Solvent Driven Process - SDP

Public Final Report

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Prepared for

Alberta Innovates

Prepared by

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Table of Contents

LIST OF FIGURES

LIST OF TABLES

3. EXECUTIVE SUMMARY

The pilot project tested an oil sands extraction technology using a solvent-driven process (SDP). This involved co-injecting solvent with steam into a well at Cenovus's Foster Creek operation after approximately one to two years of steam-assisted gravity drainage (SAGD). Unlike in previous solvent pilots conducted by Cenovus, the majority of the steam-solvent mix in this demonstration project was solvent (between 50-95% by weight). Among other things, the demonstration project evaluated the reduction in steam requirements with the goal of developing a technology that can potentially lower the cumulative steam-to-oil ratio (CSOR) significantly and with that, water treatment costs associated with steam generation.

SDP technology could lead to increased market competitiveness and environmental performance resulting from more efficient bitumen production and lower energy costs, all while lowering water use and greenhouse gas emissions (GHG). Specifically, if the technology were to be deployed commercially, the SOR, the amount of steam needed to produce one barrel of oil, and the related GHG emission intensity of in-situ oil sands operations could be reduced significantly.

The pilot was conducted on a SAGD pad at Foster Creek, one of our two producing oil sands projects in northeastern Alberta.

Figure 1: SAGD pad

The historic SOR in Foster Creek has ranged between 2 and 3 over the past 20 years; the goal of this project was to develop a technology that can potentially lower the SOR values associated with oil sands production significantly.

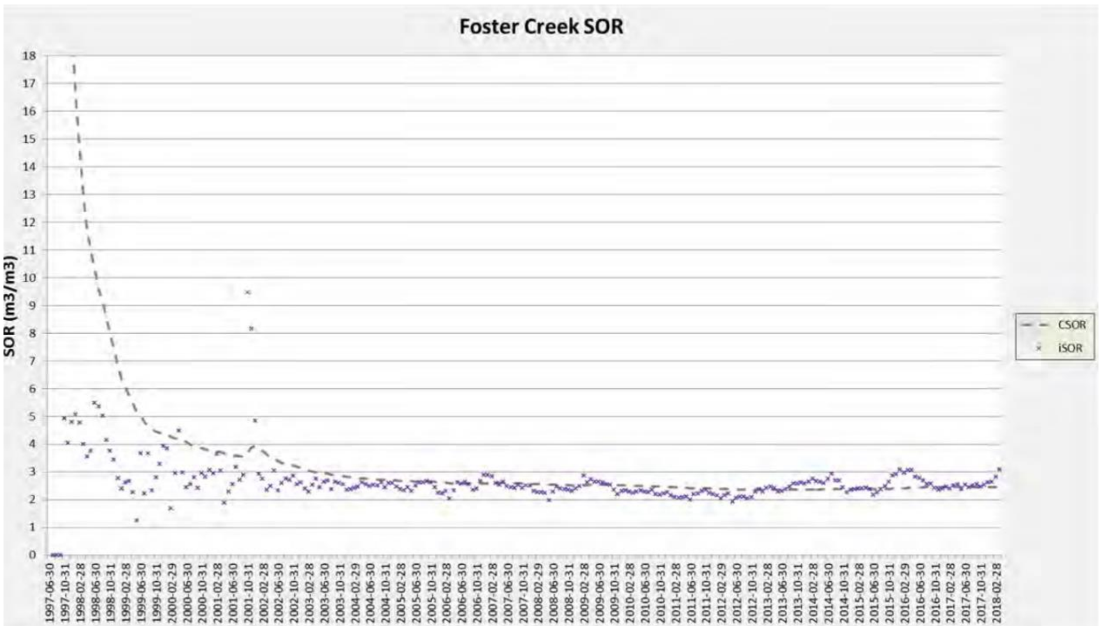

Figure 2: Foster Creek Historic SOR

The pilot was expected to yield a 20% reduction in the CSOR values and associated GHG emissions intensity 18 months after the completion of the pilot. A lower SOR contributes to lower capital and operating costs, smaller surface footprint, lower energy usage, lower emissions intensity, and less water usage. The pilot, therefore, investigated the efficiency of steam and solvent co-injection in terms of the amount of oil recovered. Reductions in SOR values were to be achieved by decreasing the amount of steam used while maintaining oil production rates similar to SAGD. The annual emissions reduction for the purpose of this report was calculated to be 12.2 kTC02e/year based on data collected in 2018 and 2019. The significant GHG emissions reduction is related to CSOR reduction by 40% and iSOR reduction by over 80% , which was achieved after two (2) years of operation.

4. INTRODUCTION

Sector Introduction

Cenovus began independent operations on December 1, 2009 when Encana Corporation split into two distinct companies: one an oil company (Cenovus), the other a natural gas company (Encana). At Cenovus, we're focused on maximizing value by sustainably developing our assets in a safe, innovative and cost-efficient way, integrating environmental, social and governance (ESG) considerations into our business plans. Operations include oil sands projects in northern Alberta, which use specialized methods to drill and pump the oil to the surface, and established natural gas and oil production in Alberta and British Columbia. We also have 50% ownership in two U.S. refineries.

A global transition to a lower-carbon future is underway, and Cenovus intends to be a part of that future. On January 9, 2020, Cenovus announced ambitious targets in its four ESG focus areas: climate and GHG emissions, Indigenous engagement, land & wildlife, and water stewardship. Sustainability considerations have also been incorporated into Cenovus's capital allocation framework to support investment decisions. These targets reflect the company's continued integration of sustainability into its strategy and business plan to help foster long-term resilience. The following ambitious targets have been established to be met by 2030:

Table 1: 2030 ESG Targets

Focus Area	2030 Targets
Climate & GHG emissions	• Reduce emissions intensity by 30% • Hold absolute emissions flat
Indigenous engagement	• Achieve a minimum of $1.5 billion of additional spending with Indigenous businesses Land
Land & wildlife	• Reclaim 1,500 decommissioned well sites • Complete $40 million of caribou habitat restoration work
Water stewardship	• Achieve a fresh-water intensity of maximum 0.1 barrels per barrel of oil equivalent

The company has demonstrated leadership through per-barrel GHG emissions reductions at its oil sands operations of approximately 30% over the past 15 years. Building on this, the 2030 GHG emissions targets are among the most ambitious in the world for an upstream exploration and production company. The company is adopting a GHG emissions strategy that includes multiple options to reach its targets.

Opportunities that have been identified are at various stages of advancement, and include: additional operational optimization, incorporating cogeneration capacity into future oil sands phases, further advancement of the methane emissions reduction initiatives, and more extensive deployment of solvent technology.

Cenovus is already a leader in managing fresh-water intensity compared to its oil sands peers and has set a target across its oil sands and Deep Basin operations of a maximum of 0.10 barrel of fresh-water use per barrel of oil equivalent by the end of 2030. This exceeds a target set by Canada's Oil Sands Innovation Alliance (COSIA) for in-situ producers of 0.18 barrel by 2022. It is expected that solvent technology has the potential to significantly contribute to Cenovus' continuous progress on its environmental performance in the area of GHG emissions and water use.

Technology Gaps

To help ensure that Cenovus can remain both cost and carbon competitive, we're focused on developing technologies to help us reduce emissions and improve our environmental performance while also increasing our efficiency and reducing costs. The SDP technology addresses the existing solvent technology gap of operating independently of steam to the extent that bitumen production is maintained and GHG emissions and water use are materially reduced.

The Government of Alberta recently replaced the *Carbon Competitiveness Incentive Regulation (CCIR)* with the *Technology Innovation and Emissions Reduction (TIER) Implementation Act*, which regulates GHGs for large industrial emitters (i.e. those emitting 100,000 tonnes CO_2e or more per year). The TIER system took effect on January 1, 2020, and regulated facilities can meet compliance requirements under TIER by reducing emissions or:

1) Using credits from facilities that have met and exceeded their emissions targets.
2) Using emission offsets from organizations that are not regulated by TIER, but have voluntarily reduced their emissions.
3) Pay into the TIER Fund at $30 per tonne.

In order to grow bitumen production within the province, new technologies are required. By implementing new technologies that have a much lower to allow a reduction in emissions intensity, new development can occur. SDP technology, if commercialized and adopted broadly, could be the single most effective solution available today to enable and drive the sector's growth while reducing emissions intensity. Like all new technologies, it is difficult to forecast a rate of adoption until successful pilot characteristics are known. However, if successful at the pilot stage, the plan may be to consider accelerated deployment to new projects.

5. PROJECT DESCRIPTION

Technology Description

The FC W06-08 demonstration project tested an oil sands extraction technology using a solvent-driven process (SDP). This involved co-injecting solvent together with steam into a well at Cenovus's Foster Creek oil sands operation after approximately one to two years of steam-assisted gravity drainage (SAGD). Unlike in previous solvent pilots conducted by Cenovus, most of the steam-solvent mix in this demonstration project was solvent (between 50 and 95 weight percent). The steam heated the solvent to about 190°C, and the heat and solvent were expected to sustain steam chamber growth in the reservoir. Among other things, the objective of the demonstration project was to evaluate the reduction in steam requirements with the goal to develop a technology that potentially can significantly lower the cumulative steam-to-oil ratio (CSOR) and with that, water treatment costs associated with steam generation.

Updates to Project Objectives

The SDP pilot started in September 2017 and is currently approved to operate for six more years. There are no changes to report related to the goals and objectives of the project.

Over the course of this project the following objectives were evaluated:

- Quantify the effect of a solvent-driven process on the oil production rate
- Evaluate the impacts of the project on steam-oil ratio (SOR)
- Evaluate steam chamber lateral growth
- Quantify expected recovery of propane
- Quantify actual project GHG emission reductions and water use reduction, and
- Confirm via demonstration total environmental benefits and cost reductions if commercially implemented.

Performance Metrics

The goal of the pilot demonstration was to help determine if the SDP injection can provide positive, economically feasible and a more environmentally friendly recovery scheme. This was be evaluated based on the following metrics (please also find the current status):

- Safe operation of the pilot – ongoing
- Cumulative recovery should be similar between SAGD and the SDP Process Production – confirmed
- Any decrease in oil production rate when propane injection starts is made up within 18 months of being on propane injection – ongoing
- Produce at least 60% of the injected propane back on a cumulative basis within 18 months of when propane injection stops – ongoing
- Reduce the CSOR by at least 20% (compared to SAGD baseline) by the time that propane injection stops after the proposed 18 months of injection. Please note that to date, the CSOR was reduced by 40%.

After two years of operation the following results were obtained:

- CSOR declined by 40%; based on the initial metric the ambition was to reduce the CSOR by at least 20% (compared to SAGD baseline) by the time that propane injection stops after 18 months of injection. This objective was clearly achieved earlier than expected. The cumulative steam injection reached 180,000 m3, and about 60,000 m3 of oil was produced during the SAGD baseline period, in line with the estimated SOR of 3. Throughout the SDP pilot, 40,000 m3 (or 250,000 bbl) of oil was produced with about 15,800 m3 of steam being injected, confirming an SOR close to 0.4. During the SDP pilot period, about 40,000 e3m3 of solvent was injected to achieve >80% reduction in SOR and GHGs emitted comparing to the operating well baseline.
- Low water-cut of about 25-40% was achieved and is currently levelled off at 35%. This was correlated to the emulsion rate drop from about 20 m^3/hr to 4 m^3/hr, which could have probable benefits when designing new facilities for water treatment as well reduction in overall water requirement injected and produced during this recovery scheme.

The energy intensity associated with the mixture injection as per the conducted simulation suggests reduction in energy intensity of >80%. This is assuming enthalpy of steam at 2.64 MJ/kg at 92% steam quality vs. the SDP injection mixture enthalpy of 0.528 MJ/kg. One of the main assumptions in this calculation was that the solvent injected didn't add any energy when mixed with steam although this value could vary. The official reduction in emissions number for the pilot is 93.3% based on the reduction in steam of about 91%. These values could have varied if the pilot was operated on a geologically different well. Thus, its practical to assume a reduction of >80% in GHGs, energy intensity and SOR when utilizing the SDP technology.

Project Success Metrics

Presented below are the results of the Program Specific metrics:

- The current oil rate is in line with SAGD-like production. On the cumulative basis, the project team has produced over 40 kT of bitumen during the SDP implementation period. During the baseline SAGD period we produced about 60 kT of bitumen from June 2016-Oct 2017. As seen in the graph below, the slope of the cumulative oil produced didn't decline over time suggesting cumulative bitumen production is similar between SAGD and the SDP as was proposed in our project objective metrics.

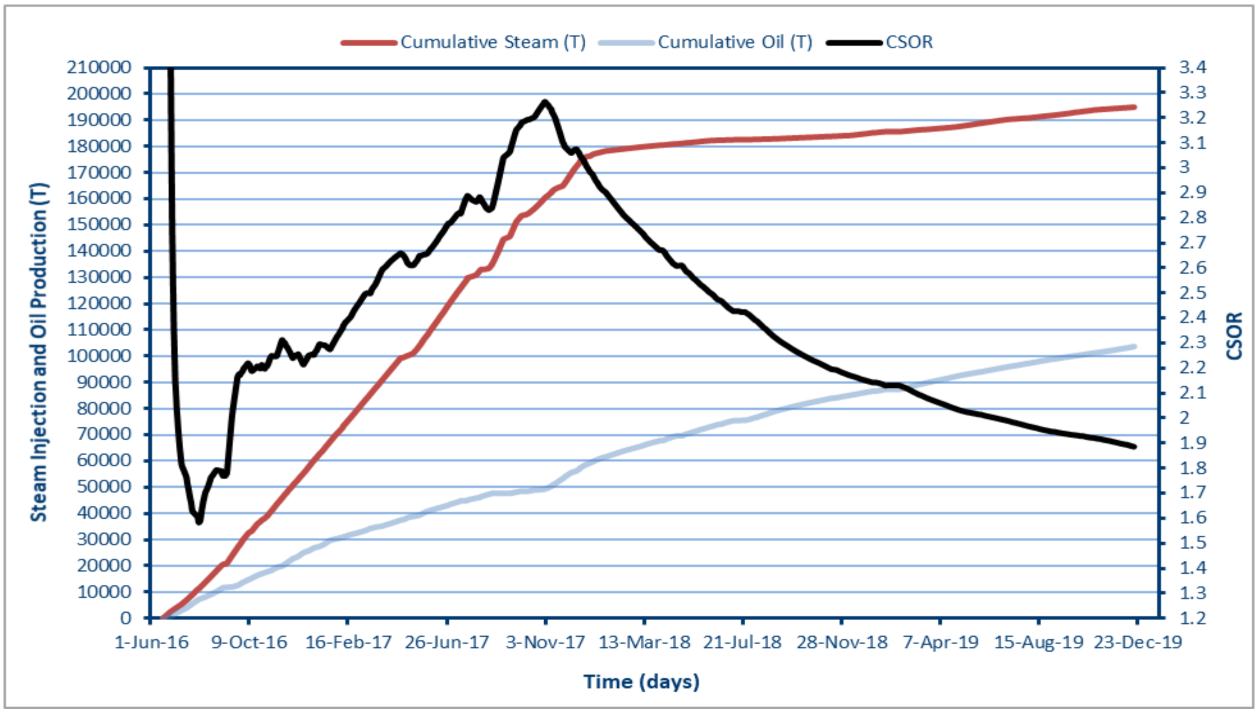

Figure 3: Current status of cumulative oil production, steam injection, and CSOR

Moreover, the cumulative steam injection reached about 180 kT when the SDP pilot started and remained in the 180 kT-200 kT range; This was attributed to the lower steam injection rates associated with SDP. As mentioned, CSOR declined by 40% during the SDP period.

Moving forward, we will continue monitoring the piloted well and collect more data. The Solvent Recovery Factor will be closely watched, and we are currently optimistic that we can produce at least 60% of the injected propane back on a cumulative basis within 18 months of when propane injection stops as per the initial metric

6. METHODOLOGY

The following table provides the engineering project equipment requirement and activity progress in a chronological order:

Table 2: Equipment and facilities

Activity	Baseline schedule	Actual
P&ID IFH	Oct 14 2016	Oct 14, 2016
P&ID Pump and unloading skid IFC	Nov 29 2016	Jan 16, 2017
Earthworks CWP	Oct 19 2016	Oct 19, 2016
P&ID field IFC	Dec 21 2016	Mar 22, 2017
Piling CWP	Jan 17 2017	Mar 15, 2017
Structural CWP	Feb 10 2017	May 15, 2017
Piping CWP	Feb 02 2017	May 10, 2017
Construction Completed	Q3 2017	Aug 03, 2017
Commissioning Completed	Q4 2017	Sep 20, 2017
Propane injection Initiated	Q4 2017	Sep 27 2017

The following table summarizes the milestones with their progress status:

Table 3: Methodology and progress

Task Description	End Date	Milestones/ Deliverables	Progress
General Engineering/ Design Start *** CVE did not apply for matching funding as this activity was earlier than Sept. 7th 2016**	Jan 1, 2017	• Initial design of the demonstration scheme • Reservoir engineering simulation, quality assurance, forecasting work • Funding approved, stage gated QA and internal approval process is complete • Reservoir behavior forecast, economic evaluation, steam input reduction calculations • Stakeholders identified, contractors have been selected • Permits received • AER application approved	100%
Tie-in work, pump pre-ordering. Consulting & Evaluations, TSE, Programming and Commissioning	Jan-31, 2017	• Solvent injection line integration at the pad • All permits obtained • Injection of solvent would be possible • Purchase orders, constructs with suppliers.	100%
Injection Pump Skid Delivery, Engineering	Mar-31, 2017	• Installation of the solvent pump skid and construction (Solvent fluid will be able to move from the tanks to the reservoir via the pump) • Commissioning reports	100%
Construction Mechanically Complete	Aug-1, 2017	• Engineering work to tie-in the process equipment related to injection skid, measurement facility on site • Mechanical work ready for Cenovus to be able to initiate the demonstration and start solvent injection during 2017	100%
Commissioning and start of injection, continuous	Jun-1, 2019	• Safe demonstration of the SDP technology • Maintain similar oil recovery to SAGD, use steam for the	100%

Task Description	End Date	Milestones/ Deliverables	Progress
measurement of the disclosed variables		purpose of heating the solvent propane only • Measurements are properly collected and analyzed	
Comprehensive report after 6 months of solvent injection	Mar-1, 2018	• Comprehensive report after 6 months of solvent injection	100%
Comprehensive report after 12 months of solvent injection	Sep-1, 2018	• Comprehensive report after 12 months of solvent injection and report overall cost for 2018 by September 1.2018	100%
Analysis and Reporting	Feb-1, 2020	• Analysis and interpretation completed • Draft reports, Final Report, Database	100%
Knowledge Transfer and Dissemination	Feb-1, 2026	Comprehensive knowledge sharing goals achieved	Pending

7. PROJECT RESULTS

First injection on the piloted well started in late September 2017 as shown in the following graph. As seen, the baseline steam injection was at about 324 m^3/D and the oil production was ranging around the 85 m^3/D during the six months SAGD baseline in 2017. The average monthly SOR was 3.86 for the first six months of 2017 and about 3.2 for the SAGD baseline time period.

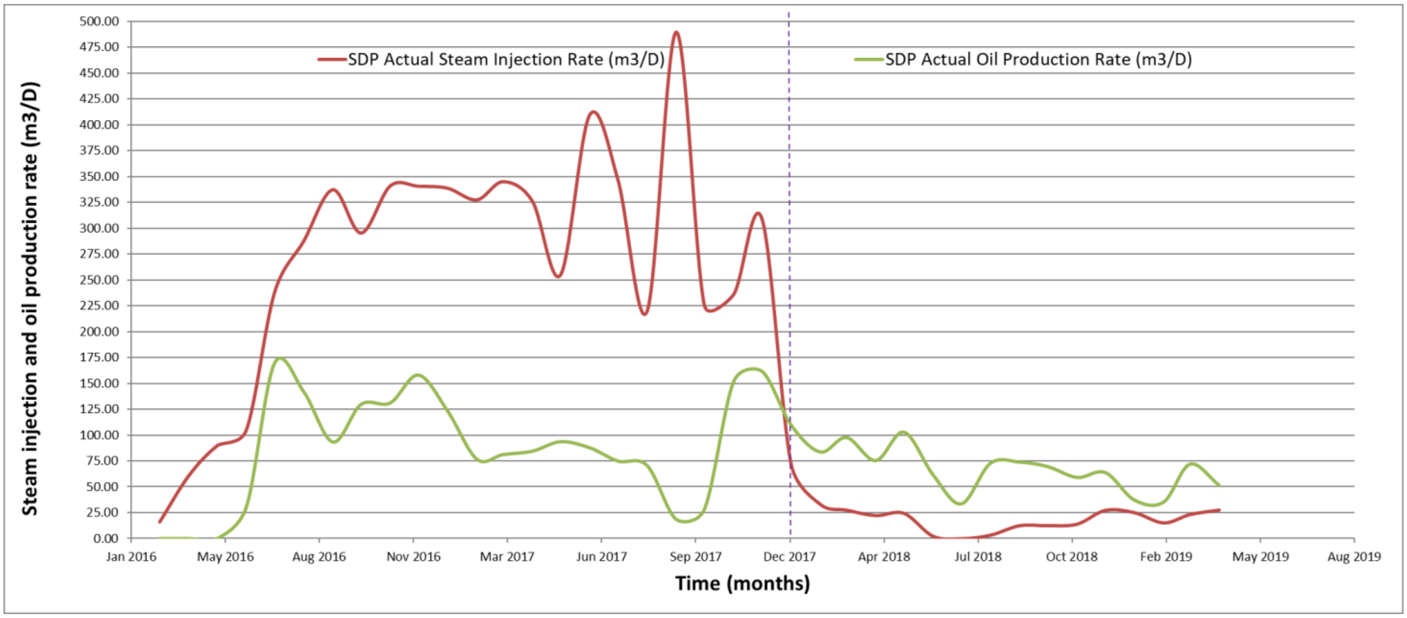

Figure 4: Current status of the pilot

Solvent injection was initiated in September 2017, resulting in steam injection rates declining by over 90% to about 30 T/d in roughly three months. In April 2018 the oil rate was at about 75 T/d and after one year fluctuated around the 60 T/d range. The monthly SOR during the SAGD baseline ranged between 1-10 with an average baseline SOR being about 3.2. The SDP monthly SOR during the pilot was below 1 between December 2017 and April 2019. The water cut recorded was about 0.8 during the SAGD stage and declined to 0.3 by July 2018.

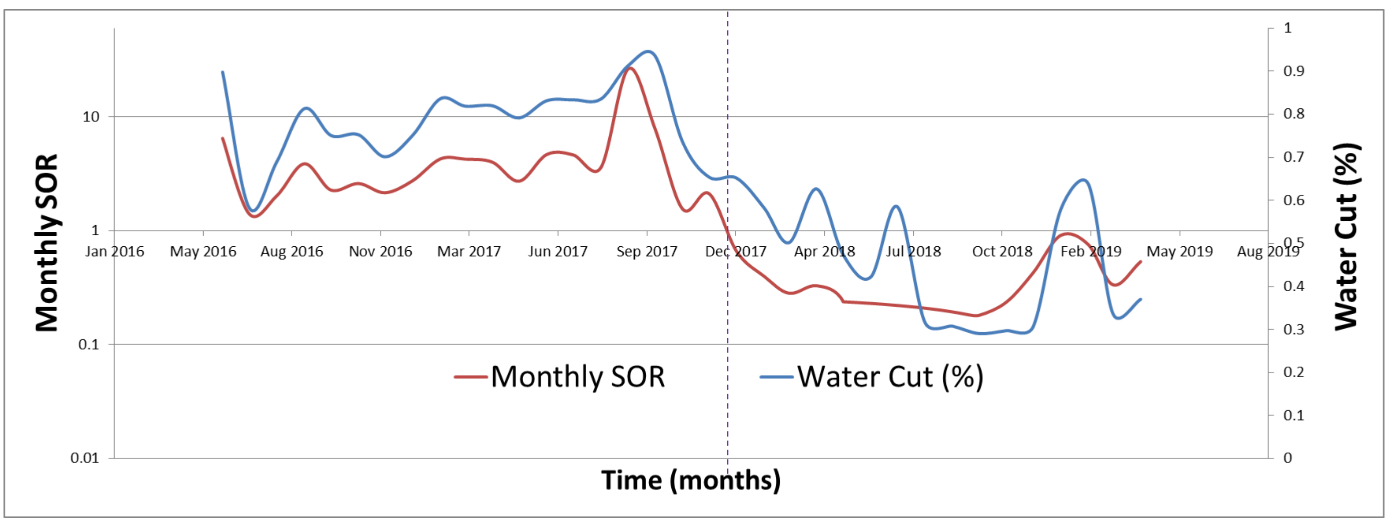

Figure 5: Produced emulsion water cut and Monthly SOR

The cumulative steam injection reached 180,000 m^3, and about 60,000 m^3 of oil was produced during the SAGD baseline period, in line with the estimated SOR of 3. Throughout the SDP pilot, 40,000 m^3 (or 250,000 bbl) of oil was produced with about 15,800 m^3 of steam being injected, confirming an SOR close to 0.3.

During the SDP pilot period, close to 40,000 e^3m^3 of solvent was injected to achieve >80% reduction in SOR comparing to the operating well baseline.

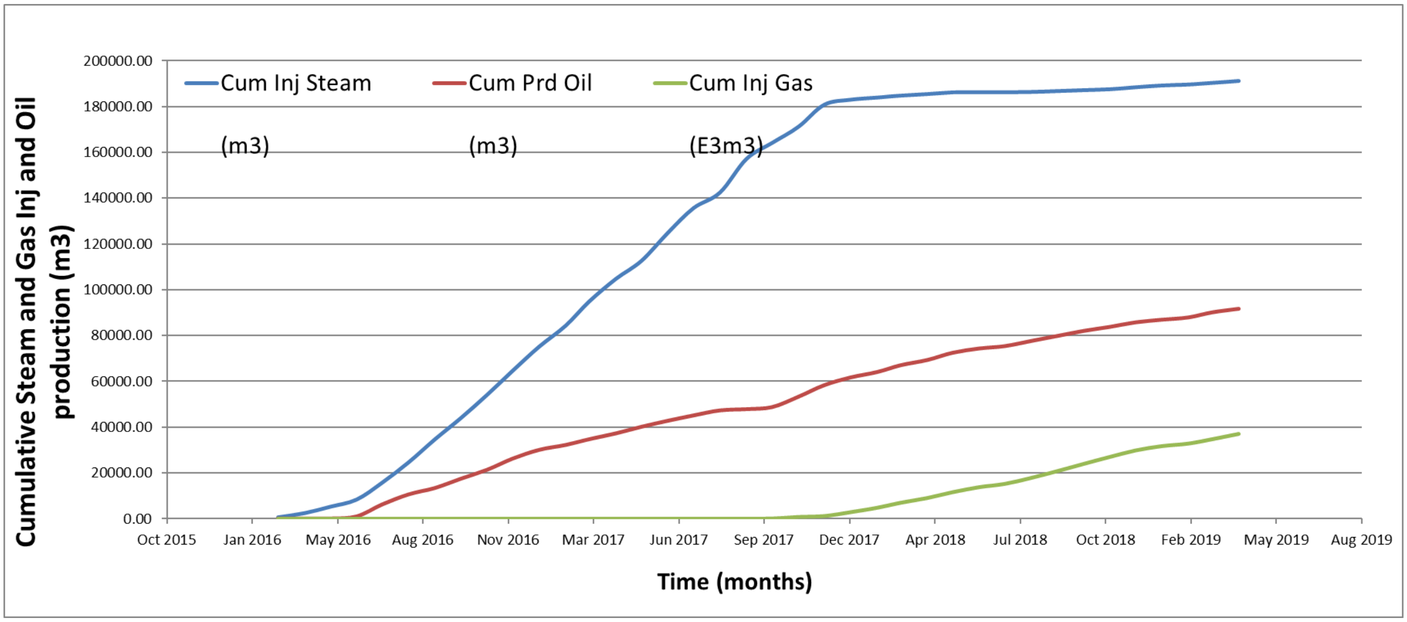

Figure 6: Cumulative Steam Injection, Oil production and Solvent Injection

The SOR reflects resource quality and execution and is one Cenovus's key metrics to measure the efficiency of its oil sands operations. A lower SOR contributes to lower capital and operating costs, smaller surface footprint, lower energy usage, lower emissions intensity and less water usage. Cenovus is the largest SAGD producer by production, with consistently one of the lowest SORs in the industry.

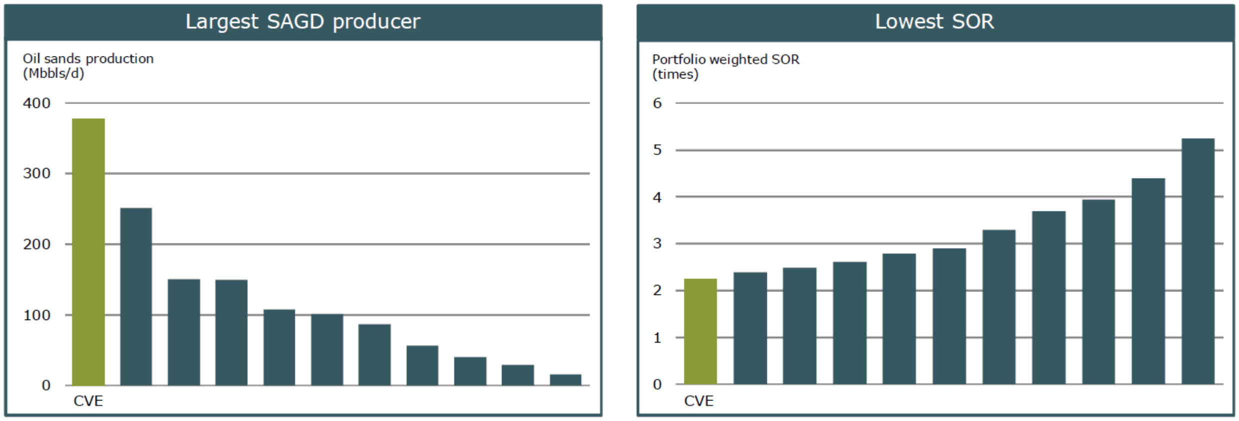

Figure 7: Cenovus Production and SOR

Note: Production data and steam-oil ratio based on AER data as of September 2018, prior to voluntary curtailment in Q4 2018 and mandatory curtailments in 2019. The portfolio-weighted SOR was calculated based on project operator and is a measure of current project efficiency. Peers include ATH, COP, CNOOC, CNQ, DVN, HSE, IMO, MEG, PGF, and SU. The SOR at Cenovus's Christina Lake oil sands project was 1.9 in 2018, while Foster Creek's SOR was 2.8.

The following graph shows the direct GHG emissions in our oil sands assets.

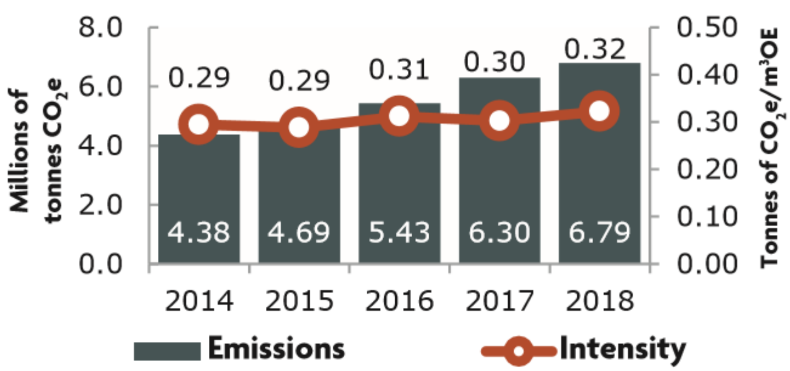

Figure 8: 2013-2018 Direct GHG emissions-oil sands

The energy intensity recorded in 2017 was 0.3 tonnes CO_2e / m^3OE with a comparable value in 2018. With Foster Creek's SOR being 2.8 in 2018, we can calculate the associated energy intensity reduction achieved during the SDP pilot. The average monthly SOR during the SDP pilot was 0.4. Thus, when using a proportional SOR reduction calculation assuming SAGD-like oil rates, we get a reduction in emissions at about 90%. The demonstration well is expected to continue producing about 40 T/day of bitumen in 2020. The annual emissions reduction for the purpose of this report was calculated to be 12.2 kTC02e/year based on the data collected in 2018 and 2019. The significant GHG emissions reduction is related to CSOR reduction by 40% and iSOR reduction by over 80% , which was achieved after two (2) years of operation. The potential for replication increases the environmental benefits proportional to the deployment rate. For example, one scenario could include that after five years post project completion at least one pad could be utilizing this technology. If that's the case, about 0.5 MT of $C0_2$ could be reduced from being emitted on that pad only if the pad has eight (8) well-pairs and has been running on SDP for at least five (5) years.

8. KEY LEARNINGS

The goal of the pilot demonstration was to help determine if SDP can provide positive, economically feasible and a more environmentally friendly recovery scheme. This was to be evaluated based on the following metrics (please also find the current status):

- Safe operation of the pilot – ongoing
- Cumulative recovery should be similar between SAGD and the SDP Production – confirmed
- Any decrease in oil production rate when propane injection starts is made up within 18 months of being on propane injection – ongoing
- Produce at least 60% of the injected propane back on a cumulative basis within 18 months of when propane injection stops – ongoing;
- Reduce the CSOR by at least 20% (compared to SAGD baseline) by the time that propane injection stops after the proposed 18 months of injection. Please note that to date, the CSOR was reduced by 40%.

The current oil rate is in line with SAGD-like production. On a cumulative basis, the project team has produced over 40 kT of bitumen during the SDP implementation period. During the baseline SAGD period we produced about 60 kT of bitumen from June 2016-Oct 2017. As seen in the graph below, the slope of the cumulative oil produced didn't decline over time, suggesting cumulative bitumen production is similar between SAGD and the SDP as was proposed in our project objective metrics.

Moreover, the cumulative steam injection reached about 180 kT when the SDP pilot started and remained in the 180 kT-200 kT range. This was attributed to the low steam injection rates associated with SDP. As mentioned, CSOR declined by 40% during the SDP period.

The SDP technology may facilitate steam reduction and therefore result in a steam reallocation to increase active well count (and oil rate) without investment in additional steam generation facilities or increases in SOR and GHG emissions. As wells age and reservoirs are depleted, SOR is expected to rise unless new technologies such as SDP are developed and commercially integrated. SDP provides a reduction of 12.2 kTC02e/year per well assuming similar well characteristics as seen in W06-P08.

Project Outputs

Cenovus external website: https://www.cenovus.com/technology/solvents.html

ESG report for 2017 and 2018: https://www.cenovus.com/reports/2018/2018-esg-report.pdf

Investor Day 2019:
https://www.cenovus.com/invest/docs/2019/2019%20Investor%20Day%20Presentation.pdf

Presented at the Alberta Innovates Solvent forum to government and peer companies on methods and learnings from the pilot measurement plan: https://albertainnovates.ca/programs/cleaner-hydrocarbon-production/solvent-leadership-series/

Presented at the Alberta Innovates Solvent forum to government and peer companies on safety during solvent operations: https://albertainnovates.ca/programs/cleaner-hydrocarbon-production/solvent-leadership-series/

9. BENEFITS

Environmental

The demonstration well is expected to continue producing about 40 T/day of bitumen. The immediate benefit due to the demonstration only is an emissions reduction of about 12.2 kTCO2/ year. The annual emissions reduction for the purpose of this report was calculated to be 12.2 kTC02e/year reduction after including 2018-2019, two (2) years for the timeframe of the pilot. The GHG emissions reduction associated with the project's success is a function of CSOR reduction by 40% and iSOR reduction by over 80% ,which was achieved after two (2) years of operation. The potential for replication increases the environmental benefits proportional to the deployment rate. For example, after five years post project completion at least one pad is expected to be utilizing this technology. If that's the case, about 0.5 MT of C02 will be reduced from being emitted on that pad only if the pad has eight (8) well-pairs and have been running on SDP for at least five (5) years.

Social

Cenovus continues to focus on delivering leading environmental, social and governance (ESG) performance. This includes identifying meaningful, practical targets and plans to achieve them for its four ESG focus areas: climate and GHG emissions, Indigenous engagement, land & wildlife, and water stewardship. The key social metric associated with the pilot is related to GHG reduction and advancing our environmental performance.

Economic and Building Innovation Capacity

-The overall expenses associated with the pilot are at $20,988,334. Out of that amount about $9,900,000 was spent on the solvent and the other portion was spent on equipment and services. Considering the amount spent related to equipment, consulting and services it is safe to estimate FTE HQSP trained at about 20 FTE.

- About $2,154,154 was spent of salaries/benefits over the course of the pilot suggesting FTE job retainment for about 11 employees. It is important to consider that there was a lot of part time effort from various teams during the injection skid design and production engineering and monitoring phases.

- The pilot project used a digitally innovative Advanced Process Control (APC) application during the solvent-driven process (SDP) pilot. The application supported the digital optimization of multiple control points including the pump speed, bottom hole pressure, multi-phase and multi-component injection and production rates.

10. RECOMMENDATIONS AND NEXT STEPS

The SOR of existing in-situ oil sands operations could be reduced significantly if SDP technology were applied on a commercial scale. New in-situ projects may also emit less GHGs while lowering capital requirements associated with reduction in water treatment and steam generation costs. To advance this technology toward a pad scale commercial deployment, further learnings are required as we continue running the pilot in the field to test until 2026. Cenovus would like to thank Alberta Innovates and NRCAN for their sponsorship and partnership in advancing SDP technology.

11. KNOWLEDGE DISSEMINATION

Cenovus may feature SDP technology in a range of company materials and events, including in news releases, on its website and other online platforms, in public reports and speaking engagements as well as through industry-related peer organizations. The external communication and knowledge dissemination plan may include the following vehicles:

- Social media
- Cenovus.com
- Internal website (intranet)
- Media interviews
- Liaise through COSIA and/or CAPP to promote it
- Promote it at speaking events (we do approximately 30 – 80 a year)
- Corporate Responsibility report
- Society of Petroleum Engineers (SPE) conference presentations and papers
- Annual Report
- Quarterly results
- News (press) release
- Local media updates in operating communities and magazines

Cenovus follows the required AER regulatory reporting processes. Cenovus is committed to operating in a way that maintains and enhances our reputation and therefore will provide reporting due diligence within the required guidance. According to AER approvals, Cenovus provides annual updates on Foster Creek activities. This project will be included in these annual updates.

12. CONCLUSIONS

The novel solvent-driven process (SDP) presented in this document was testing an oil sands extraction technology which involved the co-injection of up to 95% solvent with steam into a well after approximately one to two years of SAGD operation. The project was addressing the existing solvent technology gap of operating independently of steam to the extent that bitumen production is maintained while GHG emissions and water use are materially reduced. After over two years of operating under solvent injection, the following results were obtained: steam injection rates declined by over 90%; monthly SOR values dropped from a range of 1-10 to below 1, fluctuating between 0.4-0.7 between April 2018 and April 2019; the water cut dropped from 80% to 35%; and overall, the SOR values during the SAGD and SDP phases were 3 and 0.3, respectively – translating to a reduction of over 80%. These results suggest that SDP technology may lead to a significant reduction in GHG emissions and water usage in future in-situ processes. Since this process showed increased efficiency while reducing energy requirements, if commercialized, it may make new in-situ processes more economical. Furthermore, the economical value of this technology may become enhanced due to the lower capital requirements associated with water treatment. With new government regulations in place, such as TIER, new technologies are required to allow reduction in emissions intensity and ultimately grow production. SDP technology, if commercialized and adopted broadly, could be the single most effective solution available today to enable and drive the sector's growth while reducing emissions intensity. Moving forward, the project team got a mandate from the Cenovus executive team to continue running the pilot for additional six years. This will allow for more data to be obtained, which will enhance the understanding of the long term performance of this technology.