enhance requirements for maintenance and leak detection regarding methane
- Commence an initiative that evaluates methane emissions from existing facilities and develops regulations to come into effect in 2020 to ensure the target reductions are achieved

To develop new regulations and standards, the involvement of different government agencies and departments is required. For the methane reduction strategy, the effort will be led by the AER with support of the ACCO and Alberta Energy (Alberta Government, 2017b).

## 7.3. Implementation of the Climate Leadership Plan

For the Alberta CLP to continue its progression from and idea, to policy and to a legal requirement in Alberta, additional implementation actions are required. These include legislative actions, design standard development and activities by regulatory agencies.

### 7.3.1. Legislative

Legislation was developed to implement the Alberta CLP. Initially, the legislation will focus on carbon pricing as this instrument is the plan's initial focus. The *Climate Leadership Act* (CLA) was enacted in 2016 (Province of Alberta, 2016a) and currently only includes actions related to carbon pricing. "The purpose of this Act is to provide for a carbon levy on consumers of fuel to be effected through a series of payment and remittance obligations that apply to persons throughout the fuel supply chains" (Province of Alberta, 2016a, p. 9). The CLA also indicates that carbon levy revenue may only be used for designated activities.

Associated with the CLA, are regulations. The main regulation is the *Climate Leadership Regulation* (CLR) (Province of Alberta, 2016b) which provides details on the implementation and gathering of the carbon levy. There is a minor associated ministerial regulation that details payments by the Minister when a notice of assessment arises (Province of Alberta, 2017).

As the details of other elements of the CLP are developed, the CLA and CLR will be modified to include these elements of the plan. For example, this will include the requirements for methane reduction.

The final step of implementing the CLA and the CLR in Alberta was the order made by the Lieutenant Governor in Council in November 2016 (Province of Alberta, 2016d).

#### 7.3.2. Design Standards

The management of methane emissions from the upstream oil and gas sector is a highly technical topic. This industry sector contains a wide range of equipment from oil and gas production wells, to compressor stations, to production facilities and gas plants to name a few. Design standards associations, such as the Canadian Standards Association (CSA), develop standards to ensure that desired outcomes are met. Such standards can be included as legislative requirements. For example, the Alberta *Pipeline Rules* indicate that “except as otherwise specified by these Rules, the following standards are in force: CSA Z662, *Oil and Gas Pipeline Systems*” (Province of Alberta, 2005, p. 14).

With the attention on methane reduction, CSA has developed a new standard, CSA Z620.1-16, *Reduction of fugitive and vented emissions for upstream petroleum and natural* *gas industry systems*. The scope of this standard includes "criteria to develop emission reduction practices and programs" (CSA Group, 2016, p. 6) for "fugitive and vented emissions sources in the upstream oil and gas industry from wells, pipelines and facilities" (CSA Group, 2016, p. 6). Regulatory agencies addressing the methane aspects of the CLP may consider this design standard. The CSA Z620.1 standard could become a part of the CLR when it is amended to include provisions for methane.

### 7.3.3. Regulatory

When the Alberta CLP was introduced, the GoA's plan for the development of methane standards was to have the AER lead this effort with the support of ACCO and Alberta Energy (Alberta Government, 2017b). Alberta Energy is a long-standing department of the Alberta Government (Alberta Government, 2017a). ACCO is a newer government instrument. It was created on February 2, 2016 and "will have a large mandate to fulfill in implementing ambitious aspects of the *Climate Leadership Plan*" (Massicotte, 2016. para. 5).

The AER is leading this effort through their Methane Reduction Oversight Committee (Alberta Energy Regulator, 2017). This committee is working to "develop recommendations and options to inform cost-effective regulations for new and existing facilities in the oil and gas sector" (Alberta Energy Regulator, 2017, para. 7). The committee includes stakeholders from government, industry, NGOs and technology firms. Currently the AER is developing draft regulations that will be made available for public comment later in 2017 (Johnson, 2017).

Regarding methane emission reductions, Cenovus Energy, in a discussion paper, recommended that the CSA standards on methane (Z620.1-16) be adopted as "methane reduction policy for upstream oil and gas" in Alberta (Cenovus Energy, 2015, p. 2). This position by industry illustrates how design standards may become a part of regulations associated with legislation.

### 7.4. Federal Government Process

Jurisdiction over environmental matters is a shared responsibility between the provinces and the federal government in Canada (Muldoon, Lucas, Gibson, Pickfield, & Williams, 2015). The proposals outlined for implementation in the Alberta CLP align with federal and international targets for methane reduction.

The Canadian federal government had a parallel process to address climate change. A key component of this was the Pan-Canadian Framework on Clean Growth and Climate Change (Government of Canada, 2016b).

This framework relied on “federal-provincial-territorial working groups to work with Indigenous Peoples; to consult with the public, businesses and civil society; and to present options to act on climate change and enable clean growth” (Government of Canada, 2017, para. 7). The consultation process was like that for the Alberta CLP; notably the federal government plan included ministerial advice from the Canadian Council of Ministers of the Environment (CCME).

Recently, the Government of Canada announced its proposed methane regulations, based on the Pan-Canadian Framework. The regulations would lower methane levels by 40% to 45% by 2025 (Government of Canada, 2017b), like what is proposed in Alberta’s plans. The draft federal regulations have been developed and have been issued for comment via the Canada Gazette (Government of Canada, 2017a) and were available for review until July 27, 2017. The discussion in the Gazette included the background for the regulations and a summary of the activities, including consultation, that led to the guidelines.

The proposed regulations would be under the authority of the Canadian Environmental Protection Act (CEPA) and national regulatory standards would be addressed by Environment and Climate Change Canada (ECCC) (Government of Canada, 2016c). The concept of regulatory equivalency enters the proposed federal regulations. The Canada Gazette indicates that, "CEPA allows for flexibility via equivalency agreements with interested provinces and territories, as long as the requirements of CEPA are met, which can enable these jurisdictions to be front-line regulators where they have legally binding regimes that produce equal or better environmental outcomes" (Government of Canada, 2017a, Para. 46). This equivalency would allow Alberta to administer the methane reductions under its regulatory regimes.

It is also significant that federal government initiatives in the Pan-Canadian Framework align with international commitments that the federal government has made. In early 2016, there was agreement between the United States and Canada to reduce oil and gas sector methane emissions by 40 to 45% from 2012 levels by 2025 (Varcoe, 2016). The federal governments in both countries will look at regulations to restrict the emissions of methane from the oil and gas sector (Varcoe, 2016). Also, Mexico was added to the agreement and there was agreement among the three countries to "reduce their methane emissions from the oil and gas sector – the world's largest methane source – 40 to 45% by 2025 towards achieving the GHG targets in our nationally determined contributions" (Prime Minister's Office of Canada, 2016, para. 11). With the change in the administration in the United States, the status of this commitment is now uncertain.

### 7.5. Upcoming Actions – Methane

For remaining portions of the Alberta CLP concerning the reduction of methane emissions, additional activities are required. These will take time to complete, meaning that full implementation of all plan aspects will occur over an extended period.

#### 7.5.1. Implementation – Methane

For the implementation of methane reduction provisions additional required activities include:

- Completion of draft regulations by AER
- Public comment and review of AER draft regulations
- Review of public comments by AER and consultation on final regulations with Alberta Energy and ACCO
- Finalize development of methane reduction regulations
- GoA level discussion of the methane regulations (including legislative committees) prior to development of amendments to the CLA and CLR
- Introduction of modified CLA and CLR to the legislature with intention to approve these modifications
- Order from Lieutenant Governor in Council

### 7.6. Evaluation of the Process – Methane

The progression of the work of the GoA through CCAP to CLP and the ensuing CLA and CLR illustrates an example of the process used for development of legislation. For this situation, some approaches worked well and other aspects could have been improved.

### 7.6.1. Positive Aspects

The process used to progress the government's policy ideas to the CLA was well thought out and many opportunities for input were provided. These included voluntary town halls, online surveys, discussions with targeted stakeholders and the specific involvement of Indigenous peoples. Such broad consultation provided the panel with many opportunities to obtain input from interested individuals. This contrasts with examples of other legislative developments that offered much less opportunity for consultation and review. The legislative changes made to the *Canadian Environmental Assessment Act* (CEAA) in 2012, for example, "were buried in a large budget implementation act that included a wide range of non-environmental parts" (Muldoon et al., 2015, p. 43).

Another positive aspect of this development of policy is its staged introduction and the involvement of many different parties in its implementation. Currently the CLA and CLR (Province of Alberta, 2016a) only address the carbon levy. Work on abatement of methane is being progressed by the AER (Alberta Energy Regulator, 2017). Other aspects of the CLP, for example the emissions cap from the oil sands, are being evaluated by the OSAG (Alberta Government, 2017d). This use of different groups and staging implementation can help to ensure that there is thoughtful development of policy application and that changes are not made too quickly.

Activities that took place during the work of CCAP were also beneficial to the process. The ability for panelists to engage with members of the GoA, civil servants, industry experts and members of other levels of government allowed for understanding of different viewpoints as consultation progressed. The GoA was also open to the "ongoing feedback and advice" (Alberta Government, 2015e, p. 7) from the panel. This approach is more efficient than a panel working in isolation with the government then reviewing a final report and responding to it.

### 7.6.2. Negative Aspects

Other aspects of this process could have been improved. One key area is that the scope of activities in the CLP was not well communicated to the electorate in the 2015 Alberta election. The 2015 NDP election platform states that, "we will take leadership on the issue of climate change and make sure Alberta is part of crafting solutions with stakeholders, other provinces and the federal government. First steps will include an energy efficiency strategy and a renewable energy strategy" (Alberta NDP, 2015, p. 18). There are elements of the CLP mentioned here, but not the broad plan that ended up being implemented. It is somewhat telling that locating the 2015 NDP election platform is difficult; it can only be found on an internet archive and not on the current webpage of the Alberta NDP.

Another area for improvement concerns the composition of CCAP. The panel members did not include a member from an emissions intensive industry, such as a coal producer or a hydrocarbon producer. Given that such sectors in Alberta including conventional oil and gas, oil sands and coal could be impacted by policy changes concerning GHG emissions, it may have been advisable to include a panelist with this background for the consultation process. Having the unique perspective of someone in the industry affected may have improved the panel discussions.

While there was an extensive consultation process that allowed opportunities for interested parties to participate, there could be the tendency for self selection. Such self-selection can attract those who “care deeply about and have strong opinions on the issue” (Nabatchi, 2012, p. 704) and lead to participation bias. The panel did use a research firm to select participants to engage in the online consultation aspects (Alberta Government, 2015b), however this only represented about 10% of total respondents. Perhaps employing a larger demographic sample may have helped in ensuring representation of a wide range of viewpoints.

Another concern is one of a technical nature and concerns the estimation of methane quantities. Measuring small flows of methane can be very difficult. There is debate currently underway as to whether methane estimations are accurate. Environmental NGOs believe that British Columbia methane emissions are up to 2.5 times higher than government statistics (Nelson, 2017). The Canadian Association of Petroleum Producers (CAPP) believes that the studies by the Environmental Defense Fund (EDF) (Nelson, 2017) have “limited scope and misrepresentation of reporting mechanisms currently in place” (McCarthy, 2017, para. 7). While disagreement about estimation techniques for methane emissions can be seen as negative, the detailed work of the AER and the CSA council should ensure that reliable techniques and approaches result.

## Chapter Eight: Implementation of the 100 megatonne Cap

### 8.1. Background

Earlier, there was discussion of the progress made from the initial NDP government policy toward government legislation. Regarding the 100 megatonne cap on emissions from the oil sands, the CLP included a recommendation that included "a legislated maximum emissions limit of 100 Mt in any year" (Alberta Government, 2017d, para. 11). Progress on this aspect of the CLP lags the carbon levy and the efforts on reducing methane emissions.

For the oil sands emissions cap, legislation was enacted to limit the emissions, the legislation states that "greenhouse gas emissions limit for all oil sands sites combined is 100 megatonnes in any year" (Province of Alberta, 2016c, p. 2). The Act further indicates that the Lieutenant Governor in council is authorized to make regulations. This aspect is important as the Act contains no details on the mechanism to implement and enforce the emissions cap.

To commence more detailed work on the emission cap, OSAG was struck to provide advice in this area. When OSAG was formed the GoA tasked it with providing advice in three key areas:

- "Implementing the legislated annual GHG emission limit
- Best investments in innovation to reduce GHG emissions intensity in oil sands production
- Developing durable, effective structures and processes to address local and regional environmental issues (i.e., air, land, water, biodiversity, cumulative effects)" (Alberta Government, 2016d, para. 3)

OSAG was also tasked with other tasks related to the emissions cap; these included how to address emissions growth in the future when other initiatives may require emissions reductions. These include, for example, commitments that Canada has made to the COP (Government of Canada, 2015).

### 8.2. Panel Composition

The panel was struck in July 2016, at that time there was indication that the initial term of membership would be for twenty-four months. The current members of the panel are (Alberta Government, 2017e):

- Dave Collyer, co-chair – industry; Formerly head of CAPP and experience with Shell
- Melody Lepine, co-chair – communities; Member of the Mikisew Cree First Nation
- Veronica Bliska; Reeve of the Municipal District of Peace
- Bill Clapperton; Vice-President of Regulatory, Stakeholder and Environmental Affairs at Canadian Natural Resources
- Anne Downey; Vice President of Operations for Statoil Canada
- Simon Dyer; Associate Regional Director for the Pembina Institute
- Tim Gray; Executive Director of Environmental Defence
- Chief Isaac Laboucan-Avirom; Chief of the Woodland Cree First Nation
- Bill Loutitt; Vice President, Fort McMurray Metis Local 1935
- Jon Mitchell; Vice President for Environment and Sustainability at Cenovus
- Kevin Scoble; Deputy Chief Administrative Officer for Regional Municipality of Wood Buffalo

- Richard Sendall; Senior Vice President of Strategy and Government Relations at MEG Energy Corporation
- Arlene Strom; Vice President Sustainability and Communications at Suncor

Previously there were additional members of OSAG, these included (Alberta Government, 2017f):

- Tzeporah Berman, co-chair ENGOs; Adjunct Professor York University Faculty of Environmental Studies
- Karen Mahon; Canadian director of STAND.earth
- Alison Ronson; Executive Director of Canadian Parks and Wilderness Society
- Christa Seaman; Regulatory Policy and Advocacy Manager at Shell
- Lloyd Visser; Vice President Environment and Sustainable Development at ConocoPhillips

The panel membership has evolved due to changes in OSAG's work now that the initial recommendations have been completed. The change in membership reflects a change in OSAG's work along with changes in the upstream oil and gas industry in Alberta (i.e. corporate sales of some oil sands assets).

### 8.3. Reaction to OSAG

The initial composition of the panel was from a broad range of groups including industry, ENGOs, and Indigenous groups. This "makeup of the panel shows how some oil companies and green groups have moved from polarized positions and are trying to achieve their goals through consensus" (Jones, 2016, para. 6). There was some immediate criticism of the inclusion of one of the panel members, Tzeporah Berman, who has been active in campaigns against oil sands. In 2011 she wrote, "C'mon Canada, let's show the world why this country is the birthplace of

Greenpeace. On September 26, brave Canadians will gather on Parliament Hill to protest the tar sands" (Berman, 2011, para. 8). Her appointment specifically caused political reaction in Alberta with Brian Jean, leader of the Opposition Wildrose party to state, "Appointing a co-chair to the [panel] who is vocally opposed and has made a career off of opposing our oil sands industry is deeply disappointing" (Jones, 2016, para. 12). It appears that Berman has moved past some of her previous comments. "They are the words and tone from my past campaigning and don't reflect the opportunity I have today to be part of helping advise on the critical questions on how Alberta will operate under a [greenhouse gas] limit, innovate, better protect its environment and determine the infrastructure needs of its future production" (Lamoureux, 2016, para. 15).

There was some initial negative comments from industry about the oil sands emissions cap and the work that OSAG was undertaking. Rich Kruger, CEO of Imperial Oil, commented on the emissions cap. "We didn't think the cap was necessary. The climate leadership plan in Alberta, it has many aspects, many of which we think are really good aspects. The cap is not one of those" (Cattaneo, 2016a, para. 3). Prior to OSAG issuing any recommendations, the Fraser Institute (Green & Jackson, 2016) forecast that the 100 megatonne cap could result in cumulative production losses between 2.03 and 3.34 billion barrels of oil. The Fraser Institute study further indicated a potential economic loss between $153 and $254 billion dollars with an abatement cost of over $1000 per tonne of GHG emissions (Green & Jackson, 2016).

OSAG's goal was received more favourably by others. The industry members of OSAG "believe that by investing in technology and innovation, we can produce oil from the oil sands on a globally carbon competitive basis. The Alberta Climate Leadership Plan emissions limit acts as an incentive to continually improve our performance in a carbon constrained world" (M2 Presswire, 2016, para. 7). Elyse Allan, the CEO of General Electric Canada said, "Alberta's

Climate Leadership Plan utilizes the carbon revenue to reinvest in technologies that will lower emissions. We will work with customers and government to develop and deploy the technology that will help industry succeed within this new framework" (M2 Presswire, 2016, para. 8).

In addition to the work that was conducted by the Fraser Institute, other studies on the potential impact of the oil sands emissions cap were conducted. The Canadian Energy Research Institute (CERI), has produced a few studies concerning oil sands operations. CERI indicated that if current technologies are used as the basis for SAGD production the 100 megatonne emissions cap will be reached by 2028 (Nduagu, Sow, Umeozor, & Millington, 2017). CERI is of the opinion that if new technologies are employed however, that the emissions cap would not be reached within the study period that CERI considered (up to 2036) (Nduagu et al., 2017). CERI is of the opinion that with a "carbon tax and a 100 megatonne/year emissions cap on the oil sands industry, producing at lower GHG intensity becomes reasonable and sustainable" (Nduagu et al., 2017). CERI does not appear to have considered the potential of a reduction in the future level of the cap to a level below 100 megatonnes per year. This could impact the future production levels of bitumen even with the deployment of new technology.

### 8.4. Mandate of OSAG

OSAG's mandate was provided in documents from the Alberta Government (Alberta Government, 2016e, 2016f, 2016g). The scope of OSAG's activities was quite broad and included:

- "The list of facilities that should be subject to the emissions limit (so that there is clarity on monitoring and compliance with the Oil Sands Emissions Limit Act).
- The mechanism OSAG believes will most effectively implement the emissions limit, based on an assessment of the following:

    - The range of potential mechanisms that could be used (in a distinct or integrated manner) to implement the emissions limit;
    - The criteria that OSAG used to assess the relative merits of each of the potential mechanisms (i.e. what objectives should the design of the implementation mechanism seek to achieve); and
    - An assessment of the range of potential mechanisms against those criteria;
- The way the recommended mechanism could be implemented (e.g. through legislation, policy, regulation, etc.);
- Any changes required to the current regulatory and operating environment that facilitate effective implementation of the emissions limit;
- Any changes required to the current system of reviewing and approving applications for oil sands development to effectively implement the emissions limit; and
- Any other advice OSAG believes important in terms of ensuring the emissions limit is effectively implemented in a manner that secures broad support from stakeholders" (The Oil Sands Advisory Group, 2017b, p. 2).

### 8.5. OSAG Initial Report & Recommendations

On June 16, 2017 OSAG released their initial findings concerning the management of the oil sands emission cap (Government of Alberta, 2017b). The key aspects of the proposed implementation of this cap will be discussed along with thoughts on the path forward and evaluation of this process thus far.

The key recommendations of the report are to encourage lower intensity bitumen production and to ensure that adequate information systems are in place to allow for management of the cap. Obviously understanding the current level of emissions and a means of forecasting future emissions is key to managing to the 100 megatonne limit. Specific recommendations of the report include:

- “requirements for new facilities and expansions to use the Best Available Technology Economically Achievable (BATEA)
- submission of non-binding Greenhouse Gas Management Plans to assist with public accountability and transparency
- preparation of a technology roadmap and costs of abatement technologies by innovation entities
- changes to resource recovery requirements to no longer require high emission intensity portions of a resource to be recovered” (The Oil Sands Advisory Group, 2017c, para. 2).

Another key aspect of OSAG’s recommendations is how to manage emissions as the 100 megatonne emissions cap is approached. This is the concept of managing scarcity and what actions should take place when oil sands emissions levels reach levels of 80 megatonnes per year, 90 megatonnes per year and 95 megatonnes per year. To assist with this management process, the need for credible emissions information is required. This would be addressed by establishing information systems that will allow for detailed ten-year forecasting of anticipated GHG emissions. One specific recommendation is to require that “the EPEA renewal process for projects currently operating or under construction be amended to require the submission of a GHG management plan” (The Oil Sands Advisory Group, 2017b, p. 8).

At 80 megatonnes, OSAG recommends that actions be taken to prepare operators for emissions scarcity and to “further catalyze actions that will contribute to the oil sands sector achieving lower GHG emissions intensity” (The Oil Sands Advisory Group, 2017b, p. 8). At 90 megatonnes per year the key activity is to “determine how best to establish an operational reserve for the purpose of managing variability at the emissions limit" (The Oil Sands Advisory Group, 2017a, p. 12). At 95 megatonnes, OSAG indicates that further actions should be taken including "a review of the standards to be used by oil sands facilities developing their Annual Facility Level GHG Forecasts, requiring the Annual Long Term Oil Sands Emissions Forecast prepared by the Regulator to place increasing attention on the oil sands emissions trend and the potential impacts on existing operators and new projects in the event emissions scarcity is reached" (The Oil Sands Advisory Group, 2017b, p. 8).

Other activities as scarcity is approached rely upon the GHG emissions forecast discussed earlier. Actions will be triggered if the forecast shows that the emissions within the next five to ten-year period are forecast to be greater than 100 megatonnes. When Dave Collyer presented OSAG's recommendations on June 16, 2017, he indicated that the 100 megatonne limit was a firm backstop, it was not intended for this emissions level to be exceeded (The Oil Sands Advisory Group, 2017a). If the limit was forecast to be exceeded, the following actions would occur:

- No new, approved oil sands projects (or expansions) that would add to the GHG emissions that are not yet being constructed would be permitted without approval of the regulator
- That an apportionment approach be used to manage emissions among existing operators

The apportionment approach would be based on historical operational performance with facilities being divided into quartiles. For facilities in the lower two quartiles – these being better performing facilities with respect to GHG emissions – there would be no apportionment. For facilities in the third quartile, each facility would need to reduce their emissions by their share of

1/3 of the difference between the forecast emissions level (i.e. the forecast that shows the emissions being more than 100 megatonnes) and the emissions limit. The fourth quartile facilities (i.e. the worst performers in GHG emissions) would need to reduce their emissions by 2/3 of the difference discussed.

This apportionment approach differs from that used in other regulatory enforcement approaches within Alberta. For example, for water licenses granted under the Alberta Water Act, there is the principle of 'first in time is first in right' (Nutbrown, 2017). What this means with respect to water licenses is that the first applicants to a license have the first rights to water. If there is ever a need to restrict water withdrawals, the initial license applicants can generally still withdraw all their water allotment. If such an approach had been used for GHGs, then long term established producers would end up having more rights to emit GHGs. This would not have treated all producers fairly.

In their work OSAG recognized that there would need to be "provisions for addressing variances reasonably inherent within emissions forecasting, start-up conditions and unplanned operational events that were not reasonably foreseeable" (The Oil Sands Advisory Group, 2017b, p. 6). Penalties are recommended, the initial level is recommended at \$200/tonne but that consideration should be made for employing a multiple of the carbon levy currently in place at the time of the exceedance.

Other recommendations of OSAG's initial report include:

- Not employing – at this time – the use of internationally transferred offsets. OSAG's rationale for this is that there still is some room prior to the emissions cap being reached and that the means of transferring offsets is continuing to evolve. For example, this includes the proposed addition in 2018 of Ontario to the Western Climate Initiative to trade carbon allowances (McMahon, 2017).

- Excluding GHG emissions associated with experimental schemes and other means of production using existing definitions in current regulations
- That, in future, the government consider amendment of the emissions cap level. OSAG conditions this recommendation when it indicates that "provided that Canada and Alberta are on track to meet their 2050 GHG emissions reductions targets (where those targets have been established in a manner that enjoys broad based support), the emissions limit should be amended by the government at that time as necessary to ensure that production from any project that has an emissions intensity better than the competing barrel in the United States market (on a wells to tank basis) is not constrained" (The Oil Sands Advisory Group, 2017b, p. 10).

OSAG also recommended that a new regulation, the Oil Sands Emission Limit Implementation Regulation (OSELIR) be enacted to assist with the management of the emissions limit. OSAG anticipates a cross regulatory agency approach for managing the oil sands emissions limit. "While OSAG expects the AER will continue to be the primary regulator for oil sands, it also believes ACCO will take on an increasing role in relation to administration of the emissions limit and advancing innovation in relation to the sector" (The Oil Sands Advisory Group, 2017b, p. 6).

OSAG did recognize that not all bitumen deposits are equal, in terms of their bitumen content and the ease of extracting such resources. AER Directive 82 was written for oil sands surface mining operations and plants. It indicates what the economic cut off is with respect to depth and bitumen quantity for a resource to be mined (Alberta Energy Regulator, 2016b).

OSAG is recommending the implementation of a similar directive for in-situ based operations so that in-situ bitumen resources that have a significantly higher GHG intensity need not be developed.

OSAG believes that their recommended approach addresses the key items provided in their mandate. The OSAG recommended approach (The Oil Sands Advisory Group, 2017b) will:

- Ensure the cap is not exceeded
- Promote investor confidence
- Promote durability across election cycles
- Promote technology development and innovation in the oil sands sector
- Be simple to implement

I have already discussed the mechanisms to ensure that the emissions cap is not exceeded. Regarding investor confidence, OSAG believes that their approach will provide clarity on emissions rules, reward industry performers with lower GHG intensities and builds a framework that lowers the likelihood of the emissions cap being reached (The Oil Sands Advisory Group, 2017b).

OSAG believes that their system has the necessary design flexibility, it achieves outcomes that are broadly supported and is one that may be more likely to withstand potential changes associated with election cycles. OSAG also believes that their next phase of work which is focusing on "opportunities to improve the overall innovation system as it relates to oil sands and the issue of funding levels and partnering opportunities to ensure a shared commitment to improvement in oil sands GHG emissions performance" (The Oil Sands Advisory Group, 2017b, p. 11) will foster reductions in GHG intensity. OSAG also believes that their framework is more easily implemented as it leverages existing processes and agencies such as the AER.

### 8.6. Path Forward for Emissions Cap

OSAG, in its development of the approach to manage the 100 megatonne emissions cap from the oil sands, has had limited engagement with external stakeholders due to the “required need for non-disclosure during the development” (The Oil Sands Advisory Group, 2017b, p. 11) of their proposals. OSAG did have some informal consultation with members of industry that are significant for future work on the emissions cap. I have provided OSAG’s listing of the results of their discussion with industry as these are material to the future development of regulations. OSAG indicated, that in their opinion, “there is broad industry support for a system that:

- Recognizes the importance of accelerating oil sands technology and innovation, and of government, industry and other interests partnering (organization, funding, technology development and deployment, etc.) in this regard to achieve desired outcomes;
- Provides for policy and regulatory measures that encourage and enable performance improvement over time, with increasing expectations in this regard if / as the emissions limit is approached.
- Is compatible with, but differentiated from, the Carbon Competitiveness Regulation and the associated carbon pricing mechanism;
- Addresses competitiveness, to ensure that carbon leadership does not have undue or unintended consequences in terms of the economic competitiveness of the oil sands industry in Alberta;
- Defines a compliance pathway that provides confidence oil sands investment and production will continue under the emissions limit;

- Leaves open the option for the government of the day to make a future decision on the use of offsets (or similar mitigation options) if and when the emissions limit is reached and for that decision to be made with a consideration for the broader policy context at the time;
- Provides the necessary assurances that the overall system is durable and that the emissions limit will not be exceeded, while allowing flexibility for the government of the day to exercise its judgement, based on the circumstances of the day, as to the best mechanism(s) to be utilized to constrain emissions at or below the emissions limit;
- Strikes the right balance between encouraging entry of new projects, with potentially better GHG intensity performance, and the interests of prior investors / incumbent capital that is subject to requirements for ongoing improvement;
- Takes the right action at the right time, within a transparent framework that provides the necessary confidence to the investment community to continue to attract investment to the oil sands (other things being equal); and
- Provides the necessary clarity for industry and the investment community as to what types of investments are more likely to be successful in this policy / regulatory regime (The Oil Sands Advisory Group, 2017b, p. 12).

The next steps that OSAG recommends are:

- Involve members of OSAG in the drafting of the related regulations
- Commence with consultation with Indigenous groups (First Nations and Metis), the public and industry

- Employ a collaborative approach – involving OSAG members and GoA officials – to address recommendations that could be seen as more sensitive or controversial.

The GoA has agreed with OSAG's recommended approach. The Alberta government said it "will review the non-binding recommendations and begin stakeholder consultations, with an aim to pass the rules into law next year" (Bickis, 2017a, para. 17).

To facilitate in the gathering of public comments on the OSAG recommendations, the GoA has recently commenced a public feedback process with the ability for interested parties to make comments on-line before August 31, 2017 (Alberta Government, 2017g).

### 8.7. Evaluation of Emissions Cap Process

While the evolution of the policy goal of implementing a 100 megatonne GHG emissions cap from the oil sands is still ongoing, some evaluation of the process to date thus far is possible.

#### 8.7.1. Positive Aspects

The OSAG, to ensure a diversity of opinions and views, included in the initial panel members from industry, Indigenous groups, NGOs and different levels of government. Employing such an approach helps to ensure that a broad multitude of perspectives were understood. OSAG included "members from industry, environmental organizations, and Indigenous and non-Indigenous communities to advise government on the oil-sands aspects of its Climate Leadership Plan and ensure that its initiatives are effective and widely supported" (Hislop, 2016, para. 4). Such an approach should improve acceptance of the proposals advocated by OSAG as the diversity of the group would limit commentary from disaffected groups that they were not consulted in the deliberations of the policy.

The OSAG panel was restricted by non-disclosure provisions during the initial development of its report. Such provisions were employed to ensure that certain companies or certain groups could obtain potential advance information that could put them in an advantageous competitive position. OSAG did conduct informal consultation with industry interests (The Oil Sands Advisory Group, 2017b). Such an informal approach did allow the advisory group the ability to understand, and to consider, the perspectives of industry on the proposed regulations. OSAG believes that “broad oil sands industry support for the proposed methodology for implementation of the emissions limit can be established, given ongoing OSAG engagement in the drafting of the regulations, adequate time for consultation and with the proviso that the broader OSAG plenary members collectively support this direction” (The Oil Sands Advisory Group, 2017b, p. 13).

To assist in development of the total framework for managing the oil sands emissions cap, OSAG has employed a staged approach. The first portion was to develop the recommendations for implementation including thoughts on the regulatory framework. The initial OSAG report talks about incentives to improve GHG intensity in the oil sands sector (The Oil Sands Advisory Group, 2017b). The details of this portion of the work were given to a second OSAG team to provide recommendation on “investment in innovation as it relates to GHG performance” (The Oil Sands Advisory Group, 2017b, p. 11). Using such an approach helped to keep the OSAG team focused on their work at hand and helped to ensure that the task was more manageable. This approach also allows for selection of different team members with different expertise at appropriate times in the process. Such a structure will allow for more focused and structured deliberation of policy implementation.

Through its initial work OSAG, where possible, employed a collaborative approach in developing its recommendations and regulations. In the initial phase, this collaboration was between the OSAG committee and limited consultation with environmental groups, communities, Indigenous groups and industry. Going forward, OSAG recommends that "there would be significant value in a small team from OSAG being engaged collaboratively by the GoA throughout the drafting process" (The Oil Sands Advisory Group, 2017b, p. 13). Such an approach was used in the development of methane regulations (discussed earlier) and having a consultative approach should result in a more rapid development of regulations and one where there is more consensus and agreement. When a consultative approach is employed there is more continual alignment on development of objectives. If OSAG developed their proposals independently without collaboration, there is a higher risk of rework.

#### 8.7.2. Negative Aspects

Development of policies that could significantly impact elements of Alberta's economy can be controversial. Vested interests can feel threatened when changes are being contemplated. While OSAG should be complimented for having panel members with a broad diversity of views, OSAG's effectiveness may have been impaired by one of its members. Tzeporah Berman was the co-chair for the initial phase of OSAG's work (Alberta Government, 2016d). Ms. Berman was previously with Greenpeace and ForestEthics (Cattaneo, 2016b; Jones, 2016) and has made some statements in the past that were seen as controversial. In previous interviews Berman has likened the oil sands to Mordor, a fictional scorched land in J.R.R. Tolkien's *Lord of the Rings*. She stated about the oil sands that "when you're there it feels a bit like Mordor. As far as the eye can see [are] mines and huge open pits that are being pumped out into areas the size of lakes" (Lamoureux, 2016, para. 7). Alberta's political opposition took specific issue with Ms. Berman's appointment stating, "appointing a co-chair to the [panel] who is vocally opposed and has made a career off of opposing our oil sands industry is deeply disappointing" (Jones, 2016, para. 9). While having a diversity of views is important, selecting a controversial panelist could, in portions of the population, reduce the credibility and objectiveness of OSAG. It may have been advisable to select a member from an NGO who was less controversial.

Another area where OSAG could strive to do improve concerns communication of its message. On June 16, 2017, there was a briefing for Technical Stakeholders held by the OSAG committee and led by David Collyer. I attended this session in person and there were less than twenty people in attendance. Mr. Collyer went through the recommendations of the panel including a discussion of what might occur as scarcity approaches. There was discussion at the briefing about how to provide "the government the option of managing Emissions Scarcity, if and when it arises, by either delaying construction of new projects and/or requiring reductions in emissions from poorer performing facilities" (The Oil Sands Advisory Group, 2017b, p. 1). Mr. Collyer emphasized how this was only an option. Media reporting that arose from the press conference held later that day seems to have lost this message about delaying construction as only an option. Comments in the media about the OSAG report included discussion of "stopping construction of new projects and constraining carbon from existing projects when carbon space runs out in the next decade" (Cattaneo, 2017c, para. 9). Further comments included that "construction of new projects would be stopped and existing projects with higher intensity would be constrained" (Cattaneo, 2017b, para. 6). Media reporting does not appear to have mentioned that these proposals were only an option. If OSAG could more effectively manage its communications, there may be increased broad based acceptance of its recommendations. The fact that there are fewer specialty journalists may be a part of the difficulty in getting the message out. Bruggemann & Engesser (2014) discuss how journalists report climate related issues. They discuss how "there is a wide periphery of journalists who write on the environment or science regularly but not very often" (Bruggemann & Engesser, 2014, p. 402). They also highlight how such journalists "might not enjoy the kind of expert status and room for maneuver attributed to the traditional science journalist" (Bruggemann & Engesser, 2014, p. 402). This is a more difficult area for OSAG to address, however trying to attract as wide a range of media coverage could assist in better getting the message across.

OSAG may encounter future issues in the development of their proposed regulations. Key among these is the tendency for some degree of self-selection that can occur in consultation activities. This was discussed earlier in the discussion of methane policy development; OSAG should ensure that consultation is broad and that there is significant use of focus groups that are selected to reflect the population as a whole rather than rely on voluntary participation.

While the OSAG report talked about means to lower GHG intensity including "amending resource conservation policy" (The Oil Sands Advisory Group, 2017b, p. 7), this does little to impact current operators with poorer quality reservoirs. What is meant by conservation policy is changing the regulatory parameters that require bitumen to be extracted. This was discussed earlier when AER Directive 82 was outlined. The concern with poorer quality reservoirs is how operators with such reservoirs can manage their current capital investment. Poorer reservoirs will require more heat input. In their annual performance report for 2015, Nexen CNOOC discussed the performance of their Long Lake asset (Nexen CNOOC, 2016). Several wellpads were found to have poor performance, these are outlined below along with the reasons for poorer performance (Nexen CNOOC, 2016):

- Pad 1 – poor performance due to operational instability
- Pad 2SE – poor performance due to poor reservoir quality and unstable operation
- Pad 5 – poor performance due to reduced steam injection pressures and operational instability
- Pad 9NE – poor performance due to poor reservoir quality and unstable operation
- Pad 10W – poor performance due to top water
- K1A-A production – poor performance due to bottom water

The literature discusses the impact of such lean zones in SAGD operations. Lean zones are ones where the water saturation is larger than 0.5 (Xu, Pan, & Chen, 2016). Reservoirs with lean zones are ones that require a higher SOR to recover bitumen. Aspects of the reservoir including the presence of top water zones, bottom water zones and "intra-formational water zones impair the efficiency of the SAGD process" (Xu et al., 2016, p. 1). The work of OSAG has not yet addressed, in detail, the impact of reservoir quality on GHG intensity and how this would be addressed in regulations.

A key aspect of the recommendations from OSAG is the implementation of emissions forecasting (The Oil Sands Advisory Group, 2017b). The forecasting component is key to addressing the predictive nature of actions contemplated by OSAG, in particular those as emissions approach scarcity. For such GHG forecasting to be credible and reliable, protocols will need to be established to ensure that the monitoring of current operational performance, a key input for forecasting, are accurate and feasible to gather. The GoA has recently modified the Air Monitoring Directive (AMD) (Alberta Government, 2016a), however the Continuous Emissions Monitoring System (CEMS) Code currently in force is still from 1998 (Alberta Government, 1998). All such documentation that concerns the measurement of GHGs, such as the AMD and CEMS, needs to align with the objectives that OSLIR is trying to achieve.

# Chapter Nine: Differences in Energy Use (SAGD)

## 9.1. Introduction and Methodology

To understand the basic energy intensity associated with SAGD production, a simplified model was developed to understand the energy input differences associated with basic SAGD operations versus those employing solvent assist. A capacity of 30,000 bbl/d was used as this aligns with study work conducted by CERI (Nduagu et al., 2017). Two solvent aided processes were used in the basic modeling work conducted, the Cenovus SAP process and the Imperial Oil SA-SAGD process. The modeling was done using the AspenHYSYS (Version 8.6) process simulator. A saturated steam pressure of 10,000 kPag was used in the analysis with the inlet water assumed to be at 50 ºC. Such a water temperature is typical for SAGD operations after water treatment activities have been completed.

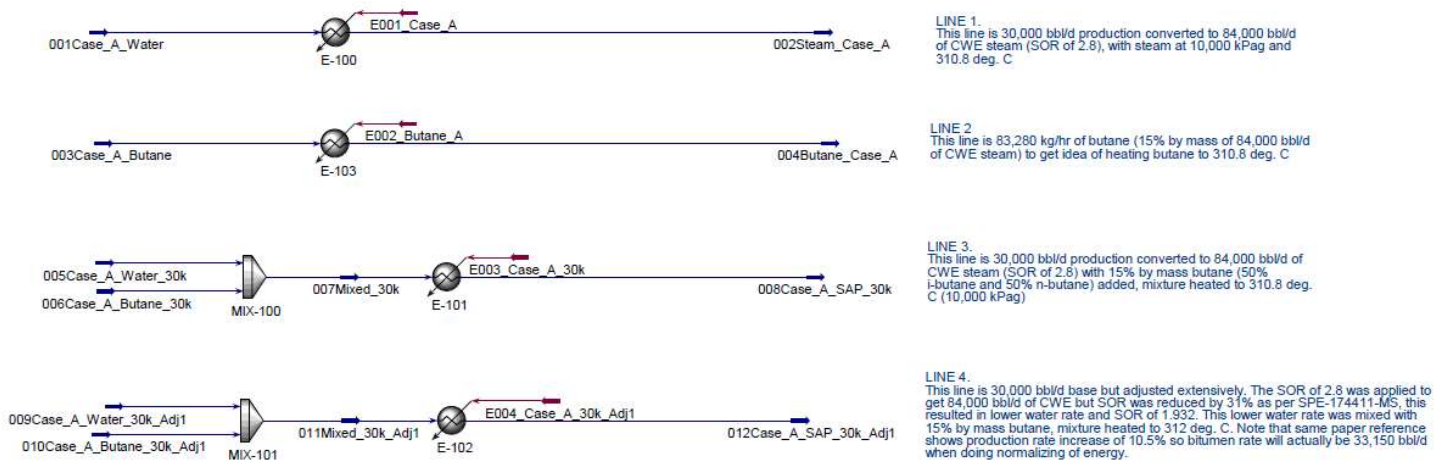
Work done at Christina Lake by Cenovus was used as a basis for an SOR of 2.8 in the aspects of the evaluation (Gupta & Gittins, 2006; Gupta, Gittins, Benzvi, & Dragani, 2015) concerning the SAP process. The pilot work done on the impacts of well spacing showed a "rate uplift of 10.5% and a SOR reduction of 31%" (Gupta et al., 2015, p. 10). The solvent for the SAP process was assumed to be an equal mixture of i-butane and n-butane. The butane was mixed with the steam at fifteen percent by mass.

Information from work presented in the literature on Imperial Oil's SA-SAGD process was also used in the development of a simplified model. Solvent composition was obtained through inspection of data provided on Diluent 3 (Khaledi et al., 2015). Data on the SA-SAGD pilot for February 2011, May 2011 and August 2011 was used for the solvent rates, steam injection rates and associated production rates (Dittaro et al., 2013). The basis for solvent injection in SA-SAGD is about 20% by volume (Dittaro et al., 2013), however for the basic simulation of SA-SAGD, the actual rates from 2011 were utilized.

### 9.2. Simulation Development and Results

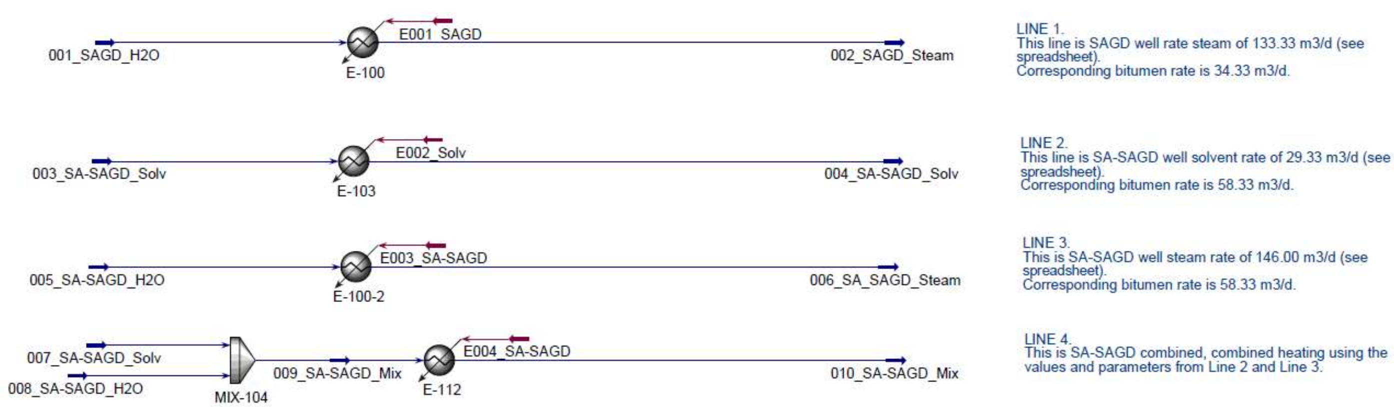
The PFDs for the SAP based basic model and the SA-SAGD based basic model can be found in Figure 8 and Figure 9.

**Figure 8 – SAP Based Basic Model**




(Source: Author)

**Figure 9 – SA-SAGD Based Basic Model**




(Source: Author)

These simulations were used to find theoretical energy input differences for heating the water from 50 ºC to 310.8 ºC (to create saturated steam) and for heating a combined water and hydrocarbon mixture to the same conditions. The results of the basic model can be found in Table 1. There was a good match between the two different theoretical methods. The SAP model showed a reduction in theoretical energy input of 34% while the SA-SAGD model showed a reduction in theoretical energy input of 32%.

**Table 1 – Theoretical Energy Differences – Basic Model**

| **Basic Model** | **Case** | **Prod Rate** | **Units** | **Prod** | **Units** | **Prod** | **Units** | **Theo Energy** | **Units** | **Theo. Energy per Unit Prod.** | **Units** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SAP | SAGD | 30,000 | bbl/d | 4769.6 | $m^3/d$ | 198.73 | $m^3/hr$ | 1463 | GJ/hr | 7.36 | $GJ/m^3$ |
| SAP | SAP-SAGD | 33,150 | bbl/d | 5270.4 | $m^3/d$ | 219.60 | $m^3/hr$ | 1068 | GJ/hr | 4.86 | $GJ/m^3$ |
| SA-SAGD | SAGD | 215.9 | bbl/d | 34.3 | $m^3/d$ | 1.43 | $m^3/hr$ | 14.6 | GJ/hr | 10.21 | $GJ/m^3$ |
| SA-SAGD | SA-SAGD | 366.9 | bbl/d | 58.3 | $m^3/d$ | 2.43 | $m^3/hr$ | 16.8 | GJ/hr | 6.91 | $GJ/m^3$ |

(Source: Author)

### 9.3. Discussion

The simplified model simulation does not consider elements such as thermal efficiency. Thermal efficiency is defined as "the efficiency of a heat engine measured by the ratio of the work done by it to the heat supplied to it"(Oxford Living Dictionaries, n.d., para. 1). For an OTSG or an HRSG, a parameter impacting thermal efficiency is stack temperature. Thermal efficiency for a steam generator ranges between about 56% at a stack temperature of 1500 ºF to about 88% at a stack temperature of 500 ºF (Fanaritis & Kimmell, 1965). Recent installations of a OTSG system show a stack temperature of 841 ºF (Innovative Steam Technologies, 2001), which corresponds to an efficiency of about 77% (Fanaritis & Kimmell, 1965). Another evaluation of a different recovery process, the SAS process, assumed a thermal efficiency of 76% (Zhao, 2007).

Based on the review of the literature, the theoretical energy per unit of production, from Table 1, should be divided by a thermal efficiency. For this evaluation of energy performance, a thermal efficiency of 76% will be employed. The relative improvements in efficiency are unchanged, but applying the thermal efficiency gives a better idea of the anticipated energy input. Table 2 illustrates the energy performance when thermal efficiency is considered.

**Table 2 – Energy Performance Considering Thermal Efficiency**

| Scenario | Theoretical Energy per unit of production ($GJ/m^3$) | Thermal Efficiency | Actual Energy per unit of production ($GJ/m^3$) |
|---|---|---|---|
| SAP Information - SAGD Operation | 7.36 | 77% | 9.56 |
| SAP Information - SAP-SAGD Operation | 4.86 | 77% | 6.32 |
| SA-SAGD Information - SAGD Operation | 10.21 | 77% | 13.26 |
| SA-SAGD Information - SA-SAGD Operation | 6.91 | 77% | 8.98 |

| | |
|---|---|
| SAP Process - Improvement in Efficiency: | 34% |
| SA-SAGD Process - Improvement in Efficiency: | 32% |

(Source: Author)

The lower energy intensity should be expected for two reasons. The first reason is that the heated solvent further enhances the viscosity reduction that is associated with conventional SAGD. The reasons why solvent addition offers improvement over conventional SAGD were discussed in an evaluation by Laricina Energy. “In general, solvent vapour accumulates ahead of the steam front, where it mobilizes and drains oil from regions that may be considerably cooler than the steam zone. Thus, the average temperature of the drained volume is much less than for the same recovery by steam, accounting for the SOR improvement. The oil rate increase is qualitatively explained by lower oil-phase viscosities in the drainage zone” (Edmunds, Moini, & Peterson, 2009, p. 34).

The other reason, which is less significant, concerns the thermodynamic properties of water versus components of solvents. While water has a lower heat capacity than the hydrocarbons being considered for solvent injection, the latent heat of vapourization of water is lower than the lighter chain hydrocarbons that are significant constituents of the solvent mixtures. In the case of the SA-SAGD solvent, there are heavier components with higher latent heats of vapourization. For the proposed SA-SAGD solvent, 78 mole percent of the solvent is decane or a lighter hydrocarbon. The latent heat of vapourization of decane is roughly equivalent to water with lighter hydrocarbons being even lower. This helps to explain why a lower amount of energy is needed. This is summarized in Table 3 with data from the NIST Chemistry WebBook (National Institute of Standards and Technology, 2017)

**Table 3 - Heat Capacities and Heats of Vapourization**

| Substance | Heat Capacity {J / (mol K)} | Heat of Vapourization {kJ/mol} |
|---|---|---|
| butane | 132.4 | 23.2 |
| hexane | 195.0 | 29.4 |
| heptane | 224.7 | 36.1 |
| octane | 254.1 | 41.2 |
| nonane | 293.2 | 42.7 |
| decane | 315.5 | 42.5 |
| undecane | 342.7 | 54.5 |
| dodecane | 376.1 | 61.8 |
| tridecane | 409.4 | 62.4 |
| tetradecane | 434.0 | 64.1 |
| pentadecane | 468.8 | 66.4 |
| hexadecane | 495.7 | 68.5 |
| heptadecane | 534.3 | 71.6 |
| octadecane | 568.0 | 74.4 |
| water | 75.2 | 40.8 |

(Source: Author)

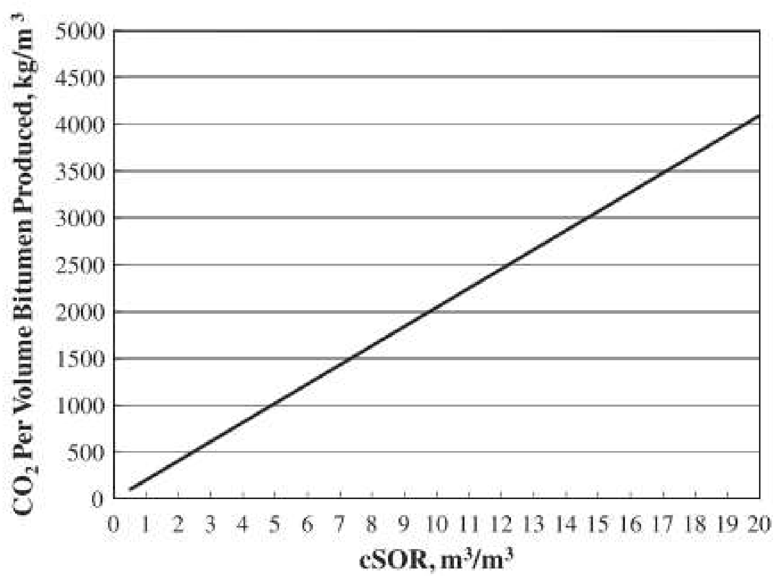
## Chapter Ten: Energy & Emissions Intensity

### 10.1. Reporting of SAGD Emissions Intensity

#### 10.1.1. Academic Findings

Given the increased concern about GHG emissions, there has been extensive research on the energy and emissions intensity associated with SAGD. As the SOR increases, the carbon dioxide associated with each unit of production increases. This makes sense as more steam is needed to liberate the bitumen and to generate more steam, more combustion of natural gas is required. This combustion releases more GHGs. On this basis SOR is directly related to energy intensity. A depiction of cSOR (cumulative steam oil ratio) for conventional SAGD (i.e. without the addition of solvent) at 2100 kPag and a thermal efficiency of 75% was developed. This can be seen in Figure 10.

**Figure 10 - Emitted $CO_2$ versus SOR**




Mass of emitted carbon dioxide-to-oil ratio versus cSOR (100% steam quality generated with efficiency of the steam generator equal to 0.75) from steam-based recovery process operating at 2100 kPa.

(Gates & Larter, 2014, p. 712)

The relationship between SOR and GHG emissions in Figure 10 is linear which is expected as there is a direct relationship between SOR and emissions.

Other research has involved an approach of consultation with experts in the bitumen extraction field to obtain their thoughts on what the future may hold with respect to GHG intensities. The results of this research point to an in-situ future where there is general agreement that there is a high likelihood of some degree of reduction in emissions intensity (McKellar, Sleep, Bergerson, & MacLean, 2017). “There may be some scope for policy makers to provide incentives to producers to pursue GHG-reducing approaches, but many technology choices are driven by reservoir characteristics along with economic and environmental considerations” (McKellar et al., 2017, p. 167). Earlier discussion of the evaluation of the work of OSAG to date discussed how the initial recommendations only are concerned with the impacts of resource quality at a high level. Further detail should be pursued by OSAG in this area – the impact of reservoir quality – to ensure that emissions intensity tries to address resource differences. The application of technology has been beneficial to reducing GHG intensity in the past. From 1990 to 2015, the GHG emissions per barrel of oil produced have decreased by 39% through the application of research and new technologies (Poveda, 2015).

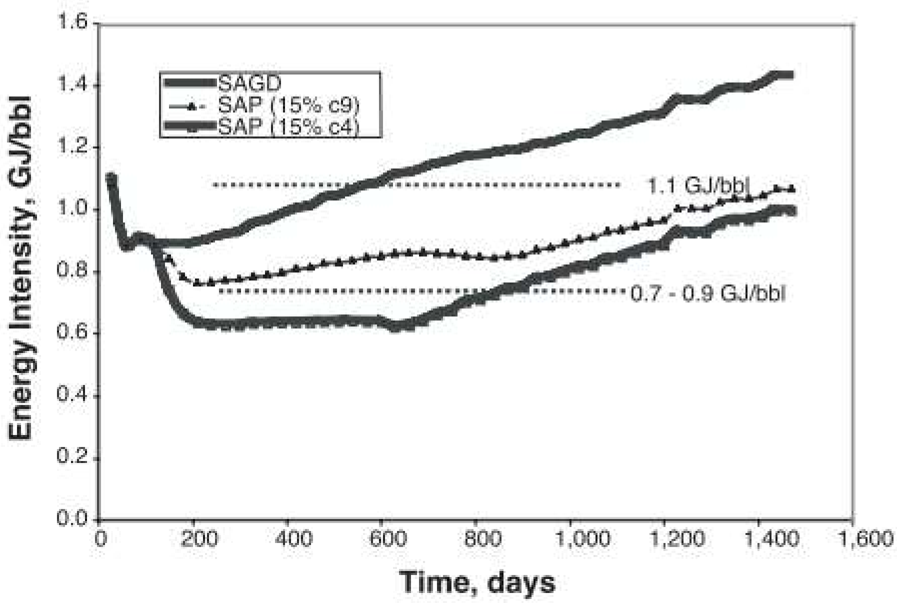
The impacts of reservoir quality, particularly for thinner reservoirs, can significantly impact reservoir intensity. The concept of cumulative energy injected to cumulative oil production was used as an indicator (Zhao, Wang, & Gates, 2014), this ratio was noted as cEOR. To correlate, a cEOR of 10 $GJ/m^3$ corresponds to an SOR of about four. For a thin reservoir under consideration the cEOR rose from 10 $GJ/m^3$ to 20 $GJ/m^3$ in one year. “It was found that 40% of heat injected was lost to the over and underburden during the first year" (Zhao et al., 2014, p. 436). Such reservoirs may need special consideration under GHG intensity comparison schemes or the exploitation of such resources may need to be reconsidered until technology further develops. It should be noted however that even for thinner, poorer quality reservoirs, the use of solvent can assist in energy intensity. At the end of an eight year simulation, the SOR for a simulated ES-SAGD process was about one while for conventional SAGD, the SOR was 2.24 (Gates, 2010).

Another solvent aided process where research has occurred is the SAS process. For this process, the energy intensity was reduced to 7.19 $GJ/m^3$ compared to 8.73 $GJ/m^3$ for conventional SAGD. If there is production of the retained solvent at the end of the reservoir production, in effect this production practice maximizes the recovery of solvent, the energy intensity is further reduced to 5.81 $GJ/m^3$ (Zhao, 2007). The academic research into solvent aided processes show that these processes offer a significant reduction in energy intensity. The advantage of the solvent assisted processes is that these processes, while not in use commercially, have had more extensive pilot application (through work done by Cenovus and Imperial Oil) than other technologies.

#### 10.1.2. Industry Findings

There is information in the literature concerning the solvent assisted work conducted by Cenovus on their SAP process and by Imperial Oil on their SA-SAGD process. The findings from industry also align with those from academia; the solvent assisted processes show significant improvements in energy intensity. For work done by EnCana (predecessor of Cenovus), the concept of energy intensity was used to compare SAP to SAGD. The energy intensities of SAP were lower than that for SAGD (Gupta et al., 2003). SAP intensity ranged between 0.7 to 0.9 GJ/bbl while conventional SAGD required 1.1 GJ/bbl. The SAP work also compared the effectiveness of butane versus nonane as a solvent (Gupta et al., 2003). Butane had a lower energy intensity, this can partially be explained by the lower latent heat of vapourization for butane than for nonane. This lower heat of vapourization equates to a lower energy input. This is depicted in a figure from the work done by Gupta et al (2003), see Figure 11.

**Figure 11 – Energy Intensities for SAP & SAGD**

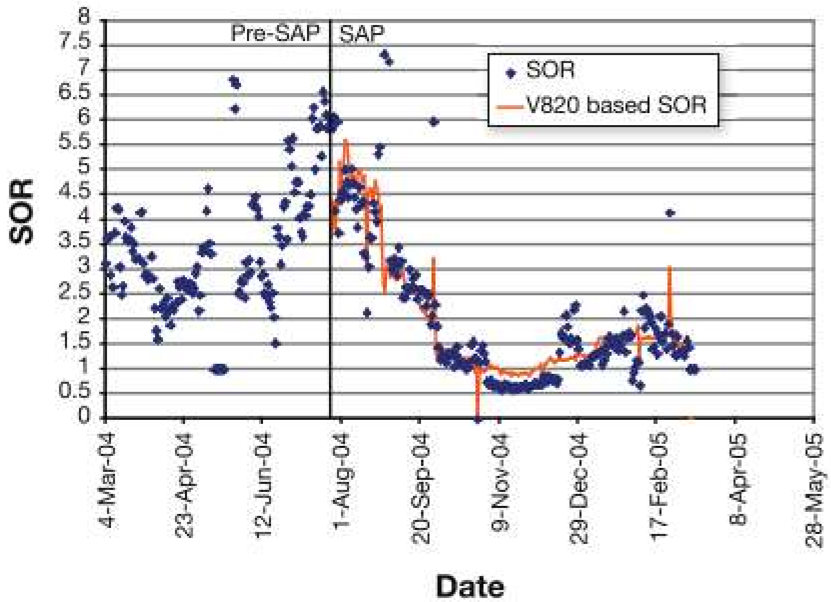



**Comparison of energy intensities for 15% solvent injection SAP with SAGD.**

(Gupta et al., 2003, p. 57)

Other research on the SAP technology shows a dramatic lowering of the SOR after solvent was introduced at the Christina Lake pilot site (Gupta & Gittins, 2006). There is scatter in the results, but the SOR with SAP was lower than two while pre-SAP results were typically higher than 3.5. This can be seen in Figure 12.

**Figure 12 – SOR for SAP Pilot**



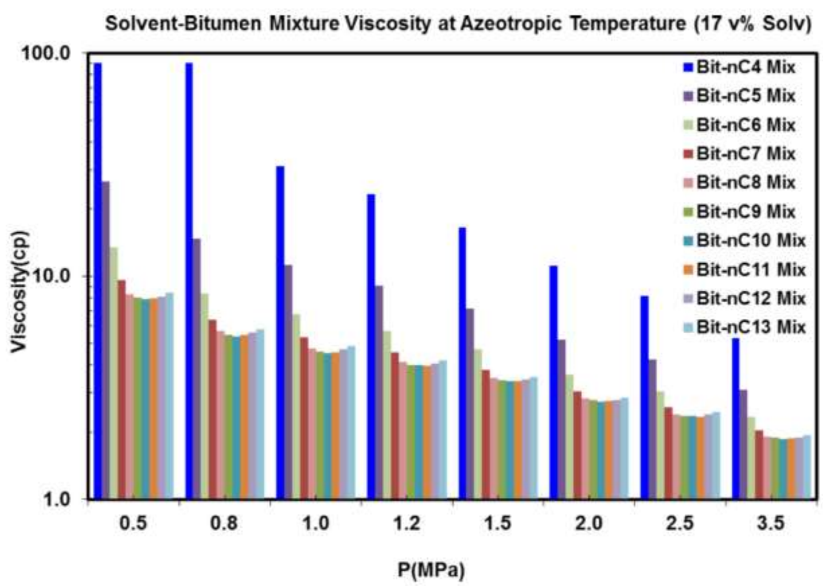

**Steam-oil ratio from the test well pair at Christina Lake SAP pilot.**

(Gupta & Gittins, 2006, p. 17)

Cenovus took their research of SAP further to evaluate the potential to use wider well spacing (Gupta et al., 2015). Wider well spacing results in lower capital cost due to the reduction in the number of wells required to be drilled to access the resource. Depending upon the well configuration, the surface disturbance may be able to be reduced as well. The extent of the reduction of surface disturbance will depend upon whether the increased well spacing can also result in a reduction in the number of wellpads required. The pre-SAP production in the pilot had an average SOR of 2.37 with an average production of 785 bbl/d. With SAP, the SOR averaged 1.66 with an oil rate of 880 bbl/d (Gupta et al., 2015). Significant improvements in intensity occur with SAP as the “rate enhancement during SAP period is of the order of 65% and similarly an improvement on cSOR (after about six years of operation) of the order of 35%” (Gupta et al., 2015, p. 18). Another key finding of this work was how SAP allowed for a larger well spacing and that this larger well spacing did not result in increased SOR.

The results of the Imperial Oil SA-SAGD process have also been discussed (Khaledi et al., 2015). Earlier there was discussion of how the SOR was reduced due to the lower latent heat of vapourization of solvent, in particular that used for SAP. The SA-SAGD process typically uses a higher molecular weight solvent. The advantage of this solvent is that despite the higher latent heat of vapourization, the resulting viscosity of the bitumen and solvent mixture is lower, which promotes flow to the wellbore. This can be seen in Figure 13 (Khaledi et al., 2015).

**Figure 13 - Bitumen - Solvent Mixture Viscosity**



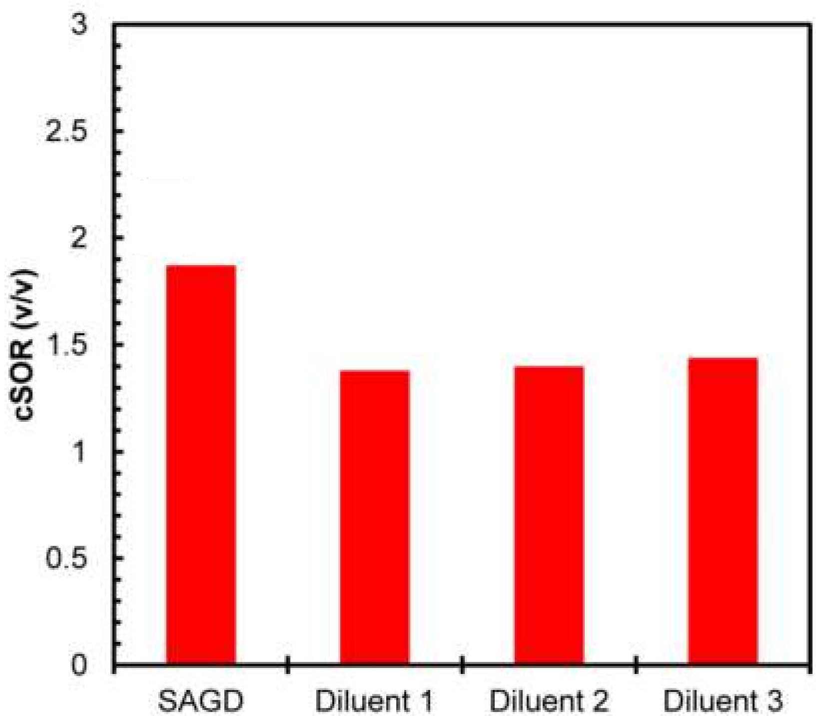
bitumen-solvent mixture viscosity at corresponding solvent-steam azeotropic temperature at different pressures.

(Khaledi et al., 2015, p. 9)

The work by Imperial Oil also included simulation of expected cSOR with three different solvents; Diluent 1, Diluent 2 and Diluent 3. Diluent 1 is lighter with a larger quantity of C5 components with some C3 and C4. Diluent 2 is a heavier mixture with a low quantity of butanes and relatively equal amounts of C5 to C8 components while

Diluent 3 is rich in C7 to C9 components. Diluent 3 performed the best in the SA-SAGD analysis (Khaledi et al., 2015). The cSOR for all the different diluent cases is lower than that for conventional SAGD which will then result in reduced emissions intensity as seen in Figure 14.

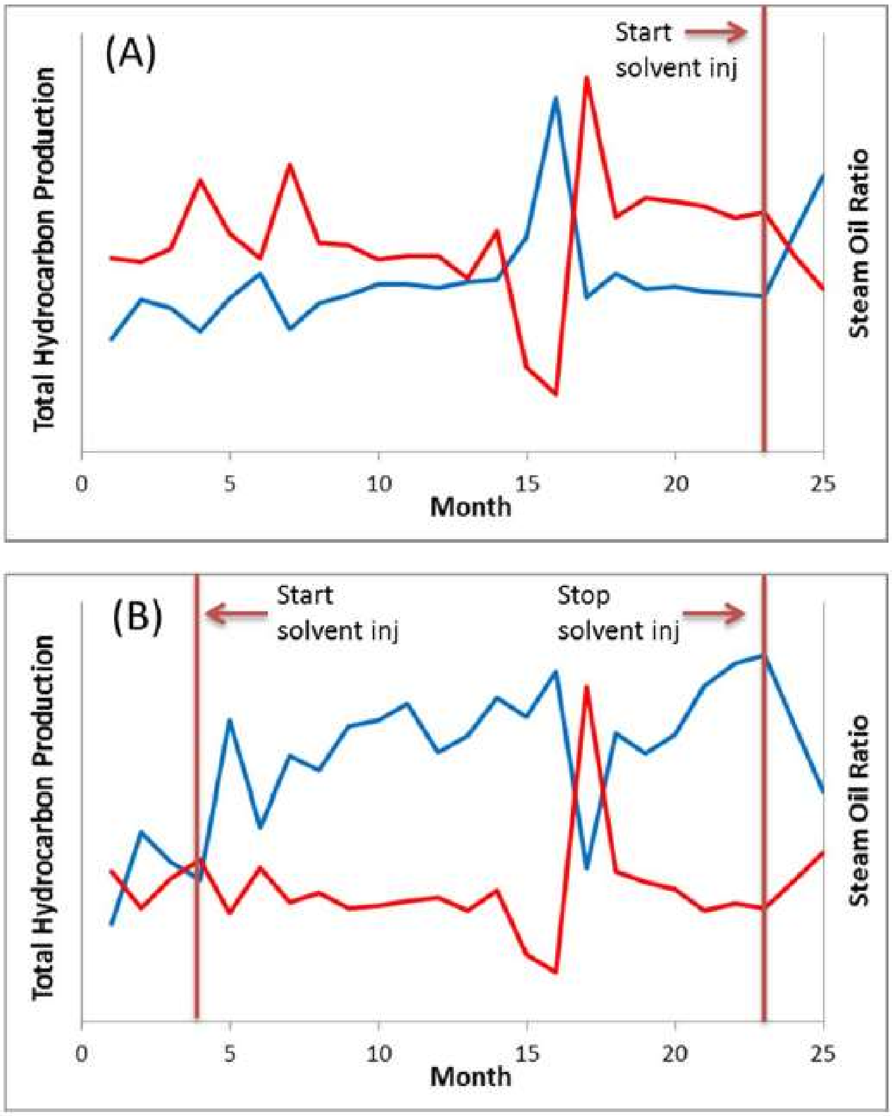
**Figure 14 - SA-SAGD cSOR at 800 kPag**




(Khaledi et al., 2015, p. 21)

The impact of solvent injection on production associated with SA-SAGD is significant. In Figure 15, the hydrocarbon rate is shown as a blue line and the instantaneous SOR is a red line (Dickson et al., 2013). With the injection of solvent, there is an increase in production and a decrease in SOR. This is more so for well pair 1 in the Imperial Oil work. Well pair 2 in this study does show a significant decrease in hydrocarbon production after solvent injection is halted, but the results with solvent injection are less clear. This may have been due to operational issues at the start of the pilot work.

**Figure 15 - SA-SAGD Performance**




Total hydrocarbon production rate (blue curve) and instantaneous SOR (red curve) for well pair 1 (A) and well pair 2 (B).

(Dickson et al., 2013, p. 10)

## 10.2. Third Party Research

Independent third-party agencies have conducted research related to emissions intensity of the oil sands. This work has been focused on the potential impacts of the 100 megatonne cap on oil sands production. The impacts are dependent upon the scenarios considered and assumptions employed.

### 10.2.1. CERI

The Canadian Energy Research Institute (CERI) has conducted extensive research on the oil sands sector in Alberta. A study conducted by CERI in 2015, prior to the work of OSAG (i.e. prior to the 100 megatonne cap), looked at GHG intensities for oil sands production in several different scenarios (Murillo, 2015). These scenarios included:

- Business as usual
- Constrained growth
- Increasing energy efficiency
- Declining reservoir quality
- Electric heating technologies

For current SAGD operations, CERI showed a thermal energy intensity for SAGD that ranged from 0.50 GJ/bbl to 2.20 GJ/bbl with a median value of 1.18 GJ/bbl (Murillo, 2015). The forecasting at the time showed the GHG levels from oil sands rising to about 100 megatonnes per year by 2020 (Murillo, 2015). Since 2015, there has been a reduction in activity in the sector and this forecast may need to be re-evaluated. Without any constraints, CERI predicted peak oil sands GHG emissions of about 130 megatonnes per year in 2031. The work by CERI also predicted GHG intensities by type of project. For the work by CERI, some assumptions were made concerning the timeframe over which energy efficiency would arise as well as the timeframe where poorer reservoirs would end up being produced. The 2015 work by CERI did not address the application of technology specifically, however it indicated that the decreasing emissions intensity scenario was generally aligned with solvent based processes. A limitation of the approach employed by Murillo (2015) is that there was some application of an increased energy intensity. This was due to the production of poorer quality reservoirs and seemed to be introduced at a somewhat arbitrary starting time and evolved over an assumed timeframe. Recognizing these limitations, some summary values are presented in Table 4.

**Table 4 - GHG Intensities for Different Scenarios (CERI)**

| Scenario | Intensity (kg $CO_2$/bbl) - In-Situ | Intensity (kg $CO_2$/bbl) - Mining | Intensity (kg $CO_2$/bbl) - Upgrading | Year for Comparison |
|---|---|---|---|---|
| Business as Usual | 68 | 38 | 58 | 2020 |
| Increased Energy Efficiency | 36 | 10 | 36 | 2040 |
| Decreasing Reservoir Quality | 130 | 60 | 115 | 2045 |
| Electric Heating Scenario | 74 | 38 | 62 | 2030 |

(Murillo, 2015)

These show the differences in intensity from the CERI work based on the different scenarios. Note that in Table 4 the years of each value do not correspond. The reason for this is that the comparison in Table 4 is meant to show the extent of difference in intensity once the scenario reaches steady-state.

More recent work by CERI projects that if current approaches to bitumen extraction are maintained, the 100 megatonne emissions cap will be reached by 2028 (Nduagu et al., 2017). In this work, the impact of the deployment of different types of greenfield and brownfield technologies are assessed. CERI concludes that if any of these technological approaches are employed that the 100 megatonne emissions cap would not be reached during the timeframe covered by their study (Nduagu et al., 2017). The GHG emissions for six different approaches for in-situ production were evaluated by CERI. These include (Nduagu et al., 2017):

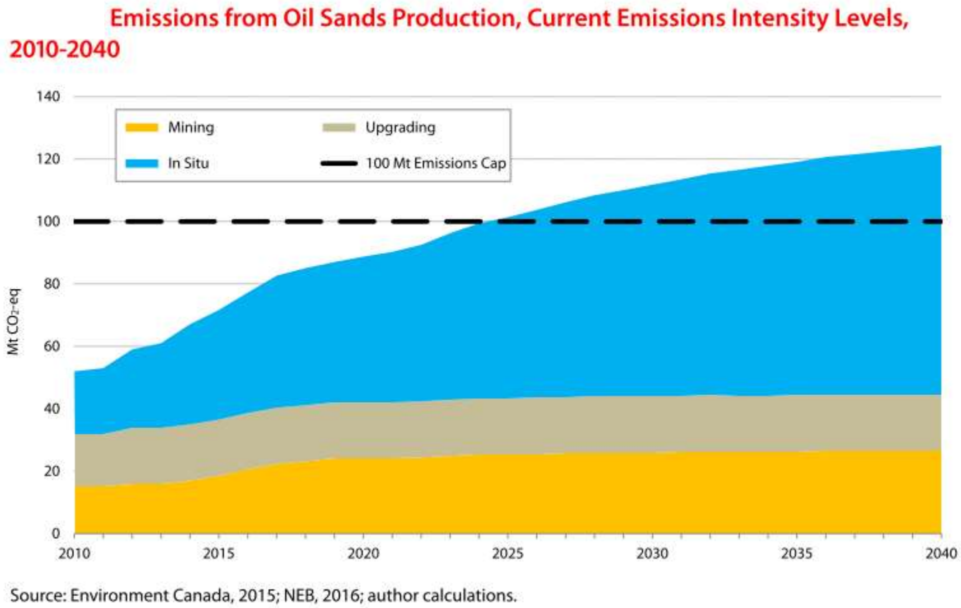
- Base case SAGD; CERI assumed a GHG intensity of 60.4 kg $CO2_{eq}$/bbl
- Pure solvent processes; could result in a 75 to 80% reduction in GHG intensity
- Steam-solvent processes (SAP, SA-SAGD); could result in 15 to 20% reduction in GHG intensity
- ESEIEH type processes; could result in 45 to 60% reduction in GHG intensity
- Chemical additives (i.e. surfactants); could result in 10 to 15% reduction in GHG intensity
- In-situ extraction techniques; could result in GHG intensity between 0 and 10 kg $CO2_{eq}$/bbl

### 10.2.2. Fraser Institute

The Fraser Institute also evaluated the potential impacts of the 100 megatonne emissions cap (Green & Jackson, 2016). Their analysis used two different approaches, one where current emissions intensities are maintained and there is no improvement in in-situ technology. While such an approach could address some of the concerns of declining reservoir quality, it may not be realistic given how Canada's oil sands sector has been able to innovate historically and improve operational performance. Figure 16 shows the anticipated GHG emissions forecast if current emission intensities are maintained (Green & Jackson, 2016).

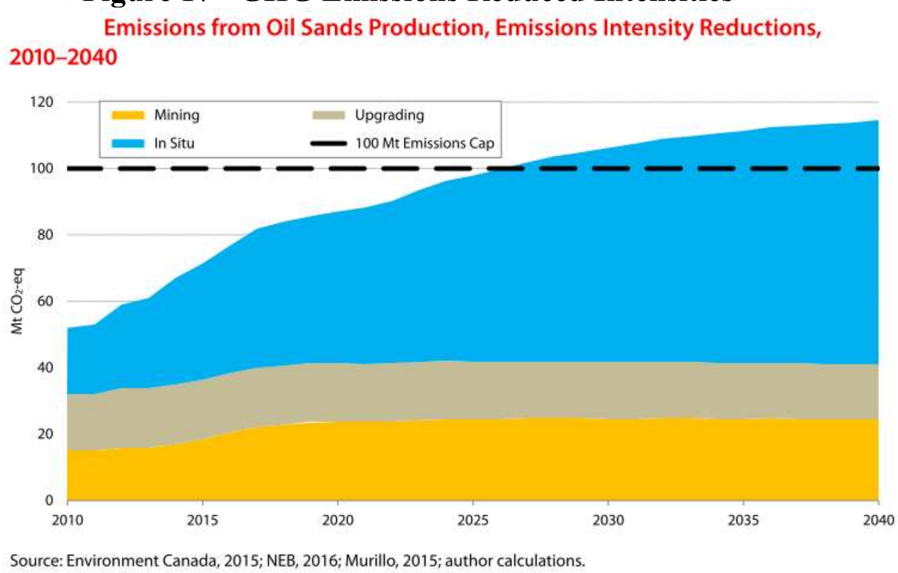
The Fraser Institute research recognizes that some technological improvements will likely occur and that GHG emissions intensity will likely decrease over time. The limitation of the Fraser Institute's analysis in this regard is that they have based some of their analysis on work from CERI that was previously discussed (Murillo, 2015). The Fraser Institute analysis for reduced emissions intensity believes that the Business as Usual case outlined by CERI (Murillo, 2015) is the most suitable means of predicting reductions in intensity. This is a more conservative analysis and does not address the technological advancements discussed by CERI including the increased energy efficiency case (Murillo, 2015) or the other technological pathways that could be employed (Nduagu et al., 2017). Using such an approach shows that the 100 megatonne cap would be reached, however not until about 2027 (Green & Jackson, 2016). This can be seen in Figure 17.

**Figure 16 - GHG Emissions Current Intensities**




(Green & Jackson, 2016, p. 8)

**Figure 17 - GHG Emissions Reduced Intensities**




(Green & Jackson, 2016, p. 10)

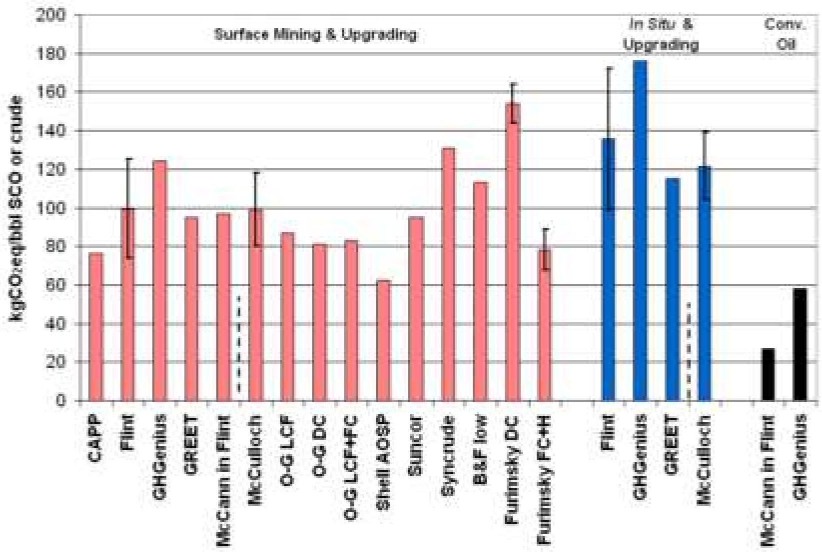
## Chapter Eleven: Comparison with Other Crudes

### 11.1. Background and LCA Analysis

Due to the interest in GHG emissions from the oil sands and from crude oils in general, there has been investigation of the emissions intensities from different crude oils. One tool used to assist in this evaluation is use of Life Cycle Assessment (LCA). "LCA studies the environmental aspects and potential impacts throughout a product's life (i.e. cradle-to-grave) from raw material acquisition through production use and disposal. The general categories of environmental impacts needing consideration include resource use, human health and ecological consequences" (Klopffer & Grahl, 2014, p. 1). LCAs are highly dependent upon the data that is available for comparison as well as the functional unit employed. The functional unit is the basis used for comparison for LCA and for crude oils could be a barrel of crude oil or it could be per megajoule of energy content. The scope of the LCA is also important for comparative purposes; some GHG emissions LCAs for crude oil cover the range from 'wells to wheels' which is the full profile from resource extraction of the crude oil to combustion in an individual automobile while others cover the range from 'wells to tank' which excludes the end use in an automobile.

For investigation of emissions from the oil sands, information is available but must be used with some caution due to the various sources and completeness of the data. One evaluation found that, for the oil sands, the data "did not include all life cycle stages and that in some cases it is not clear which stages have been included" (Charpentier, Bergerson, & MacLean, 2009, p. 5). This uncertainty is illustrated in Figure 18. The information in Figure 18 make reference to terms and information that can be found in the List of Abbreviations and in literature references (Flint, 2004; Furimsky, 2003; McCann & Magee, 1999; McCulloch, 2006). What is key to note from the work by Charpentier, Bergerson and MacLean (2009) is that there is some uncertainty in GHG emissions predictions associated with the Canadian Oil Sands depending upon the methodology used and the source data employed.

**Figure 18 - $CO_{2eq}$ Emissions in Canadian Oil Sands**




(Charpentier et al., 2009, p. 6)

Figure 18 shows that there is some uncertainty in predictions of the GHG emissions intensity for production based from the oil sands. Even with this uncertainty in data, which also arises for crude oils not based on oil sands, the use of the emissions intensity tool is still useful as a guide to look at the relative differences between different crude oil sources.

Since the work by Charpentier et al (2009), there has been further development of tools and information to help understand the relative emissions intensity of different sources of crude oil. The Carnegie Endowment has developed an Oil Climate Index (OCI). The OCI helps to provide an understanding of the emissions intensity from the upstream, midstream and downstream components of oil and gas production. The OCI is based on three databases that use public source data, these are (Gordon, Brandt, Bergerson, & Koomey, 2015):

- OPGEE (Oil Production Greenhouse Gas Emissions Estimator); this is for upstream emissions covering the production phase up to delivery to the refinery
- PRELIM (Petroleum Refinery Life-Cycle Inventory Model); for evaluation of emissions from refining
- OPEM (Oil Products Emissions Module); for emissions from transport and end use of crude oil products

Data from the OCI was used to further understand the emissions profile of various crude oils and how the oil sands compares to other crude oils. This is discussed in Section 11.2.

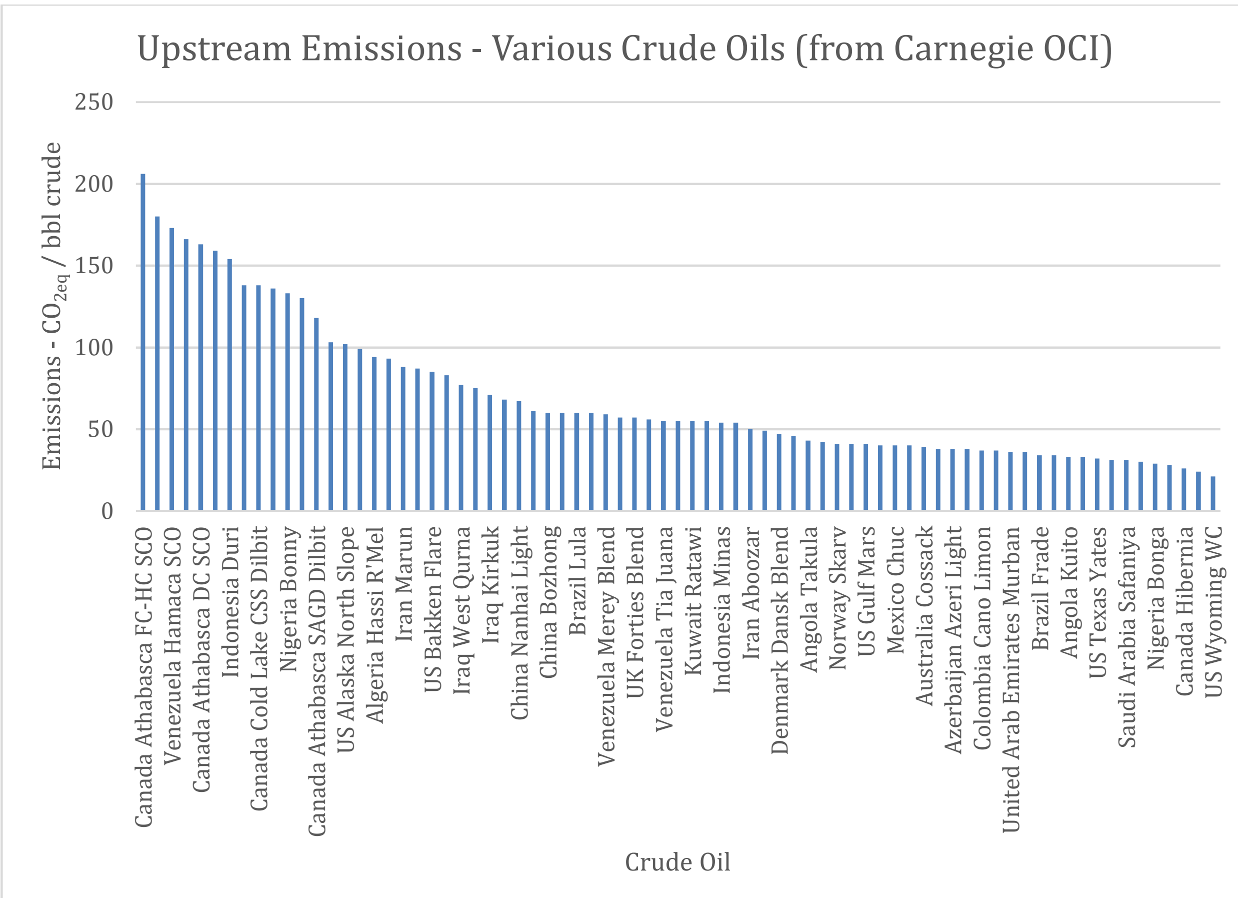
## 11.2. Comparison of Crudes

### 11.2.1. Upstream Emissions

Various crudes were compared using the OCI data discussed previously. The focus of this portion of the discussion is on upstream emissions intensities for oil sands production. Because of this, only the upstream component of data was used for understanding emissions as shown in Figure 19. In this analysis, the upstream GHG emissions from oil sands were higher than other crudes. For oil sands production that was upgraded on site, the upstream emissions intensity was 206 kg $CO_{2eq}$/bbl crude (this is for Athabasca FC-HC SCO) and diluted bitumen from SAGD was 118 kg $CO_{2eq}$/bbl crude. Other crudes, particularly conventional crude oil production, have lower upstream emissions. North Sea crudes, such as the Forties blend have emissions of 57 kg $CO_{2eq}$/bbl crude and Arabian crudes have emissions levels around 34 kg $CO_{2eq}$/bbl (Saudi Arabia Ghawar).

With this approach, the data indicates that the upstream component of oil sands emissions is significantly different than other crudes, and could be seen to put oil sands production at a more competitive disadvantage if the basis for comparison is on a carbon intensity basis. To fully understand this however, overall emissions need to be understood. All crude oils need to be refined to make them more useable products.

**Figure 19 - Upstream GHG Intensities for Different Crudes**




(Carnegie Endowment, 2017)

### 11.2.2. Total Emissions

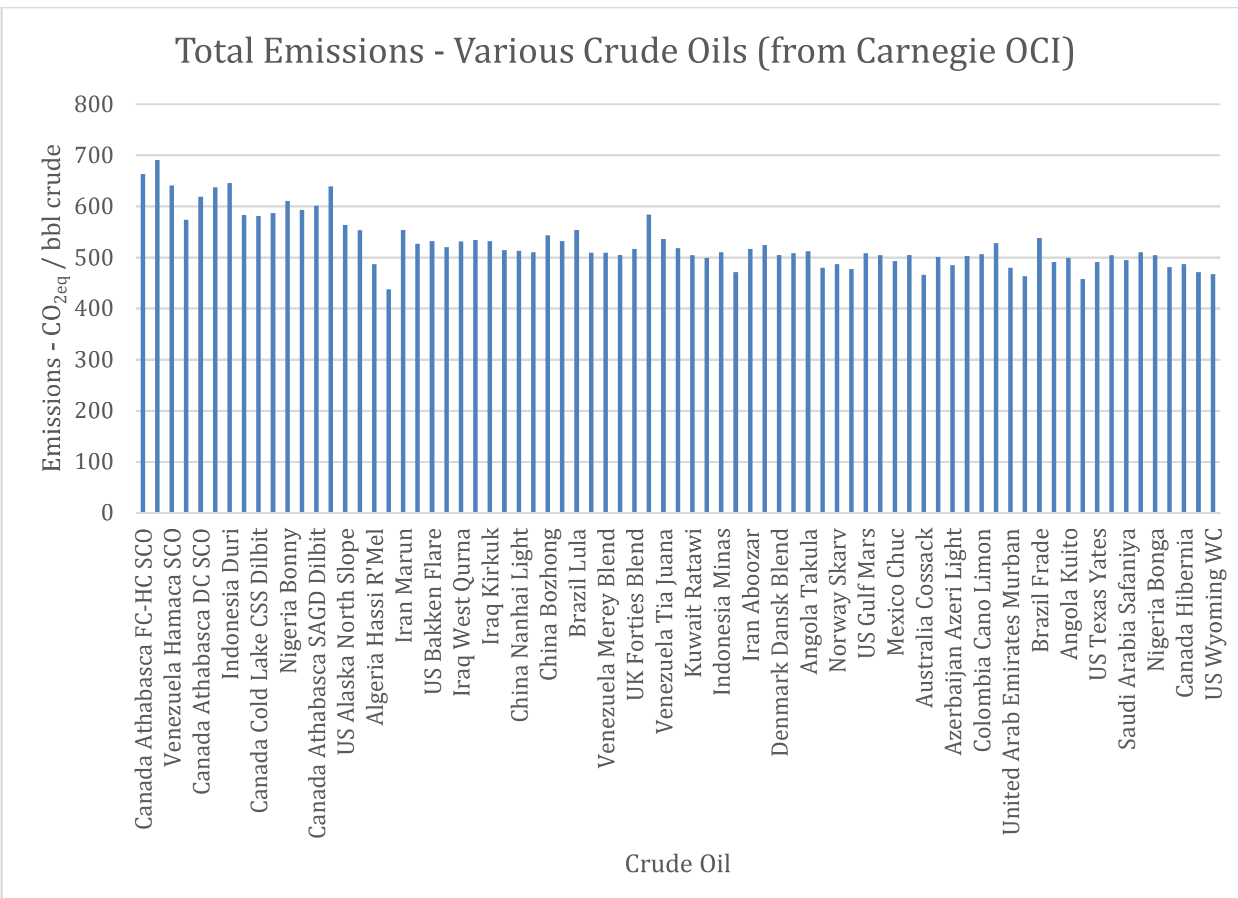
When total GHG emissions, from the production phase through to refining are tabulated, the oil sands based production has a more favourable overall ranking for GHG intensity as seen in Figure 20. Highlighting the same crudes as discussed earlier, the results do show higher intensities for oil sands based production, but with a less marked difference as shown in Table 5.

**Table 5 - Upstream and Total GHG Intensities - Selected Crudes**

| Crude | Upstream kg $CO_{2eq}$/bbl crude | Total kg $CO_{2eq}$/bbl crude |
|---|---|---|
| Canada Athabasca FC-HC SCO | 206 | 663 |
| Canada Athabasca SAGD Dilbit | 118 | 601 |
| UK Forties Blend | 57 | 517 |
| Saudi Arabia Ghawar | 34 | 491 |

(Carnegie Endowment, 2017)

**Figure 20 - Total GHG Intensities for Different Crudes**

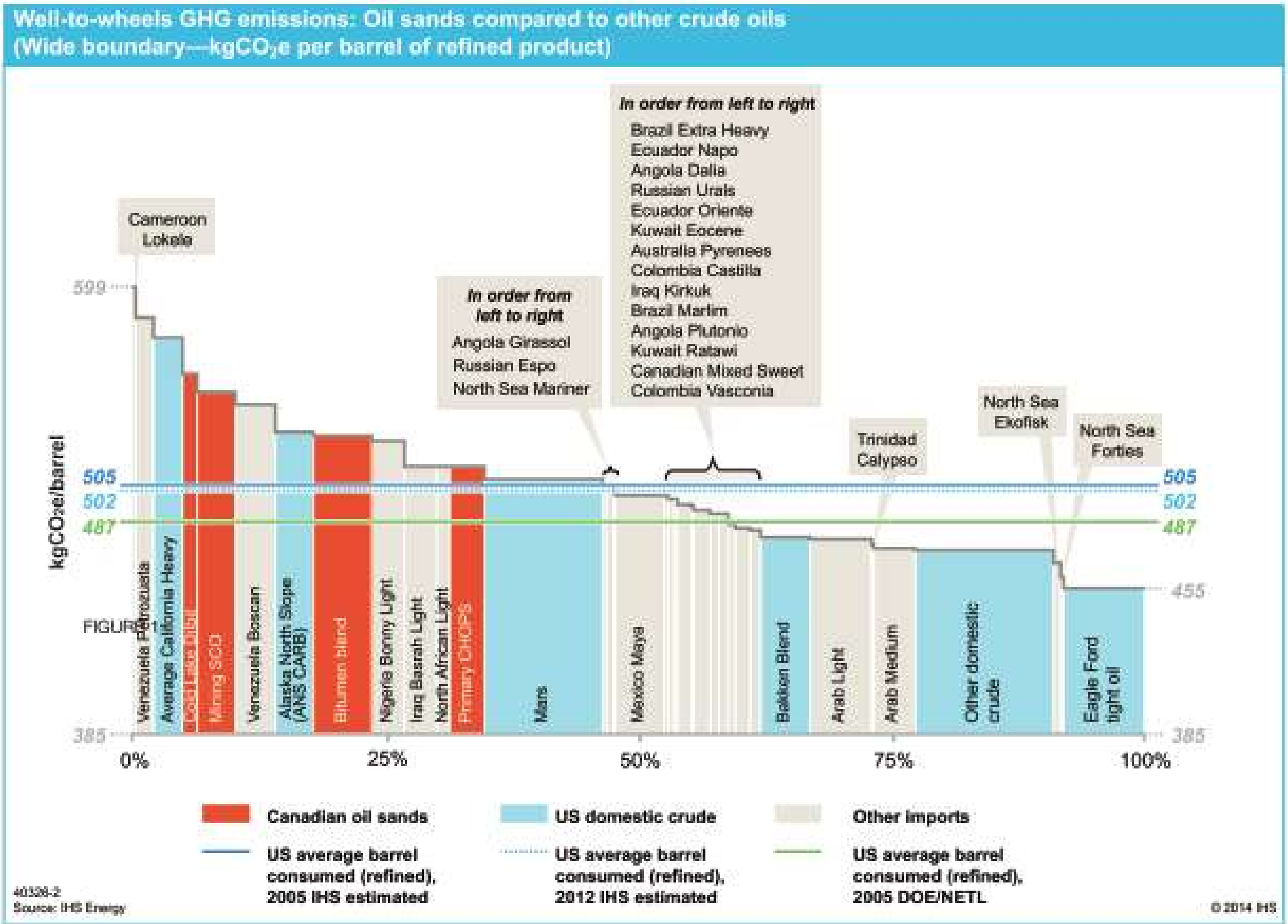



(Carnegie Endowment, 2017)

The use of solvent assisted processes could significantly improve the performance of oil sands based in-situ production in the overall GHG intensity of this production. If the upstream GHG intensity for SAGD was reduced by 20%, the upstream component would change from 118 kg $CO_{2eq}$/bbl to around 95 kg $CO_{2eq}$/bbl. This would reduce the overall intensity from 601 kg $CO_{2eq}$/bbl to 578 kg $CO_{2eq}$/bbl. For Cold Lake based CSS production, a similar approach of 20% reduction of upstream emissions would change the upstream emissions from 138 kg $CO_{2eq}$/bbl to 110 kg $CO_{2eq}$/bbl and a total of 552 kg $CO_{2eq}$/bbl. These intensities would be similar to North Slope crudes and close to values from Iraq (Rumaila) and some Eagle Ford production (condensate zone).

IHS Energy has also evaluated GHG emissions from the oil sands. In their analysis, a total GHG emissions (i.e. including all cycles of use, not just upstream) was used. In IHS's opinion, the oil sands based production was not significantly different from other sources. "Despite commonly held views that oil sands are the highest-carbon crude oil, 45% of US oil supply falls within the same GHG intensity range as oil sands. Two-thirds of these crudes are coming from sources other than the Canadian oil sands, such as from Latin America, Africa, the Middle East, and some US domestic production" (Forrest, Dereniwski, & Birn, 2014, p. 13). This is illustrated in Figure 21.

**Figure 21 - Wells-to-Wheels GHG Emissions (IHS Energy)**



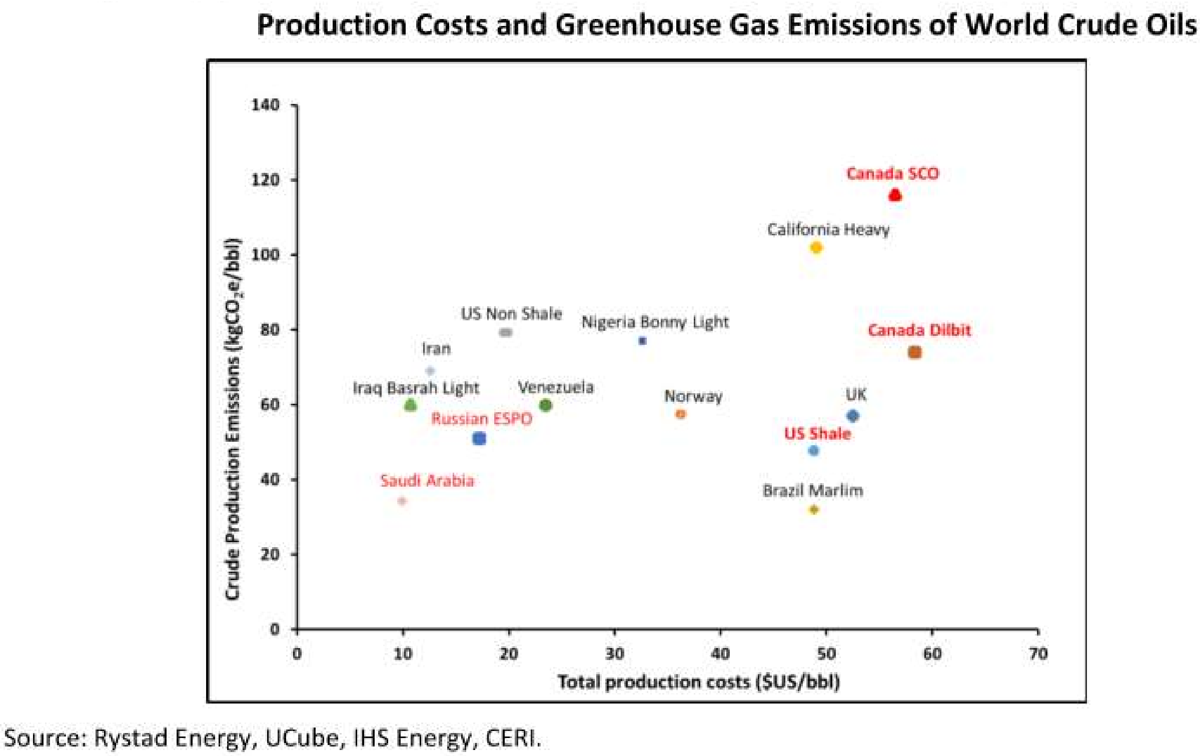

(Forrest et al., 2014, p. 11)

## Chapter Twelve: Economic and Development Considerations

### 12.1. General

Economics also enter discussions concerning oil sands production. For oil sands based production, upstream emissions intensities are higher than some other forms of production as discussed previously. Also, oil sands production has a higher supply cost than some other forms of production. Some analysis by CERI shows that in addition to having higher GHG emissions, oil sands based production has a higher production cost (Nduagu et al., 2017). This is illustrated in Figure 22.

**Figure 22 - Production Costs and GHG Intensity (CERI)**




(Nduagu et al., 2017, p. 1)

As discussed earlier, solvent assisted SAGD processes will result in a reduction in GHG intensity. With these processes, however, significant volumes of solvent are injected and the purchase of this solvent represents a significant cost to the operation of such schemes. The extent of recovery of solvent is a key parameter to understand regarding the economics of such oil sands projects. A review of the anticipated recovery of solvent has been conducted (Ardali, Barrufet, Mamora, & Qiu, 2012). The recovery ranges for solvent are:

- SAP: between 70% and 90% (Ardali et al., 2012)
- LASER: around 70% (Ardali et al., 2012)
- ES-SAGD: not reported, but a heavier solvent was used which may have impaired recovery (Ardali et al., 2012)
- Suncor Firebag: about 70% (Ardali et al., 2012)
- Nsolv: between 50% and 70% (Sow, 2016)

The extent of solvent recovery needs to be considered in the overall economic evaluation of such alternative SAGD schemes.

### 12.2. OSAG and Reaction

Earlier, the role of OSAG was discussed regarding the implementation of the 100 megatonne emissions cap from the oil sands. OSAG was concerned in their work to ensure that the oil sands remained economically competitive in a global context (The Oil Sands Advisory Group, 2017b). In informal discussions with industry, the message that OSAG heard was “to ensure that carbon leadership does not have undue or unintended consequences in terms of the economic competitiveness of the oil sands industry in Alberta” (The Oil Sands Advisory Group, 2017b, p. 12). Another feature of the OSAG recommendations was to not advocate the use of “internationally transferred mitigation options (offsets) as a tool to be used in the implementation of the emissions limit” (The Oil Sands Advisory Group, 2017b, p. 9). OSAG recommended that the GoA evaluate the use of offsets at a time when the emissions limit was being approached.

The reaction to the Alberta CLP and the 100 megatonne oil sands emissions cap has been mixed. Claudia Cattaneo has reported more extensively on the oil sands file for the Postmedia group. Her coverage has focused more on the potential negative aspects of the CLP and the oil sands cap. “Of these [GHG reduction measures], the 100 megatonne cap on oil sands emissions is the most destructive. Why would anyone invest in a notoriously long-term business if it runs out of room in the next 10 years, where existing plants would be shut down if emissions hit the limit, where new projects would be put on hold, if recommendations to the government by a panel including environmental activists are implemented” .(Cattaneo, 2017d, para. 9). Another issue that Cattaneo raised was allocation of oil sands based GHG emissions. “Already, some have expressed concerns that the approach will pit company against company and favour the four largest oil sands companies – Suncor Energy Inc., Cenovus Energy Inc., Canadian Natural Resources Ltd., and Royal Dutch Shell PLC – that proposed the emissions cap in the first place and backed Premier Rachel Notley's climate change plan” (Cattaneo, 2017a, para. 5).

Cattaneo had discussions with members of industry concerning the oil sands cap. “ ‘It's going to be harder for anyone to rationalize incremental investment,’ said Dennis McConaghy, a retired TransCanada Corp. senior executive who recently wrote a book about pipeline politics entitled Dysfunction. ‘If I was an unemployed engineer today, this ... report is frankly very crucifying, because it makes the prospect of a revival of capital investment that much more difficult’, he said. The plan would be unthinkable in other sectors. Imagine, for example, grounding the airline industry, or the auto manufacturing industry, or the shipping industry, because they have used up their emissions allocation” (Cattaneo, 2017c, para. 11).

There was discussion in industry that the concept of an emissions cap from the oil sands as a concept would be economically limiting. “ ‘I’m not aware of any other oil-producing jurisdiction in the world that has said they're going to impose limits on their productive capacity — indirectly, of course — through carbon emissions limits,' said Gary Leach, chief executive of the Explorers and Producers Association of Canada (EPAC), acknowledging that few oil sands producers number among EPAC's members. Some, especially within government, point out that the new cap limits emissions, not production, but Leach argues the net effect will be much the same" (The Daily Oil Bulletin, 2017b, para. 5).

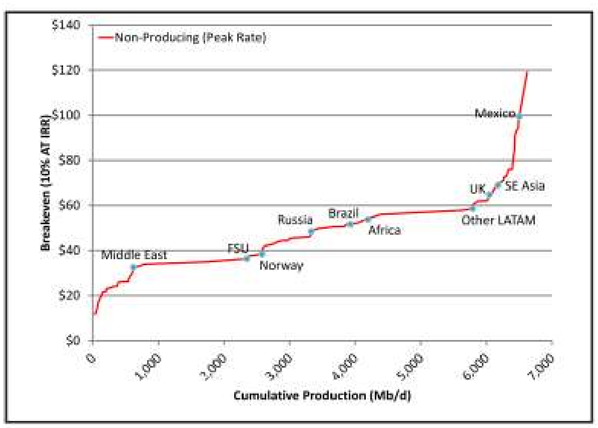
Other reaction to the CLP and the 100 megatonne cap was more favourable to continued investment. Canadian Prime Minister Justin Trudeau indicated that the approval of the expansion of the Kinder Morgan Trans Mountain pipeline would likely not have occurred without the emissions cap (Bellefontaine, 2016). The *Oil and Gas Journal* reviewed a report by Dina Ignjatovic, a TD Bank economist, written in 2016. This report indicated that "Alberta's emissions limit on oil sands work represents 'more of a long-term story and may only be an issue if there is enough market access to demand higher production'. Operational improvements probably will continue to lower emission rates and would have been implemented even if the cap hadn't been imposed" (Oil and Gas Journal Editors, 2016, para. 19). Others, including Ed Wittingham of the *Pembina Institute*, believe that the 100 megatonne emission cap "shows leadership for an energy-producing jurisdiction" (Smith, 2016, p. 70). A VP at CAPP believes that policies that promote technology development to improve emissions intensity are in alignment with industry (Bickis, 2017b). Regarding concerns expressed about allocation of the emissions cap, it should be noted that OSAG proposed an allocation based on operational performance and not on the operator involved in the facility (The Oil Sands Advisory Group, 2017b). It will take some time however, to determine the overall economic impacts of the CLP and oil sands emissions cap on overall investment in the future.

## 12.3. Supply Cost and Break-Even Cost

The supply cost for a barrel of crude oil is important to understand in economic analysis of the oil sands. A similar concept is the idea of break-even cost. There are many definitions for break-even cost, this definition typically being defined as the point at which costs are recovered. One definition used in oil and gas business is the total of "production costs (including taxes), plus F&D costs, plus SG&A, plus transportation costs and WACC" (Evaluate Energy, n.d., p. 2). Much of the data on supply cost and break-even cost is conducted by business consultancy firms (i.e. Wood Mackenzie, McKinsey and others). The break-even cost will vary based upon assumptions used and when the evaluation was conducted. BMO Capital Markets evaluates global oil supply annually (Ollenberger & Dziuba, 2016). The BMO non-OPEC and non-North American supply cost information can be found in Figure 23.

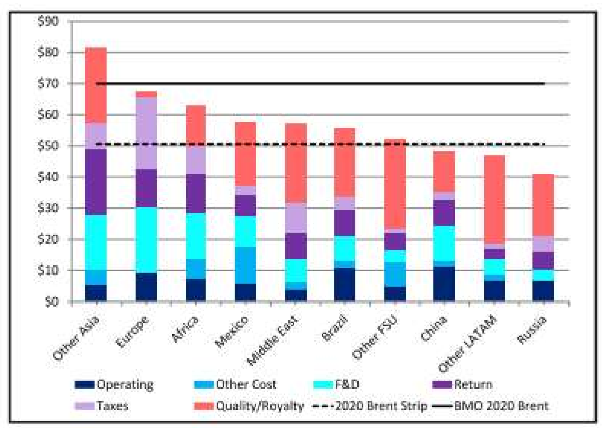
**Figure 23 - Break-even (Non-OPEC), 2016**

*Non-OPEC Supply Cost Curve – Undeveloped Fields*




Source: Wood Mackenzie, BMO Capital Markets

*Field-Level Full Cycle Breakeven (US$/bbl, Brent)*



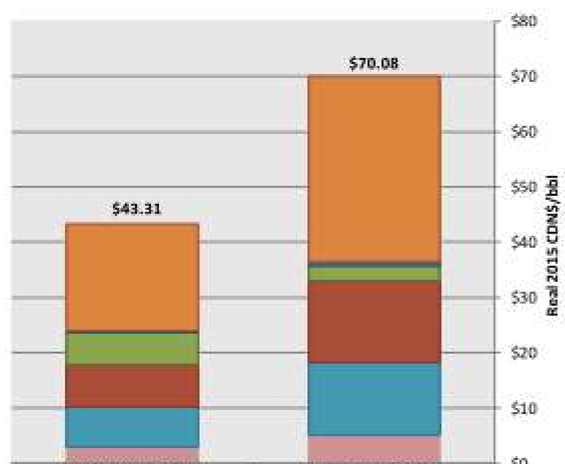

Source: BMO Capital Markets
Note: Full cycle supply costs include a 10% return on capital

(Ollenberger & Dziuba, 2016, p. 26)

The BMO information shows a 2016 supply cost for much of the production being over $50 USD/bbl. For Canadian oil sands production, information from CERI indicated a supply cost of $43.31 CAD/bbl for SAGD and $70.08 CAD/bbl for surface mining in 2016, both reflecting the value at the plant gate (Millington, 2017) in Alberta. When these costs are adjusted for blending, transportation and for delivery at Cushing, the oil sands supply cost would be equivalent to a WTI crude at Cushing of $60.52 USD/bbl for SAGD and $75.73 USD/bbl for surface mining (Millington, 2017). The supply cost in $CAD at the plant gate in Alberta is depicted in Figure 24.

**Figure 24 - Supply Costs Oil Sands (CERI)**

Total Field Gate Bitumen/SCO Supply Costs




| | SAGD 10% ROR (a) | Mining 10% ROR (a) |
|---|---|---|
| Fixed Capital (Initial & Sustaining) | $19.25 | $33.68 |
| Operating Working Capital | $0.40 | $0.70 |
| Fuel (Natural Gas) | $5.87 | $2.68 |
| Other Operating Costs (incl. Elec.) | $7.53 | $14.84 |
| Royalties | $7.14 | $13.05 |
| Income Taxes | $2.82 | $4.94 |
| Emissions Compliance Costs | $0.27 | $0.13 |
| Abandonment Costs | $0.03 | $0.05 |

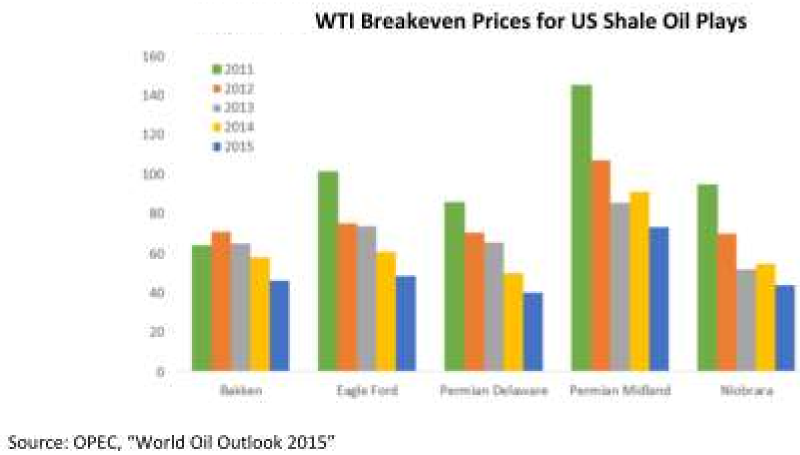
ªReturn on capital included.

Source: CERI

(Millington, 2017, p. 22)

CERI compared these break-even costs to selected shale oil plays, as shown in Figure 25. As can be seen, some of these break-even costs are lower than those for the equivalent WTI values for SAGD based production and surface mining based production.

**Figure 25 - Break-even for Selected US Shale Oil Plays (CERI)**

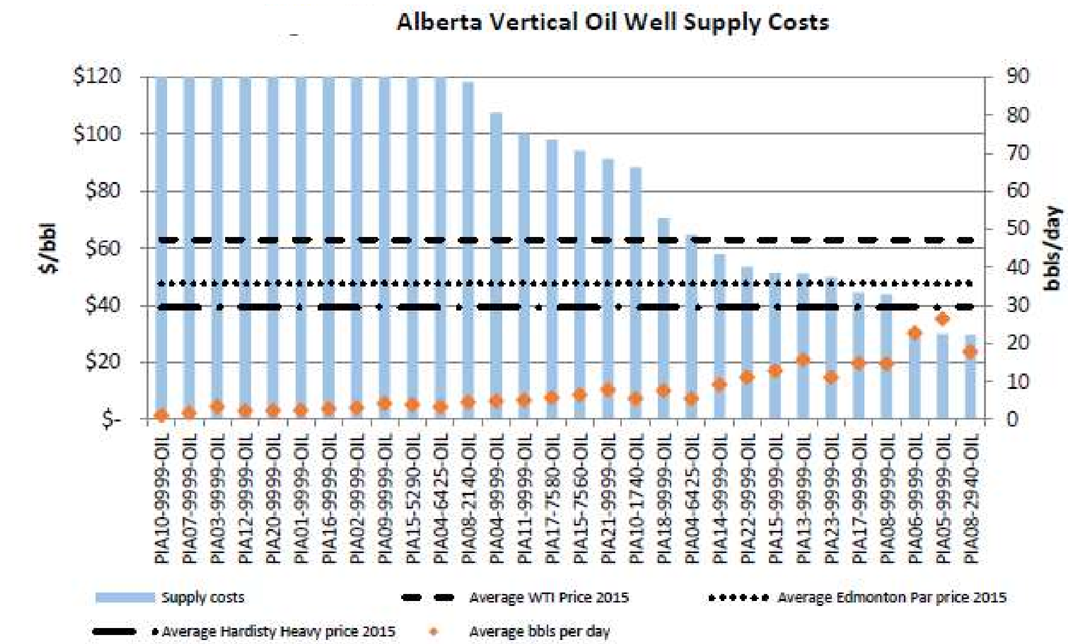



(Millington, 2017)

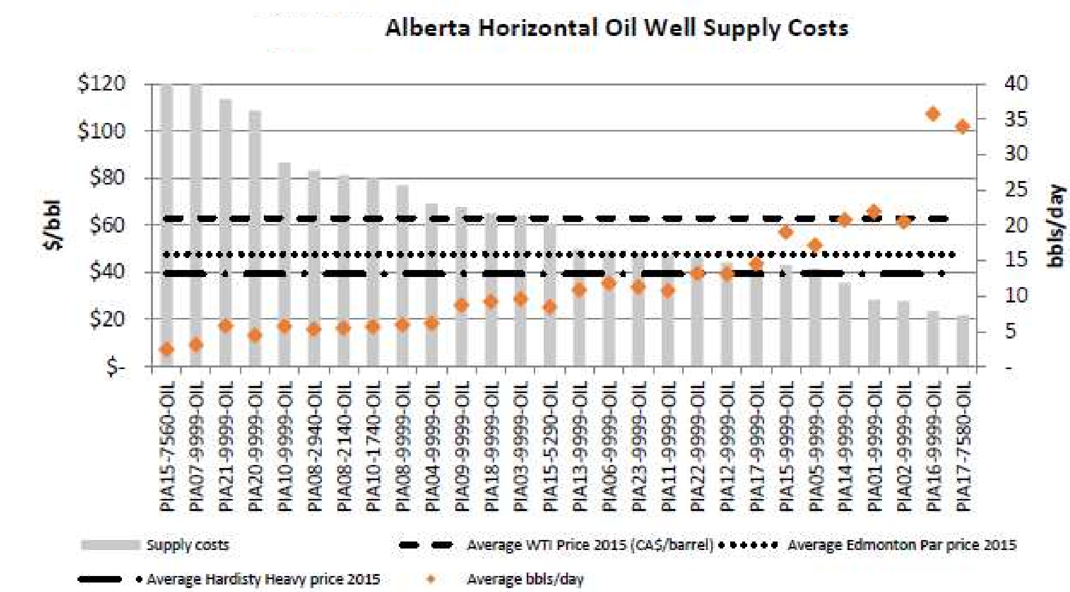
It should be noted that Alberta conventional oil supply costs are also in a similar range to SAGD and surface mining based production. This is shown in Figure 26. There has been broad investigation into break-even and supply costs for oil supply using different assumptions and scenarios. The break-even costs for shale gas plays in North America compared with SAGD and surface mining also shown can be found in Figure 27.

With the challenges of a lower price environment, there have been improvements in the cost curve. Wood Mackenzie indicates that in 2016, the break-even costs had fallen by $19 USD/bbl to $51 USD/bbl (Wood Mackenzie, 2016). Most of the production volume associated with this reduction is associated with tight oil production in the United States. The oil sands sector has also been able to respond to the lower price environment by reducing costs. Rystad Energy has shown the significant cost reductions that have been achieved by the oil sands sector. Operating costs for SAGD are shown as low as approximately $6.00 USD/bbl (Liles, 2017), however it is not clear what specific costs have been included in this analysis. These results from Rystad Energy are depicted in Figure 28 and Figure 29.

**Figure 26 - Alberta Conventional Oil Supply Cost (CERI)**



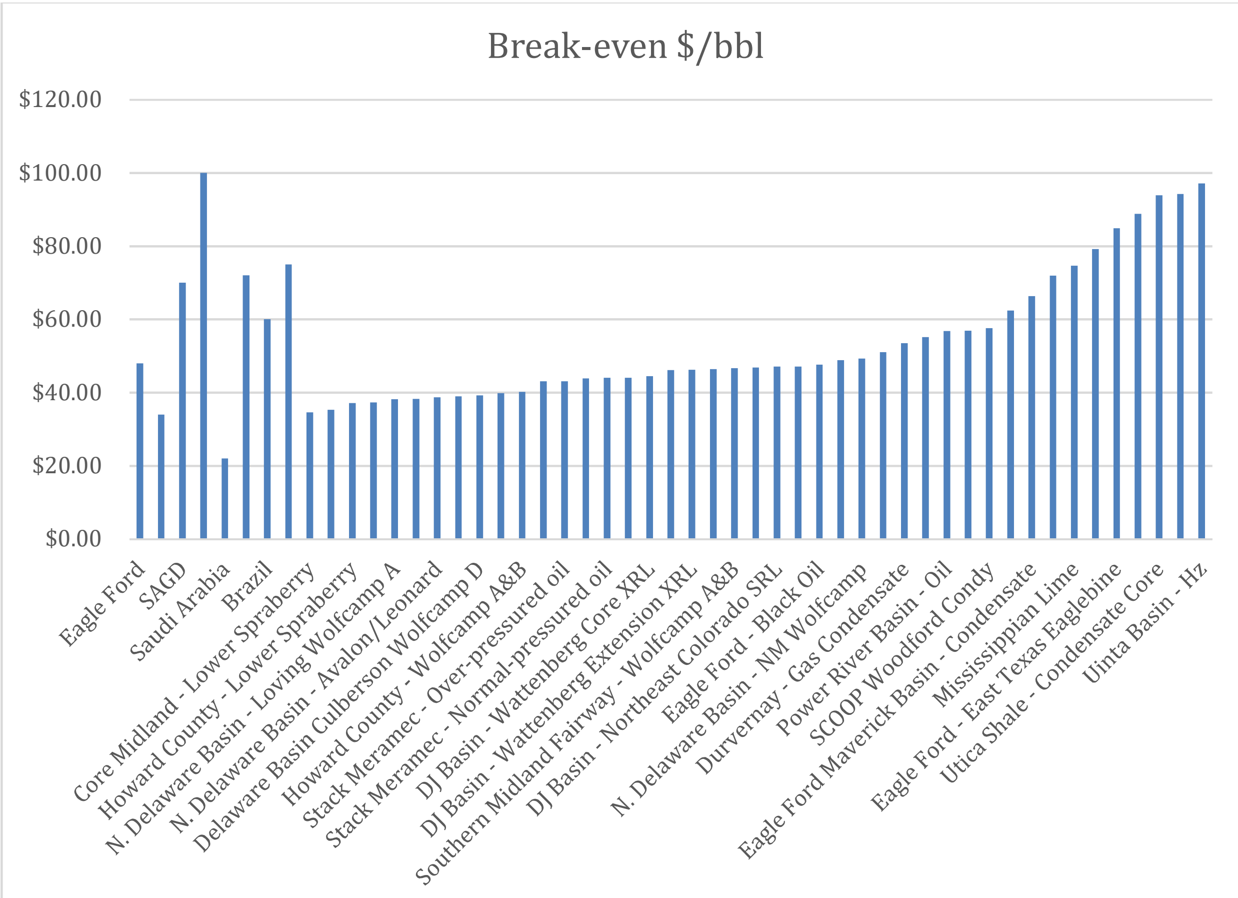

Source: CERI, AER, PSAC, CAPP




Source: CERI, AER, PSAC, CAPP

(Johnson, Kralovic, & Romaniuk, 2016, p. 11)

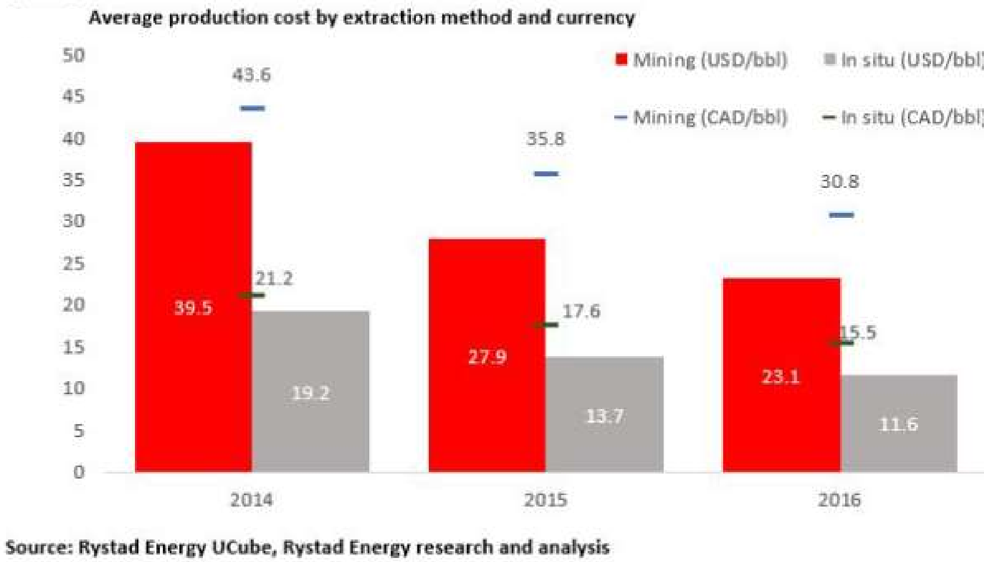
**Figure 27 - Break-even for US Shales, GOM and Oil Sands**




(Birn & Meyer, 2015; Deepwater International, 2015; Haines, 2017; Jayaram et al., 2016)

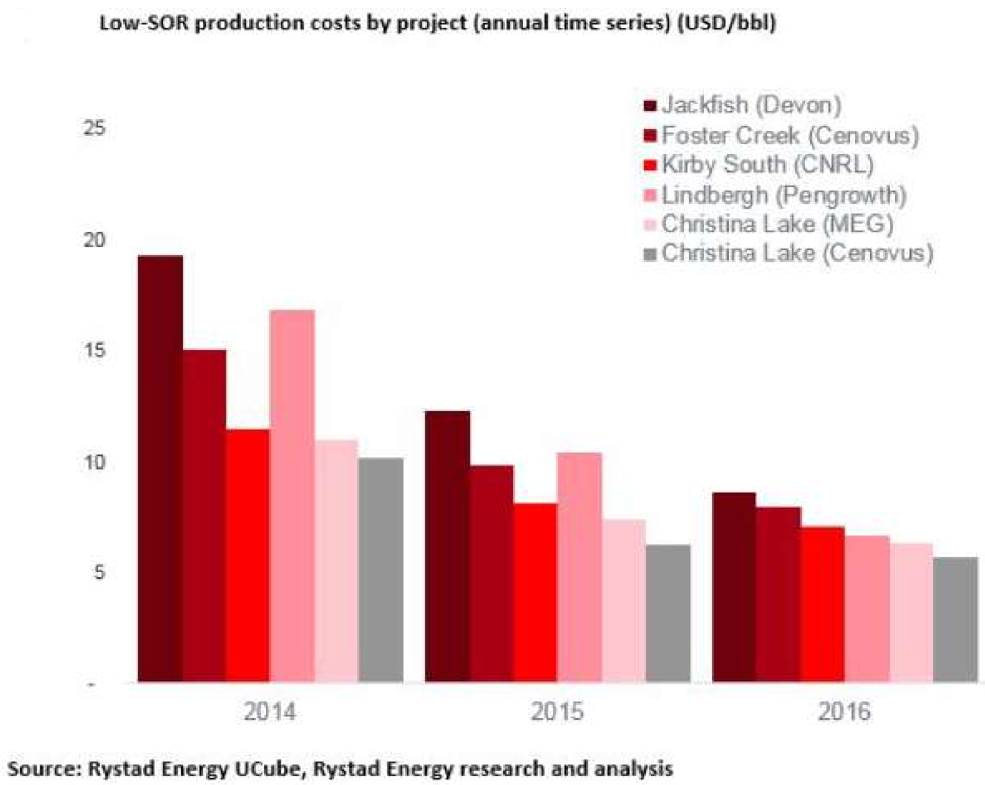
Other analysis shows a mixed outlook for oil sands production. Wood Mackenzie also notes that a number of oil sands projects are viable at $60 USD/bbl (Gibson, 2016), however current prices are below this level. The Wood Mackenzie analysis is depicted in Figure 30. Supply costs for oil sands mining are shown as near $90 USD/bbl, based on a marginal Brent cost (Lucas, 2014), see Figure 31 for details. Despite these high supply costs, if , on an annual basis, there is a growth of demand of around one million barrels per day and annual depletion is five million barrels per day, supplies still must be added, meaning that oil sands production will become more viable as time progresses (Lucas, 2014).

**Figure 28 - Average Production Costs - Oil Sands (Rystad)**



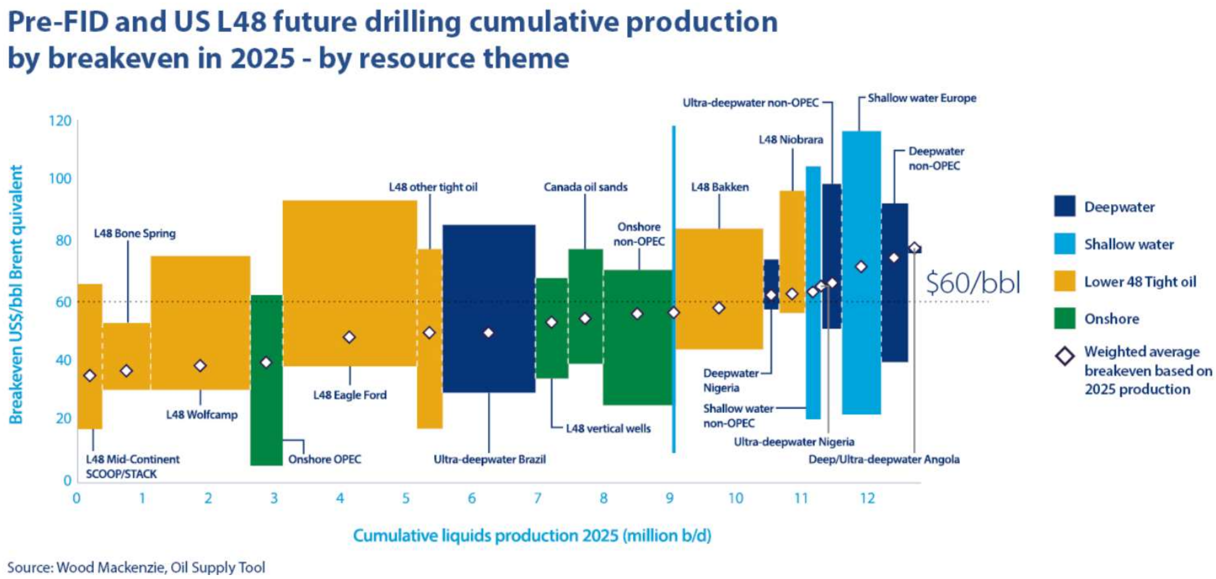

(Liles, 2017, p. 2)

**Figure 29 - Low SOR Production Cost (Rystad)**



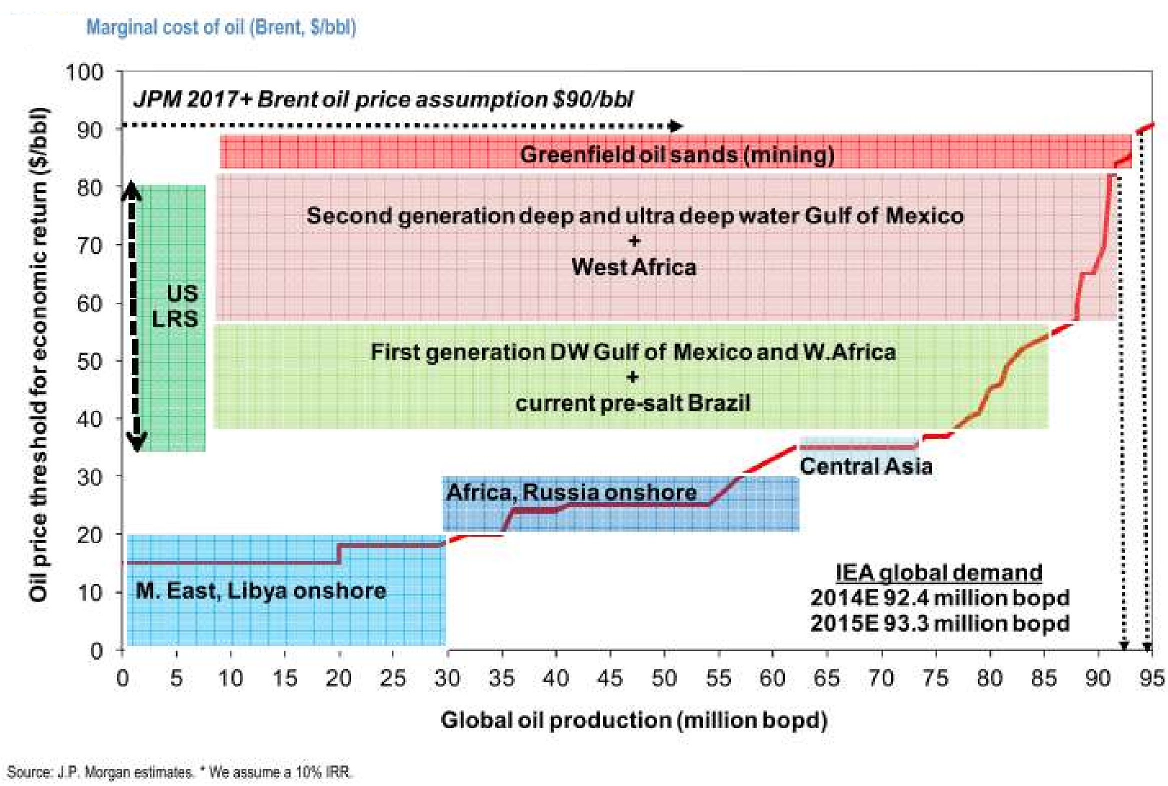

(Liles, 2017, p. 4)

**Figure 30 - Viability of Projects at $60 USD/bbl (Wood Mackenzie)**




(Gibson, 2016, p. 2)

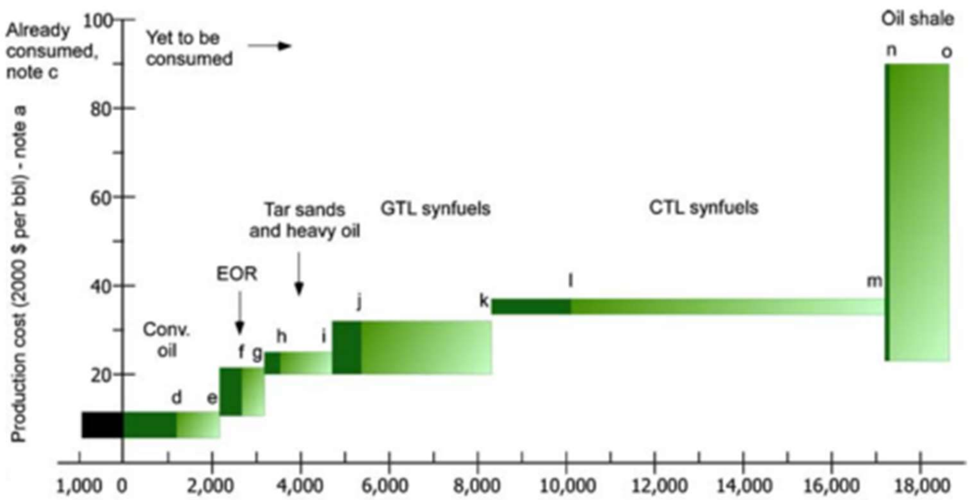
**Figure 31 - Marginal Cost of Oil**




(Lucas, 2014, p. 2)

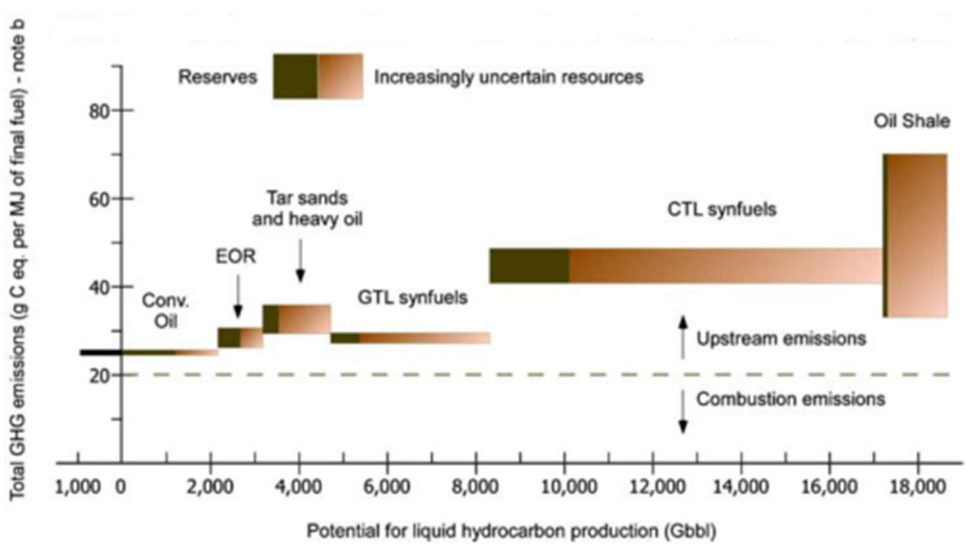
When carbon intensity is shown in conjunction with the production cost, oil sands do face more challenges than conventional oil. The production cost of oil sands is lower than Gas-to-Liquids (GTL) synthetic fuels, Coal-to-Liquids (CTL) synthetic fuels and oil shale sources, however (Brandt & Farrell, 2007). Oil sands GHG emissions are lower than production from CTL synthetic fuels and production from oil shale. This can be seen in Figure 32 and Figure 33.

**Figure 32 - Liquid Hydrocarbons - Cost Basis**




(Brandt & Farrell, 2007)

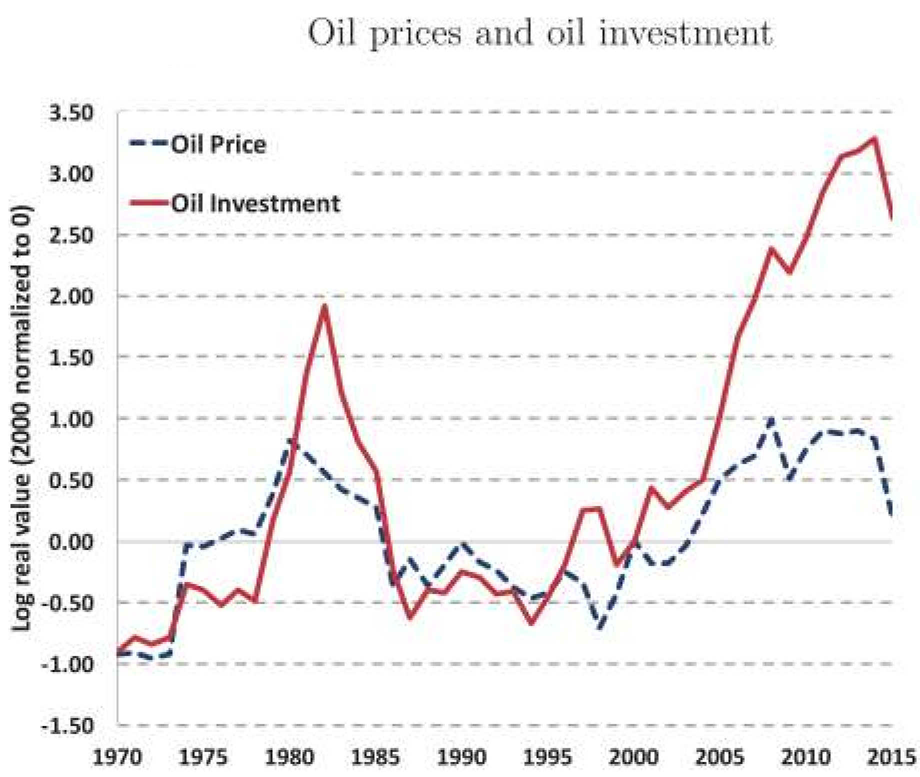
**Figure 33 - Liquid Hydrocarbons - GHG Intensity Basis**




(Brandt & Farrell, 2007, p. 253)

The low revenue for oil and gas production is already being reflected in the investment in the oil and gas sector (Bornstein, Krusell, & Rebelo, 2017), as seen in Figure 34. Investment levels will likely only improve when the price of oil improves. Such an improvement will be due to global macroeconomic factors. It could be argued that the CLP and the 100 megatonne emissions cap would currently have a minimal effect on oil sands investment as supply cost concerns dominate. However, such an argument needs to consider concerns about stability of any proposed changes to the regulatory regime in Alberta and concerns about market access. Market access issues arise due to projections about a lack of pipeline capacity to tidewater.

**Figure 34 - Oil Prices and Investment Levels**

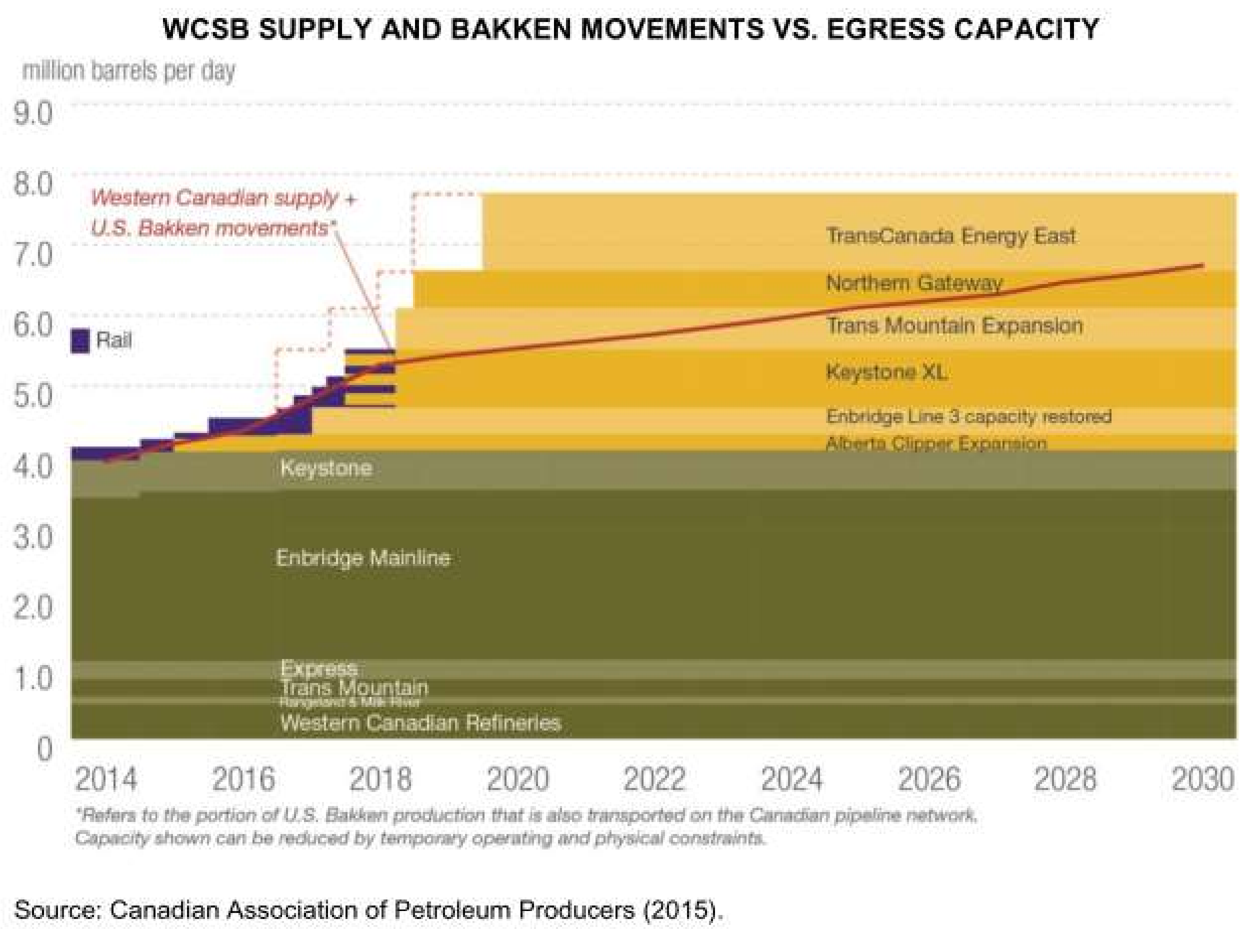



(Bornstein et al., 2017, p. 6)

Crude oil and bitumen, both require refining to make useful products. Refining capacity tends to congregate in areas of larger populations, ones with readily accessible export access (i.e.

tidewater) and hydrocarbon deposits (Findlay, 2016). Regarding the three factors about refining just mentioned, Alberta only really has the advantage of extensive hydrocarbon deposits as it lacks ocean access and a large local population. There are various projections on available pipeline capacity from Alberta to tidewater. One common denominator is that a lack of market access will result in a discount for oil sands based production. This is part of the reason why WCS trades at a discount to WTI. A projection of pipeline capacity can be found in Figure 35.

**Figure 35 - Pipeline Capacity from WCSB**




(Findlay, 2016, p. 27)

A final source of information concerning supply costs is the AER. In their ST98 report, the AER analyzes the supply costs for production from Alberta based hydrocarbon sources

(Alberta Energy Regulator, 2016a). Table 6 shows the AER's current estimates for bitumen supply costs in Alberta for 2016.

**Table 6 - Crude Bitumen Supply Costs (2016)**

**Table 1.4 Crude bitumen supply costs, 2016**

| Project type | Production (10[3] m[3]/d) | Production (bbl/d)[a] | Capital cost range (millions of dollars) | Estimated supply cost | Estimated supply cost ($US WTI equivalent per barrel) | Purchased natural gas requirement (10[3] m[3] gas/ m[3] oil) | Purchased natural gas requirement (Mcf/bbl)[b] |
|---|---|---|---|---|---|---|---|
| In situ SAGD | 4.8 | 30 000 | 750 – 1 350 | 90% | 30 – 50 | 0.177 – 0.354 | 1.0 – 2.0 |
| Standalone mine | 15.9 | 100 000 | 9 000 – 11 000 | 90% | 65 – 80 | 0.071 – 0.106 | 0.4 – 0.6 |

[a] bbl/d = barrels per day.
[b] Mcf/bbl = Thousand cubic feet per barrel.
Revised March 2017.

(Alberta Energy Regulator, 2016a)

Another variant on SAGD may also improve both economics and GHG performance. This involves the injection of non-condensable gases (NCG). This process involves the injection of an NCG such a methane with the steam or the steam / solvent mixture. Methane doesn't condense so it helps maintain pressure downhole. In addition, the methane forms an insulating layer of gas at the top of the producing formation, this helps to reduce heat loss to the cap rock (Roche & Jaremko, 2017). This use of NCG is a key part of the MEG Energy trials of their eMSAGP process which was discussed earlier. MEG energy believes that this could reduce SORs by up to 50% and could lower operating costs significantly (Roche & Jaremko, 2017).

Finally, regarding current economics of oil sands based production, recent prices in July 2017 (July 17, 2017) were:

- WTI at $46.00 USD/bbl (Bloomberg Energy, 2017)
- WCS at $37.24 USD/bbl (The Daily Oil Bulletin, 2017a)

With prices at these levels, all crude oil sources are in a point where breaking even is difficult.

### 12.4. CanOils Data

Obtaining relevant data for analysis of the oil sands can be difficult due to the differences between operations, in particular between SAGD based production and surface mining based production. Different firms also handle data differently in terms of how asset performance is collected and measured. CanOils is a data service for the Canadian oil and gas sector (CanOils, 2017); it is a service from Evaluate Energy, a division of June Warren Nickle's group. Information from CanOils includes financial data, operating data and related information.

Through the AER and an arrangement with June Warren Nickle's group, I have been able to access to CanOils data to better understand the performance of oil sands based firms. The CanOils information also includes information on GHG intensity, however this information has an approximate two-year lag as to when it available. Consequently, the data addressed in this section will focus up to 2015. Note that all data presented in this section (Section 12.4) is from CanOils (CanOils, 2017) unless otherwise indicated.

The focus of the data analysis from CanOils was to better understand both the environmental performance and financial performance of existing SAGD based operations. Environmental performance investigated included the annual SOR and the total kg $CO_{2e}$/bbl. Financial performance parameters included:

- Realisations ($/bbl)
- Royalties ($/bbl)
- Non-fuel operating cost ($/bbl)
- Annual natural gas cost ($/bbl)

- Annual transportation cost ($/bbl)
- Annual netback ($/bbl)

Data presented will be for the year 2015 and is limited to sources from CanOils where data is available. There is a more limited set of operations with full financial data which is why the economic analysis includes a smaller group of operations. Table 7 and Figure 36 show the 2015 environmental performance for selected operators.

**Table 7 - 2015 Environmental Performance SAGD**

| Project Name and Operator | Annual SOR | Total kg $CO_{2eq}$ per Barrel |
|---|---|---|
| Firebag - Suncor | 2.6 | 79.135 |
| Foster Creek - Cenovus | 2.5 | 61.648 |
| Great Divide - Connacher | 3.9 | 98.334 |
| Jackfish - Devon | 2.5 | 75.324 |
| Kai Kos Dehseh - Athabasca Oil Corp. | 3.0 | 99.553 |
| Kirby South - CNRL | 2.6 | 103.882 |
| MacKay River - Suncor | 2.9 | 116.398 |
| Orion - OSUM | 3.0 | 74.427 |
| Surmont - ConocoPhillips | 3.8 | 97.612 |
| Tucker - Husky | 5.3 | 141.848 |
| Tangleflags - CNRL | 8.4 | 159.687 |
| Senlac - CNRL | 5.7 | 75.440 |
| Christina Lake - MEG | 2.5 | 82.450 |
| Christina Lake - Cenovus | 1.7 | 39.751 |
| Bolney Celtic - Husky | 2.4 | 75.216 |
| Paradise Hill - Husky | 2.8 | 70.400 |
| Sandall - Husky | 2.0 | 76.516 |

(CanOils, 2017)

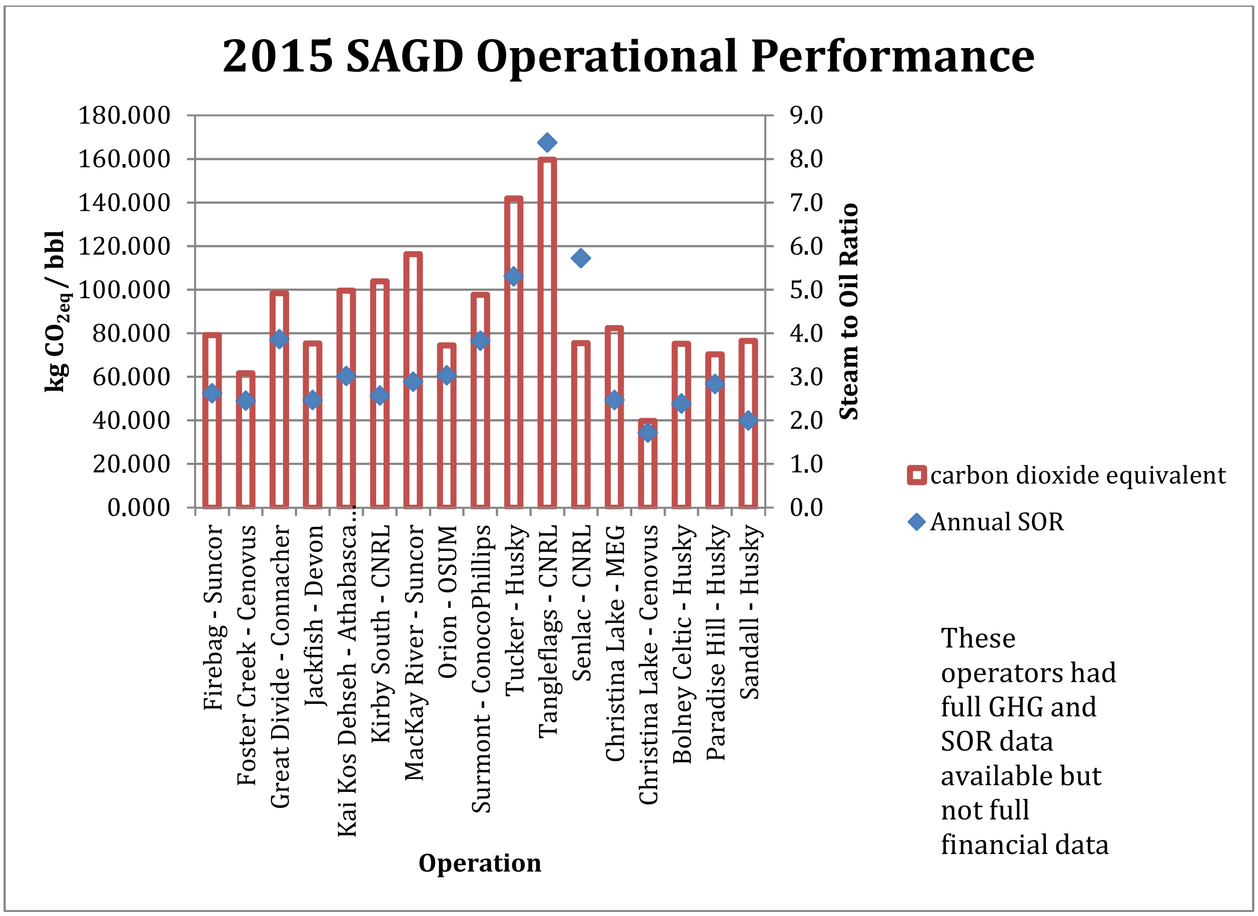
From this information, two operations, Husky's Tucker operation and the Tangleflags operation of CNRL stand out as being significantly poorer performers – on an environmental basis – in 2015. Husky Energy Inc. prepared an annual performance report for the AER (Husky Energy Inc., 2016). In this report, Husky has indicated several factors impairing performance (Husky Energy Inc., 2016):

- Original well pairs had poor performance due to "placement in the transition zone where oil saturation is low" (Husky Energy Inc., 2016, p. 56).

- Poor start-up strategy
- Issues with steam chamber development, for example minimal development in some areas
- Ensuring that operating pressure remains somewhat constant and at a level near the bottom water pressure

The Tangleflags facility is a CNRL facility in Saskatchewan that was initially a pilot SAGD facility that also employed vertical injectors (Butler, 2001). Due to the pilot nature of this facility, its GHG emissions may be higher than for a typical operation.

**Figure 36 - 2015 Environmental Performance SAGD**

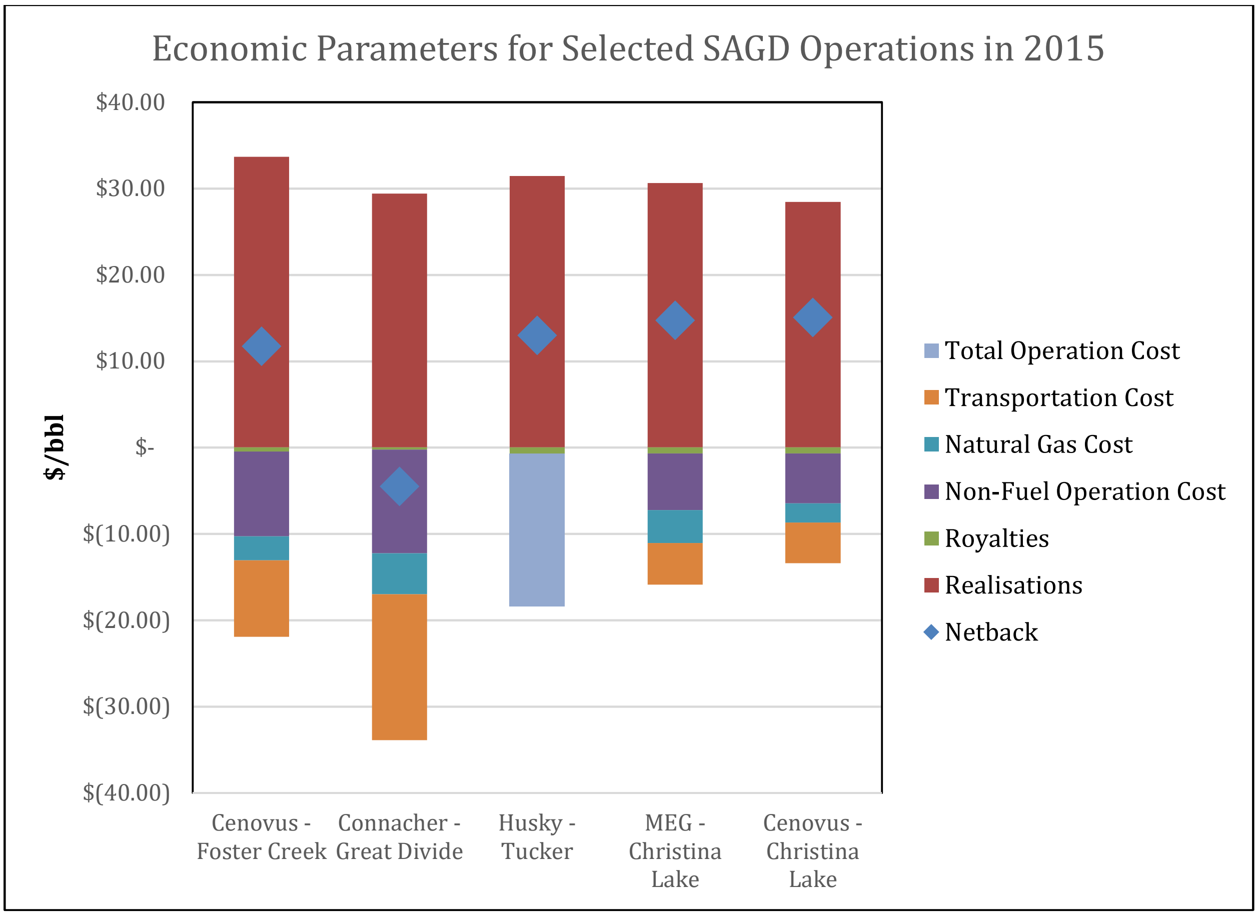



(CanOils, 2017)

Data on emissions intensity is also available from other sources (Government of Alberta, 2017a), however this information was only available until 2011 and is not presented here.

Economic parameters for selected SAGD operations from 2015 can be found in Figure 37. Note that Husky did not break down some components of costs, for Husky Tucker these were provided as a total operational cost, other operators broke costs down further into non-natural gas costs, natural gas costs and transportation costs.

**Figure 37 - Economic Parameters for Selected SAGD Operations**




(CanOils, 2017)

In Figure 37, a wide variation in economic performance can be seen. One operation, Connacher Great Divide, shows a negative netback for 2015. It can be seen that Great Divide has a much higher transportation cost. The reason for this is that the initial plans that Connacher had for their development were to truck diluted bitumen from the facility with a sales pipeline being considered for a later date (Connacher Oil and Gas Ltd., 2010). Connacher also delivered diluent supply by truck to this facility. This reliance on trucking explains the higher transportation costs.

### 12.5. Simple Model

A simple economic model was developed to show the impact of solvents on project economics. To assist the development of this model, the 2015 data from the CanOils database (Section 12.4) was used for three operations:

- Cenovus Foster Creek
- MEG Christina Lake
- Cenovus Christina Lake

These three operations were used as they show similar performance and do not have facility specific issues that other facilities selected for analysis from the CanOils data had. These specific issues were a reliance on trucking for Connacher and well placement issues for Husky.

The methodology and key assumptions used for the solvent assisted case are outlined below followed by a discussion of the results.

- The energy impacts with solvents and the production impacts discussed earlier (Sections 9.1 and 9.2) were used to quantify the impacts on energy and production.
- The revised SOR and revised production rate were applied to the CanOils data (Section 12.4) for the three operations discussed above.
- A butane rate of 15% by mass was applied to the injected fluids (Section 3.1.1.1).
- The mass rate of butane was converted to a volumetric rate by dividing by the density of 600 kg/m$^3$ (PubChem Open Chemistry Database, 1999).

- Costs (at Edmonton) for butane of $36.78 for 2015 were used to get a daily cost of butane (GLJ Petroleum Consultants, 2016).
- Butane recovery from the reservoir of 70% was assumed (Section 12.1).
- Royalty rate per barrel assumed constant.
- Non-fuel operating cost assumed to be the same for the solvent assisted case. This is because it is assumed that there is no additional non-fuel costs (i.e. maintenance, staffing, etc.) with the solvent assisted production.
- Reduction in natural gas (i.e. energy input) of 32% based on evaluation done in this project (Section 9.2).
- Transportation Cost per barrel assumed constant.

In all three cases, the overall netback achieved with the simulated SAP application to the two Cenovus operations and the MEG facility was lower. This shows that, with the assumptions made, the current economics for solvent assisted processes appear to poorer than base case SAGD. The main reason for this is the cost of butane that needs to be made up each day. A sensitivity case was run with 90% butane recovery from the reservoir for the Cenovus Christina Lake data. This resulted in an improvement in netback over the base 2015 SAGD operation. Depictions of the analysis can be found in Figure 38 for Cenovus Foster Creek, in Figure 39 for MEG Christina Lake and in Figure 40 for Cenovus Christina Lake. The Cenovus Christina Lake analysis shows the impact of the increase in solvent (butane) recovery. Based on this economic model, a key parameter to focus on to improve the viability and profitability of solvent aided processes is the recovery of solvent.

Note that this economic model has not made any consideration for implications of the CLP and the 100 megatonne cap. Using a solvent assisted process could improve the relative performance of a facility, potentially to the point where it could benefit (i.e. have a lower production impairment) if scarcity entered consideration.

**Figure 38 - Economic Model - Cenovus Foster Creek**

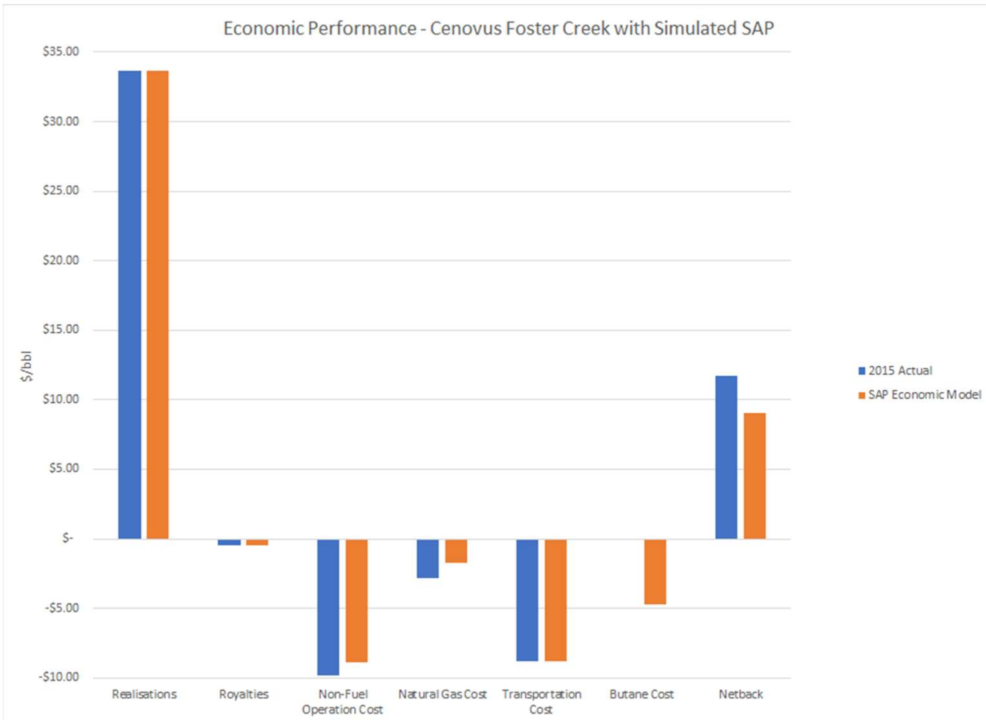


**Figure 39 - Economic Model - MEG Christina Lake**

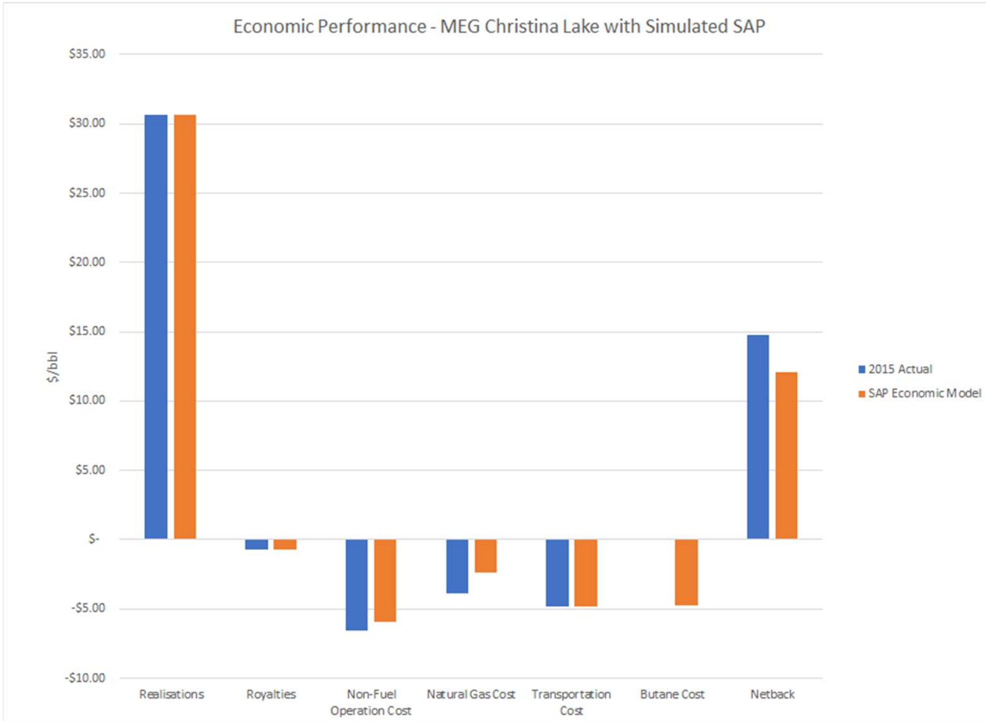
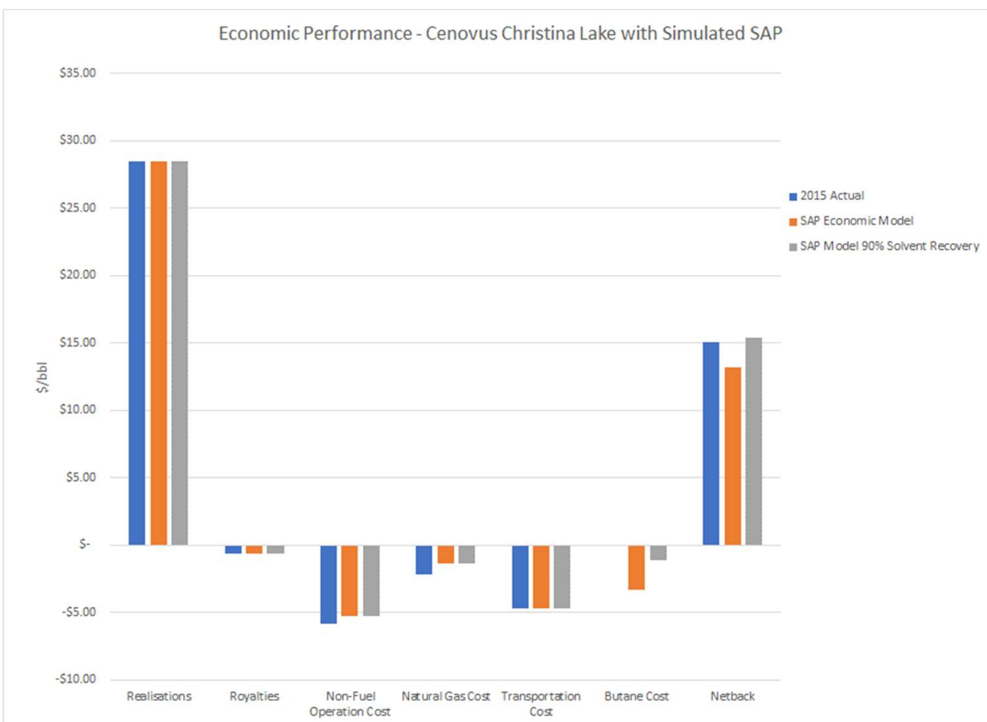



**Figure 40 - Economic Model - Cenovus Christina Lake**



## Chapter Thirteen: Other Considerations

### 13.1. Reservoir Considerations

Each individual hydrocarbon reservoir is different. The issues potentially related to SAGD performance and the 100 megatonne emissions cap were introduced earlier (Sections 8.7.2, 10.1.1, 10.2.1, and 10.2.2). The literature indicates that reservoir quality does have an impact on SAGD performance. The presence of bottom water or top gas can require that a very specific and stable injection pressure be maintained (Dickson et al., 2011). These narrow operating conditions can make SAGD more difficult, in particular if the stable injection pressure that the bottom water and top gas demand causes concerns with the geological stability of the formation. The potential for narrow operating pressure is also discussed as a obstacle to improving SAGD operational performance (Das, 2005). If the steam chamber pressure is higher than the bottom water pressure there can be outflow of fluid from the reservoir into the surrounding reservoir (Butler, 2001).

OSAG should consider, in some fashion, the impacts of reservoir quality for the implementation of the 100 megatonne cap. Research has shown that “bitumen reservoirs can be impaired for thermal EOR, by top or bottom water, top gas, thin pays, lean zones, mudstones or other factors” (Jonasson & Kerr, 2013, p. 17). Higher SOR, and consequently higher GHG emissions (because of increased steam generation), can occur for thin reservoirs or ones with thin pay zones. “Thermal-based methods become uneconomical due to large heat losses to the overburden and the underburden” (Jia, Zeng, & Gu, 2015, p. 832).

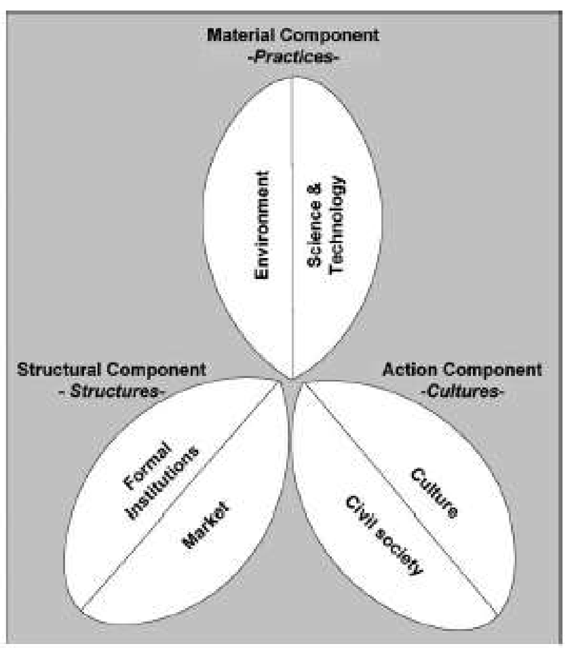
### 13.2. Policy Considerations

Implementing changes in policy, such as the CLP and the 100 megatonne emissions cap can be a difficult process. In research for this project, I have seen how there is controversy about the CLP and about issues concerning climate change in general. More recent discussion of societal transitions has brought attention of how change occurs. One view of transition theory is that "change of the system does not only come from outside but also from within" (Frantzeskaki & de Haan, 2009, p. 594). The structure proposed by Frantzeskaki & de Haan (2009) of transitions, involves four steps:

- Identification of the forces
- Finding the forces
- Understanding of the intermediate changes through the transition
- Understanding of the conditions of change

This structure is summarized into a clover model that helps to better understand the interactions between the various components and parties, see Figure 41.

**Figure 41 - Clover Model for Societal Transitions**




Clover model conceptualisation of a societal system.

(Frantzeskaki & de Haan, 2009, p. 600)

The climate change initiatives underway by the GoA have arisen due to a few conditions for change. Tensions exist between the established oil and gas industry and between other parts of society advocating change. Tension also arises between NGOs who argue that radical action on climate change versus governments who do not want to move too quickly. These tensions can result in pressure on the government to act. The CLP could be seen as a manifestation in Alberta of the actions of these forces.

The clover model (Figure 41) can assist in identifying these forces to help promote effective change. "Every component of the clover model is conceptually linked with the other two in a way that a change in one of the dimensions affects the others" (Frantzeskaki & de Haan, 2009, p. 599). In this model, the actions components can cause changes in the structures of societies which can result in changes in practices. This model helps to understand some of the challenges with changes.

Change can be more gradual. An example of this concerning action on climate change issues in Alberta are activities prior to the CLP. Prior to the CLP, the previous Alberta government implemented the SGER in 2007 (Government of Alberta, 2016). The purpose of the SGER was to require large emitters to reduce their carbon intensity. The SGER is an example of how an evolution approach started from a point where there was very limited regulation of emissions of GHGs, to an evolving point (the SGER) which has led to the CLP.

The implementation of change can be top down, internal or via a bottom up approach. Depending upon perspective, the CLP could be seen to demonstrate aspects of all such approaches. Those opposed to any changes on regulation could see the effort as a top-down implementation of a change in policy being implemented by the GoA without any concern for potential impacts. NGOs and activists might argue that their bottom up approach of trying to influence government is resulting in action that is not occurring fast enough and that a crisis issue to them – climate change – is not being adequate consideration. The internal aspect of change to the CLP can be demonstrated by the internal workings of the GoA in trying to understand how to best address the issue.

One caution with any change is to understand that there can be resistance. “Conditions for change are not always welcomed by the societal system” (Frantzeskaki & de Haan, 2009, p. 602). Those involved in the implementation of changes need to recognize that the extent of “whether resistance is beneficial or harmful for the societal system is defined by the existing values, norms and perceptions that are embedded in the culture of the societal system” (Frantzeskaki & de Haan, 2009, p. 602). When significant changes in policy and approach are being considered, there should be evaluation of the current conditions and views of the societal system to ensure that these are addressed in discussion of change.

Changes to the existing structures that result in a more sustainable society can be more difficult to implement due to current entrenched positions of components of society (individuals, NGOs, industry and government as examples). Strictly framing a focus on growth models, efficiency and economic profitability may make implementation of a more sustainable society more difficult (Rotmans, 2005). The idea of transition management is introduced as a means to implement change, one where there is a “visionary process of agenda building, learning, instrumenting and experimenting” (Rotmans, 2005, p. 43).

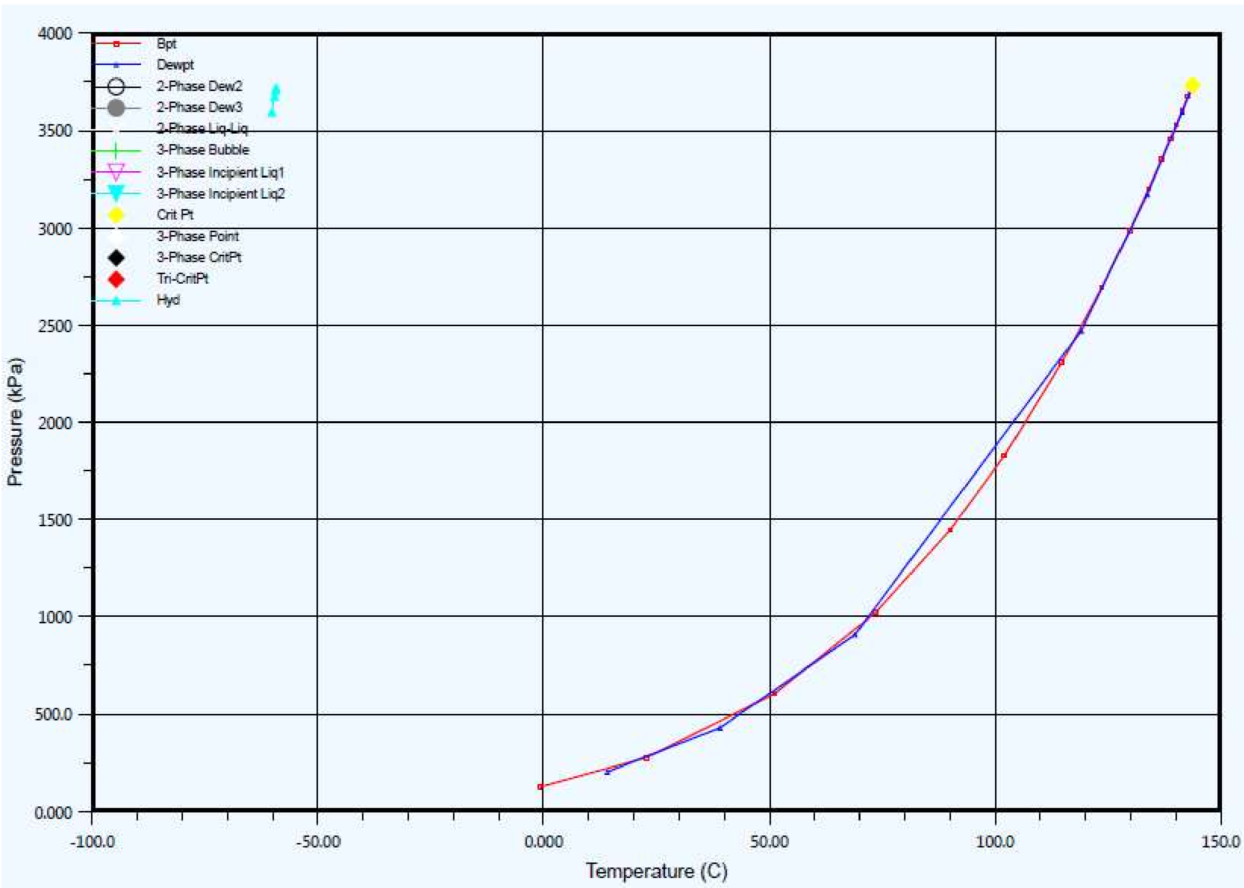
The lesson to be applied to implementation of the CLP and the 100 megatonne emissions cap is to try to ensure that there is broad a base of support as possible for the plan, to fully consult all impacted parties and to understand what the concerns and tensions are for the change. Employing the techniques discussed by Rotmans and by Frantzeskaki & de Haan could be a means to improve dialogue between impacted groups and result in a more effective introduction of these changes.

### 13.3. Solvent Handling Considerations

SAGD operations are typically conducted with injection of 100% quality steam, or as near as possible to 100% quality steam. To ensure 100% quality steam for conventional SAGD operations, separation systems are used to ensure that the steam will produce "the required 100% steam quality for SAGD process" (Heins, 2009, p. 29). Mixing cooler solvent with the steam will result in part of the energy of the steam being used to heat up the solvent. This will result in a reduction in the quality of the steam and an impairment of the steam being used for the SAGD process.

To avoid this issue, the solvent needs to be heated prior to mixing with the steam, this will reduce the issue of water condensing prior to reaching the reservoir. Transporting solvents, either the butanes used in SAP or the other hydrocarbons used with the SA-SAGD process, could occur at elevated temperatures and pressures. Butane is normally a gas at normal temperature and pressure with a boiling point of -0.6 $^{o}$C (Mannan, 2012). If butane for a solvent assisted process is transported in a pipeline at elevated temperature and pressure, there is the potential for a vapour cloud to be released. Based on molecular weights, with air having a molecular weight of about 29 kg / kmol and butane having a molecular weight of 58 kg/ kmol, the butane molecule is heavier than air. This means that if there was a release from a pipeline containing butane, the vapour would fall towards the ground and could result in a vapour cloud near the ground. This could pose some safety and design concerns as there could be ignition sources at the ground that could ignite such a vapour cloud. Some potential ignition sources could be motor vehicles passing through the area. A phase envelope for butane can be found in Figure 42; this phase envelope was developed using the AspenHYSYS (Version 8.6) process simulator. The left side of this phase diagram is the liquid only region, the narrow band is the mixture of liquid and vapour and the right-hand side is the vapour only region.

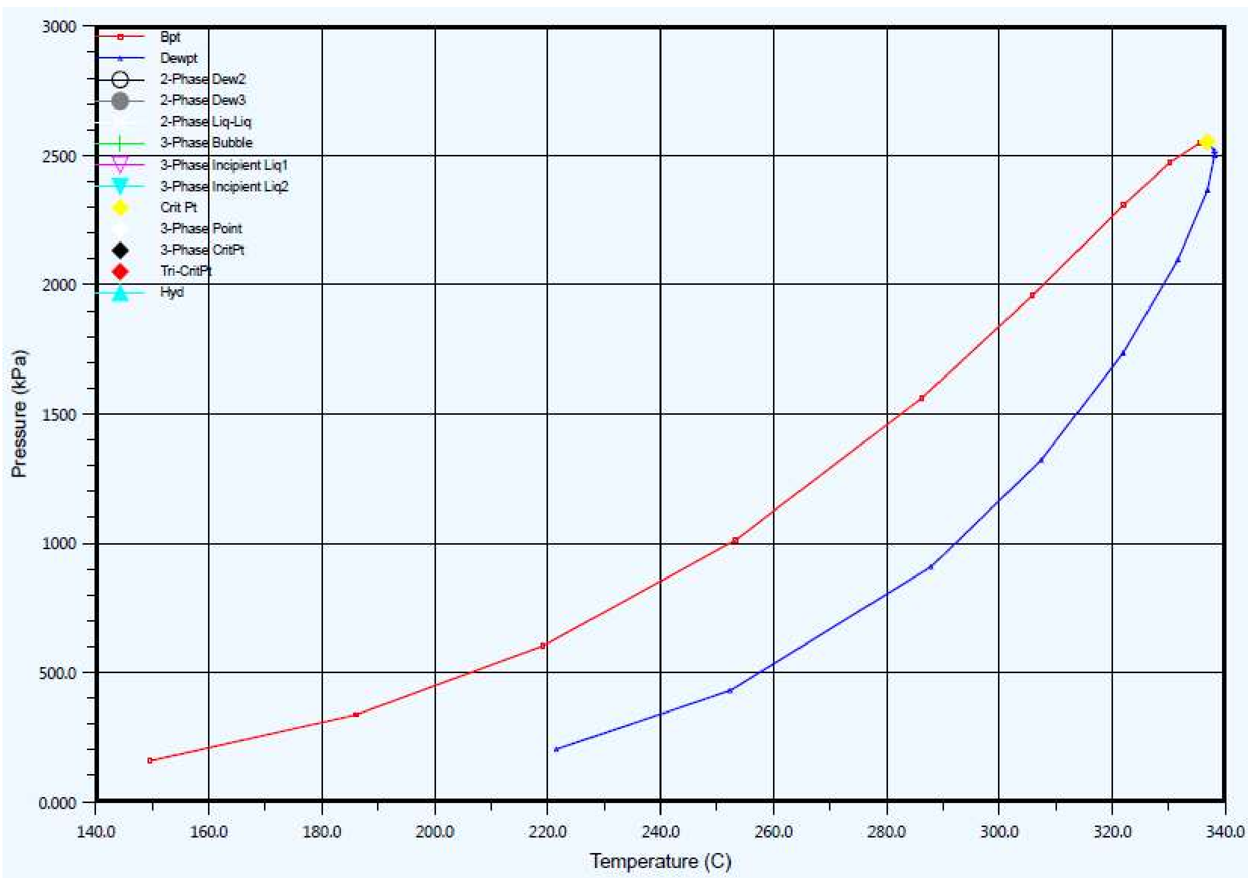
**Figure 42 - Phase Diagram for SAP Solvent**




(Source: Author)

The solvent for the SA-SAGD process is a heavier solvent. Heavier hydrocarbons typically have higher boiling points and this may reduce the vapour forming potential arising from such solvents. If there is any lighter hydrocarbon vapour created with a potential release, any vapour that would be produced would be heavier than air and could collect in lower lying areas and could be prone to an unintended ignition of a vapour cloud. For steam generated at 10,000 kPag, the saturated steam temperature is about 311 °C. For the SA-SAGD solvent, these conditions are above the critical point and there is no vapour present below 150 ºC as seen in the phase envelope shown in Figure 43. The solvent for SA-SAGD appears to have a lower risk associated with release, however the presence of trace light end components could result in the formation of vapour clouds. As the composition of the SA-SAGD solvent was obtained from scaling information from a chart (Khaledi et al., 2015), there could be trace lighter end components that have not been considered.

**Figure 43 - Phase Diagram for SA-SAGD Solvent**




(Source: Author)

Further evaluation of the potential for vapour clouds to occur in the event of a solvent pipeline breach should be considered prior to the widespread application of solvent assisted processes.

# Chapter Fourteen: Future Work

## 14.1. Policy Development

The work of OSAG has not yet been completed as consultation activities are underway and the associated regulations have not yet been developed. One area where the research in this project regarding the emissions intensity of SAGD and the 100 megatonne cap could continue and be further developed is to continue to evaluate and analyze the process as it progresses. If I had the opportunity to participate in an OSAG session, or if I were to share the results of this research with OSAG, this could provide means to further understand the policy development with respect to the 100 megatonne cap.

Another area where additional work could occur with respect to policy development is to better understand the concerns from industry, but focusing on companies that were outside the initial group who commenced working with the GoA on the CLP and the emissions cap. Some midsized producers have indicated concerns in the media about the climate policy; ensuring that these voices are engaged would help to ensure effective policy development that has a broader range of support.

## 14.2. Technical Issues

One key technical issue is related somewhat to policy development. It would be beneficial to further understand the impacts of reservoir quality on emissions intensity. An improved understanding would help to understand how to better treat producers with existing assets in poor reservoirs. This work would also assist in the development of regulations concerning government regulations on what bitumen resources could be considered uneconomic.

A second technical area where further work would be beneficial concerns safety and risk issues associated with the transportation of high-pressure and high temperature solvents via pipeline. Evaluation of different configurations, and the safety implications of each would be beneficial. Scenarios to be investigated for solvent transportation could include:

- Mix heated solvent with steam at the CPF and convey via a single pipeline
- Route solvent at low temperature and low pressure via pipeline to wellpads with heating and pumping occurring at the wellpad
- Pump high pressure, high temperature solvent from the CPF via separate pipeline and mix at the wellpad

### 14.3. Economic Breakdown

Having an improved understanding of the supply costs and levers associated with existing SAGD production and the potential impacts of solvent assisted processes on economics is an area where further work is recommended. In particular, a focus on the GHG implications of the economics of SAGD production would be beneficial. Some of this work may need to wait until the recommendations of OSAG have been finalized. Another area where further economic work is warranted surrounds a detailed breakdown of both the supply cost and the capital cost of oil sands projects compared to other hydrocarbon developments. This breakdown would include what component of cost (either for operational or construction phases) is due to local costs of labour, what is due to the CLP, what is induced by the 100 megatonne emissions cap and the like. Compilation of a detailed listing of components for comparison would be the first step in this work.

# Chapter Fifteen: Conclusion

## 15.1. Impact

I have developed an improved understanding of how newer technologies for in-situ SAGD production have the potential to reduce GHG intensities. The application of such technologies will allow for the production of more bitumen under the 100 megatonne emissions cap that is part of the CLP. The work regarding progression of the CLP policy imitative through to development of regulation was reviewed and analyzed. First, the work concerning the methane regulation was discussed to provide insights for how the work that OSAG is still progressing might be improved. A high-level understanding of the economic drivers for solvent assisted SAGD was outlined. The key parameter for such solvent assisted processes appears to be maximizing the recovery of injection solvent. Another impact is an improved understanding of how the management of the absolute emissions cap from the oil sands will be managed and regulated.

## 15.2. Audience

The audience for this research includes industry practitioners who may gain a better understanding of the policy elements at play in the oil sands and how the oil sands emissions cap could influence their future development plans. Those developing policies in the oil sands are also an audience as this work may better help them understand the different potential technologies at play for in-situ bitumen extraction that could result in reductions in GHG emissions. Those involved in planning future in-situ projects may be interested in the findings regarding economic performance, in particular the need to maximize the recovery of injected solvent.

### 15.3. Outcome

One outcome of this work is a better understanding of how corporate plans, development of new in-situ projects and regulatory requirements all fit together to develop a lower carbon footprint for the in-situ recovery of bitumen resources in Alberta. I believe this project can increase awareness of the impacts of solvent based processes that might lead to a more rapid adoption of lower intensity in-situ recovery techniques. I've also identified areas of future work that could benefit the bitumen industry, these include further evaluation of policy development, increased understanding of technical issues concerning reservoir quality and the transportation of solvent. A better understanding of the components and factors that influence SAGD economics to provide comparison to other hydrocarbon sources is also an area where further work is recommended.

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