CYCLIC SOLVENT PROCESS PILOT

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EXECUTIVE SUMMARY

Imperial Oil Resources is conducting a pilot of the non-thermal, in-situ bitumen recovery process, Cyclic Solvent Process (CSP), at Cold Lake under ERCB Approval 11604A, dated January 19, 2016. CSP is a viscous (heavy) oil recovery method that uses primarily hydrocarbon solvents to mobilize bitumen by cyclic stimulation from a preferably horizontal well. The process is targeted at reservoirs where thermal inefficiencies of steam-based recovery processes are of concern. The greenhouse gas (GHG) intensity reduction of about 80% compared to cyclic steam stimulation (CSS) may expand its application to reservoirs where a steam-based process would ordinarily be considered.

Initial development of the project began in August 2010 with preliminary engineering and the drilling of observation (OB) wells in early 2011. CCEMC began contributing to project costs on March 1, 2012. From March 2012 to August 2013, the project was focused on drilling of horizontal wells and detailed design of pilot facilities. During the next reporting period from September 1, 2012 to October 31, 2013, the milestone of Mechanical Completion had been achieved, including completions of OB wells and construction of pilot surface facilities. Following mechanical completion, from November 1, 2013 to April 30, 2014 the tasks required for preparing facilities for startup were completed, including horizontal well completion as well as pre-commissioning and site turnover activities. Pilot operation began in May 2014 and have continued through the end of the reporting period of June 2018.

The overall goals of the pilot were achieved during the CCEMC reporting period. High quality data was obtained to allow definitive interpretation of the pilot results. Sufficient learnings were obtained to assess the commercial viability of CSP. Lastly, necessary operational experience with the process was obtained to enable cost-effective deployment of the technology. CSP technology has been deemed commercially viable through Imperial's internal technology development system. The GHG reductions that are inherent to the process will be realized as the technology is deployed commercially.

1 PROJECT DESCRIPTION

1.1 Technology Description

CSP is a non-thermal, in-situ bitumen recovery process that utilizes injected solvent to reduce the viscosity of the bitumen, enabling its production from the sub-surface. The liquid-phase solvent is injected into a horizontal well in a cyclic manner. The large mobility contrast between the solvent and the bitumen causes the solvent to finger into the bitumen creating the mechanical dispersion and large contact area for rapid mixing of solvent into the bitumen. Solvent injection volumes will grow with each cycle to ensure mixing with previously uncontacted bitumen.

Following injection, pressure is reduced and the mixture of solvent and bitumen flows back to the same horizontal well and is produced to surface using artificial lift. Depending on the solvent, one or two liquid phases are expected. As the pressure in the reservoir falls, the produced fluid rate declines, and the production phase ceases when oil rate is too low or gas production is too high. Reservoir pressure management determines the production volume and solvent recovery during the cycle, which in turn influences long term performance. With production rate decline, a decision is made to end the cycle and inject the next slug of solvent.

Cyclic injection and production operations continue for multiple cycles over several years until the bitumen produced is no longer economic. The cyclic operation is followed by a final blow-down period, when additional solvent is recovered by vaporization at low abandonment pressure.

Since CSP is a non-thermal process, the two key challenges facing traditional thermal processes (e.g. Cyclic Steam Stimulation and Steam Assisted Gravity Drainage) are avoided: (1) production of GHGs arising from burning natural gas to produce steam and (2) thermal inefficiencies which limit applicability to thinner and/or lower bitumen saturation reservoirs.

1.2 Pilot Overview

The pilot is located at K50 pad in Imperial's Cold Lake development and was conducted into the Clearwater formation. Three short-horizontal wells are being operated using CSP as a recovery process.

Surface facilities include receiving and storage facilities for the solvent, a blending and injection system to deliver 150 [m^3/d] of solvent to the horizontal wells, with the capability to inject at double that rate for short durations. The capability to heat the injected mixture is provided for hydrate prevention and surveillance purposes. Production and testing facilities are included and the facility is tied in via buried pipeline to the existing Mahihkan plant.

The pilot is commercial scale, with two exceptions. The horizontal wells are 100 m in length versus a planned commercial design of 1000 m. This change was made to recognize limitations in propane supply given the existing infrastructure. Also, the well spacing is 200 m, a parameter that will be optimized based on the results of the pilot. For the pilot, it is important to minimize well-to-well interference so that repeatable results can be generated on key CSP performance indices. It is expected that commercial spacing will be less than the pilot spacing to improve recovery factor.

Approximately 17 M$ of the total pilot budget has been allocated to surveillance. In addition to collecting injection and production rate and volume data, fluid sampling is used to establish the solvent concentration within the production stream. Temperature and pressure are measured in the horizontal wells and the observation wells. Surveillance plans include repeat 3D seismic surveys and passive seismic monitoring in three of the observation wells. Based on the results and learnings from the cross-well seismic baseline survey, it was determined the value of repeat cross-well surveys is limited and thus was dropped from the surveillance program.

1.3 Well and Pad Layout

The pilot consists of six observation (OB) wells and three horizontal production wells:

IMP 08 OV COLD LK 14-18-65-4 – UWI 1AA/14-18-065-04W4/00
IMP 10 CSP OB-1 LEMING 14-18-65-4 – UWI 105/14-18-065-04W4/00
IMP 10 CSP OB-2 LEMING 14-18-65-4 – UWI 100/14-18-065-04W4/00
IMP 10 CSP OB-3 LEMING 14-18-65-4 – UWI 102/14-18-065-04W4/00
IMP 10 CSP OB-4 LEMING 14-18-65-4 – UWI 103/14-18-065-04W4/00
IMP 10 CSP OB-5 LEMING 14-18-65-4 – UWI 104/14-18-065-04W4/00

IMP 11 CSP H-01 LEMING 3-19-65-4 – UWI 100/03-19-065-04W4/00
IMP 11 CSP H-02 LEMING 14-18-65-4 – UWI 110/04-18-065-04W4/00
IMP 11 CSP H-03 LEMING 14-18-65-4 – UWI 111/04-18-065-04W4/00

The layout of the wells is shown in Figure 1. The six OB wells are drilled from three pads and the three horizontal wells are drilled from a fourth pad, as shown in Figure 2. Well 14-18 was drilled in 2009; the remaining five OB wells were drilled in 2011. The horizontal wells were drilled in March 2012. All wells were completed from late 2012 to early 2013; however, complications in HW2 delayed final completion of the subsurface work to Q1 2014, as described in the previous reports.

2 PROJECT GOALS

2.1 Introduction

The CSP pilot project represents the culmination of the integrated research applied to the CSP technology. Imperial has developed CSP with a stepwise approach which includes lab-scale experimentation, numerical simulation development and field piloting. Imperial follows a stage-gated system developed by ExxonMobil for technology development, namely: the Technology Development and Commercialization Management System (TDCMS). The process aims to steward technology development by incrementally building technical and commercial readiness through Project Delivery Milestones (PDMs) with key deliverables. The report herein, will describe the CSP pilot program and how the field pilot has contributed to the commercial readiness decision of the CSP technology. The following sub-sections outline the objectives, strategy and methods applied the CSP pilot.

2.2 Pilot Goals

The field testing or piloting of the technology represents an important contribution to technology development as it bridges the gap from lab-scale experiments to full field deployment. The overall goal of the CSP pilot project is to test the technology at a representative field scale with the intention of addressing uncertainty that cannot be delineated at the lab scale or with numerical simulation. The specific pilot goals are given below:

- Safely acquire high-quality data to allow for definitive interpretation of pilot results
- Provide sufficient information to assess whether CSP is a commercially viable recovery process at Cold Lake
- Gain necessary operation experience with CSP to enable future design of a cost-effective commercial application

2.3 Pilot Technical Objectives

The objectives are guided by an operational and surveillance plan specific to the CSP pilot. The plan was developed to assess the pilot performance in terms of reservoir, wellbore and facilities, surveillance and the overall operability. The technical objectives of the pilot are as follows:

- Quantify key metrics over multiple cycles, including the bitumen recovery, solvent effectiveness and solvent recovery
- Measure solvent injectivity and map the solvent conformance zones
- Gain understanding of factors impacting solvent effectiveness
- Evaluate horizontal well design and wellbore utilization
- Demonstrate consistent performance between multiple wells

- Assess and understand impact of phase behavior in the reservoir and wellbore on process effectiveness

2.4 Performance Metrics

The reservoir performance is quantified using the following key performance indicators, defined as:

Oil solvent ratio: $$\mathrm{OSR} = \frac{B_{prod}}{S_{inj}} \quad (1)$$

Solvent Recovery: $$\mathrm{SR} = \frac{S_{prod}}{S_{inj}} \quad (2)$$

where, S_{inj} is the injected solvent volume, B_{prod} is the produced bitumen volume, S_{prod} is the produced solvent volume. The oil to solvent ratio is a measure of the solvent effectiveness, where larger values indicate higher bitumen production per unit of solvent injection. It is analogous to oil-steam ratio (OSR_{steam}) of traditional steam-based processes.

Aside from the key reservoir metrics given above, the solvent injectivity, reservoir conformance, and wellbore utilization are also evaluated during the pilot. The instrumented horizontal wells and six observation (OB) wells are equipped with an array of measurement devices to assist with understanding of these items.

2.5 Testing Plan

Prior to pilot startup an operational plan was developed to prescribe the well start-up sequence and per well testing objectives. HW3 was planned as the first well online, followed by HW1 and ultimately HW2. Facility operability was a key objective of HW3. HW1 was to be used to establish repeatability of the process and would attempt to be operated similarly to HW3. HW2 was thought to pose additional challenges as the downhole heater was damaged during installation. As such, HW2 was the last well to come online. A stepwise approach was taken during the early pilot life to fully understand any operational limitations. The approach was successful as the pilot underwent an early debottleknecking phase, largely necessitated by learnings about the facility and process. More details are given in Section 3.2 in the Pilot Progress Summary. The changes to the operational plan are described below:

Early learnings of the pilot led to key changes regarding the use of diluent as a utility solvent and as the co-injected solvent. Diluent was found to cause unfavorable phase behavior which led to plugging of surface lines and the production pipeline. Since propane is only partially miscible with bitumen, at high fractions of propane concentration the liquid (oil) phase will separate into a light liquid and heavy liquid phase with different density and viscosity. The heavy liquid is particularly challenging from a flow assurance perspective due to the high viscosity. The addition of diluent to the propane-bitumen system, compared to other aromatic solvents, tends to increase the two-phase envelope in which heavy liquid formation is possible. After experiencing plugging during the early pilot operation, diluent was replaced by a proprietary flow-assurance solvent. The flow assurance solvent reduced the propensity to form heavy liquid at the pilot conditions.

The injected solvent composition was kept constant for HW3 and HW1 for cycles 1 through 3 with 12% vol. of co-injected flow-assurance solvent. HW2 injected pure propane solvent for all cycles, thereby representing the most commercial viable injection strategy. The success of HW2 led to the phasing out of co-injection for the later cycles of HW1 and HW3.

The downhole heating for flow assurance was also tested. HW3 was left as the control case for downhole heating. The bottom-hole temperature set-point was set to 30°C for the duration of the pilot. The heater for HW1 was turned off after cycle 1, essentially testing if down-hole heating was required for flow assurance. This change was largely due to the effects of down-hole heating on the surveillance measurements. As the heater cycles on and off, the surface temperature of the heating element within the wellbore is much greater than the set-point of 30°C and causes solvent flashing. The solvent, in the gas phase, will tend to be produced through the casing opposed to the well tubing. As a result, the measured liquid density will fluctuate with each heating and cooling cycle as the solvent concentration changes. To improve the steadiness of the wellhead measurements, particularly at low pressure, the heater was turned off on HW1. No detrimental effects were observed and thus the heater remained off to further test the effects of heating between HW1 and HW3. Lastly, HW2 did not have an operational heater and was therefore operated similarly to HW1. HW2 was the control case for propane only injection.

The last deviation from the pre-startup plan was a change to the bottom hole pressure strategy. The CSP process uses artificial lift to produce the fluid to the surface. At low pressures, close to the vapour pressure of the solvent and solution-gas mixture, venting through the casing is used to maintain the pump fillage and improve the liquid production rate. The level of venting has a direct effect on the bottom-hole pressure. For HW3 it was observed that operating below the solvent vapour pressure tended to increase the water production. For HW1 and HW2, the same behavior was not evident. As such, HW3 was operated above the solvent vapour pressure for the majority of the cycles, while HW1 were operated below the solvent vapour pressure.

2.6 Surveillance Plan

The pilot surveillance plan was implemented to ensure the technical objectives of Section 2.3 could be obtained. The surveillance plan included four categories, namely: surface measurement and monitoring, sub-surface measurements and monitoring, fluid sampling, 4D seismic and a post flood core sample. Each item is described in the following sub-sections.

2.6.1 Surface Measurements

Each of the three wells have gas and liquid production lines that are instrumented with Coriolis meters. The measured mass flow rate and density provide real-time measurement of the volume flow rate. The injection system is also instrumented with three Coriolis meters for the propane, co-injection and total solvent injection metering. There is also a group line Coriolis meter for the co-mingled liquid stream and by-pass gas stream. An Agar meter is upstream of the groupline to meter the real-time water-cut. Lastly, the plant-side of the group line pipeline is instrumented with an additional Coriolis meter.

Real-time pressure and temperature measurements are located at key locations throughout the pad facility, such as the wellhead tubing and casing, the pad surface facilities and along the production pipeline.

2.6.2 Sub-surface Measurements

Down-hole monitoring of the horizontal wells and OB wells is used to monitor the reservoir solvent conformance and the wellbore conformance (utilization). Each horizontal well has two-redundant electric resonance diaphragm (ERD) temperature and pressure measurements at the heel location. A thermo-couple string provides distributed temperature measurement along the wellbore, and redundant temperature monitoring at the heel.

There are six OB wells at the CSP pilot site. The layout of the OB wells relative to the HWs is shown in Figure 3. HW1 has one neighbouring OB well which is located at about mid-length. HW2 has three OB wells at the heel, mid-length and toe. The well labelled 14-18 is also referred to OB6 and was the original OV well for the CSP pilot site. HW3 has two OB wells at the heel and toe. All of OB wells at the pilot site are not equally instrumented. In Figure 3 each OB well is numbered and labelled with an instrumentation identifier and follows the nomenclature below:

TF: DTS thermal fiber with heater
TFP: TF with BHP
PSW: Passive seismic well
PSWP: PSW with BHP

All of the wells have DTS (Distributed temperature sensing) thermal fiber instrumentation, but only wells without passive seismic geophones (non-PSW) have heaters installed. The heaters are used to elevate the DTS nominal temperature relative to the surrounding reservoir, thereby increasing the sensitivity to cooling by fluid movement in and around the OB well. OB wells with DTS and heaters are indicated as TF. If the TF well is also perforated it then has an ERD sensor and is identified at TFP.

PSW wells have an array of passive seismic geophones installed within the tubing. The PSW wells measure the subsurface acoustics and “listen” for events indicative of fluid movement. PSW wells may also be perforated at the HW depth and instrumented with an ERD sensor, indicated as PSWP. An ERD sensor measures the BHP and BHT.

2.6.3 Fluid sampling

CSP sampling and sample analysis program are planned to capture change in composition and physical properties (e.g. density and viscosity) of CSP produced fluids. Sample analysis results have proved to be instrumental in validating assumptions for preliminary production allocation, as well as providing high quality data for simulation modelling.

Figure 4 shows the layout of wellhead and liquid production lines. Producing wells are directed to the separator one at a time. Liquid production from the other wells flow to the groupline, where the separator streams tie in. In total, there are 6 points assigned for taking pressurized liquid samples: 3 for routine wellhead sampling, 2 for periodic separator sampling, and 1 at the groupline. Sample cylinders are used at these locations to collect representative CSP produced liquid: to keep propane entrained in the liquid phase.

While wellhead samples are mainly collected to monitor physical property and composition change of CSP tubing production, separator samples are taken to evaluate oil/water separation efficiency. As a result, sampling frequency for these locations is different and adjusted based on needs.

2.6.4 4D seismic

Three seismic acquisitions were performed during the pilot multi-well operation in addition to the pre-startup baseline shoot. The shoots were carefully planned such that surveys allowed each of the wells to be shot at different operating conditions. The ability to successfully visualize the solvent chamber at both high and low pressure operating conditions was uncertain prior to performing the shoots. For each well, images of the solvent chamber were successfully recorded.

2.6.5 Post-Flood Core Sample

A sub-surface well is to be drilled and cored in the solvent swept region. Routine core and special core analyses are planned for samples extracted from the core. The residual oil saturation, asphaltene content, absolute and relative permeability are all parameters of interest.

3 PROJECT OUTCOMES

3.1 Introduction

The current section describes the pilot outcomes relative to the pilot goals and technical objectives described in Sections 2.2 and 2.3, respectively. An introductory progress summary is followed by outcomes in terms of the reservoir performance, sub-surface surveillance, fluid sampling and phase behavior, and the 4D seismic results. The section concludes with a summary of the GHG reductions offered by the CSP technology.

3.2 Pilot Progress Summary

The pilot progress is shown in Figure 5. Injection and production cycles are identified along with key activities during periods of pilot downtime. The pilot timeline is divided into an early, middle and late-stage activities, as indicated. The early phase is from the start-up in May 2014 to August 2015; the middle phase is from September 2015 to November 2016; and the last stage is from December 2016 to June 2018. These stages are based on the pilot events opposed to the Milestones outline in the CCEMC agreement. The progress during each phase is described below:

3.2.1 Early Pilot Phase

The pilot was started in May 2014 with HW3 coming online. A key objective of the early pilot phase was to assess the operability of the facility. Significant operational learnings were developed during this period. Two flow assurance challenges led to prolonged shut-ins during HW3 cycle 1 production, as shown in Figure 5. In the first instance, inadequate methanol treatment and residual water from commissioning activates led to hydrate formation within the production pipeline in June 2014. The hydrate removal procedure ensued and the hydrate was successfully removed. Production then continued for a brief period in August 2014, but was subsequently shut-in due to facility plugging with heavy liquid production. Diluent had been selected as the co-injection and utility solvent for the pilot. However, the resulting phase behavior was found to be more severe than anticipated through the laboratory studies. As such, the pilot was shut-in in September 2014, so that debottlenecking studies could be completed prior to continuing operation. During the 8 month shut-in period, a new flow assurance solvent was sourced and additional equipment modifications were planned.

HW3 was resumed in January 2015. Cycles 1 and 2 were completed by September 2015, marking the end of the early pilot phase.

3.2.2 Mid-Pilot Phase

The mid-pilot phase began in September 2015. The focus of this period was on achieving stable operation of all three wells. Facility modifications were completed for multi-well operation in January of 2016. Thereafter, HW3 resumed cycle 3 production while HW1 and HW2 were started in February and May 2016, respectively.

The remainder of 2016 would progress HW3 to the end of cycle 4, while HW1 and HW2 would continue cycle 3 production through the year end. The mid-pilot stage was significant progress for the CSP pilot. High quality surveillance data was measured for all three wells over multiple cycles. The initial struggles for the pilot facility were overcome and smooth and stable operation was achieved.

3.2.3 Late Pilot Phase

The late stage of the pilot was focused on continued stable operation and the additional collection of high quality surveillance data. A key deliverable was to demonstrate the repeatability of the reservoir performance metrics. More specifically, the larger cycles tested during this period are influential to the cumulative performance metrics of the overall process. Therefore, the capturing of the cycle 4 and cycle 5 performance for each well was necessary to understand the larger cycle performance. Form a surveillance perspective the focus was the on the successful execution and interpretation of the three 4D seismic shoots. By the end of the Late Pilot phase HW3 had progressed into cycle 6, while HW1 and HW2 were progressing cycle 5.

The pilot will continue to operate past the current reporting period. The focus of the pilot will shift from testing the base CSP technology as described herein to testing CSP enhancement concepts.

4 GHG Impact

The GHG emissions estimate for the pilot has not changed since the pre-project estimates. The CSP pilot was not intended to provide significant GHG reductions. Rather, the purpose of the pilot was to test the commercial readiness of the CSP technology. Then, if applied commercially it would provide significant GHG reductions relative to existing steam-based recovery technologies. The key difference in the pilot facility design and commercial concept is that the pilot does not recycle the produced solvent for re-injection. Rather the produced solvent is sent to the Cold Lake Mahiken plant and combusted as fuel for steam generation. The commercial concept will recycles the majority of the produced solvent, and therefore leads to significant reduction in emissions relative to traditional steam based technologies. The following section describes the most recent GHG estimate of a commercial CSP development.

The emissions calculation is based on a commercial CSP concept and the corresponding design flow streams. The resource is characterized as thick-lean. The design flow streams are forecasts generated from a reservoir simulation model that has been calibrated to the pilot data. Comparisons are made to an equivalent development of the same resource using the traditional CSS technology. Equivalency is assessed in terms of the bitumen oil rate profile, the project life and the total bitumen recovery. Flowstreams generated for each technology within the target resource provide estimates of the overall performance metrics for each technology.

For the purposes of the GHG calculation each process is divided into key activities. For each activity, an emission intensity is computed using an emission factor and a key variable of the respective processes. For example: in CSP, a small amount of fuel is combusted for solvent heating prior to injection. The emissions associated with the combustion process are computed using the solvent injection volume profile, the energy input required for the heating and the emission factor (per unit energy) for the combustion of propane. For CSS, the combustion of the natural gas is required for steam generation. Again, the emissions for CSS are computed using the steam injection profile, the energy input required to generate the steam and an emission factor for the combustion of the natural gas. The emissions intensity for each case is then the emissions per unit volume of bitumen produced.

The key activities for the processes are described below and the emissions intensity for each category can be calculated in a similar manner as described above.

1. *Fuel Burn for Steam Generation or Solvent Heating:* the emissions associated with the combustion of fuel for steam generation or solvent heating.

2. *Natural Gas Feed for Steam Generation:* the indirect emissions associated with the extraction and production of purchased natural gas used in the steam generation process.

3. *Make-up Solvent:* a fraction of the injected solvent is unrecoverable. Indirect emissions are associated with the make-up solvent purchased for the process.

4. *Solvent Recovery:* the emissions associated with on-site solvent recovery process. Electricity is used for solvent compression and fuel is burned for solvent heating.

5. *Facility Electricity:* the emissions associated with the use of electricity at the site (not including electricity for solvent recovery).

6. *Solvent Trucking:* Emissions associated with trucking the solvent to site.

7. *Oil processing:* the emissions associated with processing the produced hydro-carbons. The processing of bitumen is approximated as equivalent between the baseline and project case. However, additional emissions arise for the combustion of residual solvent that remains in the production stream sent to the processing plant.

8. *Water processing:* the emissions associated with water processing at the plant are small (multiple orders of magnitude) relative to the other sources (steam generation and solvent recovery) and can be neglected. Also, since the project will produce significantly less water than the baseline, excluding this item would lead to a more conservative GHG reduction estimate.

Table 1 summarizes the GHG intensity (tCO2e/m3 of bitumen) for CSP and CSS. As shown, the total reduction of emissions relative to the CSS process is about 80%. Approximately, 50% of the emissions for CSP are indirect emissions related to the processing and extraction of the required make-up solvent. Thus, the reduction of direct emissions are up to 90% compared to CSS. The solvent recovery and oil processing represent the next largest categories with 22% and 15% of the CSP emissions, respectively.

5 SUMMARY AND OVERALL CONCLUSIONS

5.1 Summary of Project Outcomes

The Project Outcomes are summarized below with respect to the pilot goals given in Section 2.2:

- Safely acquired high-quality data to allow for definitive interpretation of pilot results.
    - The pilot achieved high quality data across its surveillance plan such that the results could be interpreted for technical assessments of the CSP process. Examples include the successful metering of the injection and production fluids that were validated with a comprehensive sample analysis program. Sub-surface surveillance was successful in detecting and visualizing the solvent conformance for all three wells. In addition learnings were gained regarding the usefulness of the measurement instruments.

- Provide sufficient information to assess whether CSP is a commercially viable recovery process at Cold Lake
    - High-quality production data (rates, pressure, etc.) and sample data (fluid properties such as density, viscosity, and composition) provided a deep understanding of the process. The pilot results were then the basis for a predictive simulation model development. The model is calibrated to the pilot results and then used to extrapolate the performance of CSP for a commercial development.

- Gain necessary operation experience with CSP to enable future design of a cost-effective commercial application
    - The pilot provided valuable learnings from an Operational & Surveillance perspective. The early pilot phase had challenges that were overcome with novel solutions. Encountering these challenges at the pilot project has led to a technology that is commercially viable not only from a reservoir perspective but also operationally. In addition, important learnings have been obtained regarding the challenging phase behavior of the process, which will directly influence future commercial design choices.

5.2 Conclusions

The CSP pilot was successful in accomplishing the pre-project goals. The CSP technology has been deemed commercially viable through Imperial's internal technology development system. The GHG reductions that are inherent to the process will be realized as the technology is deployed commercially.

6 RECOMMENDATIONS AND NEXT STEPS

6.1 Recommendations for Future CSP Development

The CSP pilot has tested the base CSP process. Like any technology there are areas of improvement in which the process can be enhanced. Imperial has an active CSP enhancement research program. It is recommended that pilot operation continue with the focus shifting from the base process to enhancement concepts.

6.2 Next Steps for Commercial Deployment

Commercial deployment will leverage the pilot results and learnings to further understand the feasibility of deploying CSP on a larger scale. The team continues to seek process improvements to deliver additional economic and environmental benefits.

7 SCIENTIFIC ACHIEVEMENTS

A list of publications related to CSP technology where Imperial is either the lead or co-author is given in Table 2. A list of CSP related patents filed by Imperial is give in Table 3.

8 COMMUNICATION PLAN

Imperial will continue to share project information and updates related to CSP developments with stakeholders, on its website and through its digital channels as part of ongoing efforts to reduce emission intensity at its oil sands operations. Imperial has previously been an active participant in disseminating scientific research with the community through journal publications, patents, workshops, conference presentations in addition to the reporting requirements related to funding agreements. Lastly, consultation with the local Indigenous groups will continue with any CSP related projects. Consultation will be similar to past projects; following all regulator, provincial, and federal requirements.

TABLES

Table 1: GHG Estimated for CSS and CSP

GHG intensity (tCO2e/m3 of bitumen)	CSS	CSP
1. Fuel Burn for Steam Generation or Solvent Heating	0.621	0.003
2. Natural Gas Feed for Steam Generation	0.043	0.000
3. Make-up Solvent	0	0.069
4. Solvent Recover	0	0.031
5. Facility Electricity	0.007	0.016
6. Oil processing	0	0.002
7. Water processing	0	0.022
Total	**0.671**	**0.143**

Table 2: List of publications related to CSP and authored by Imperial

Article Type	Article ID	Date	Authors	Title
SPE paper	SPE 30298	June 1995	G.B. Lim, R.P. Kry and B. C. Harker; Imperial Oil Limited K.N. Jha, Canada Centre for Mineral and Energy Technology	Cyclic Stimulation of Cold Lake Oil Sand with Supercirtical Ethane
IPTC paper	IPTC 18214	Dec. 2014	Thomas J. Boone, Jasper P. Dickson, Pengbo Lu, ExxonMobil Upstream Research Company John Elliott, Imperial Oil Resources	Development of Solvent and Steam-Solvent Heavy Oil Recovery Processes Through an Integrated Program of Simulation, Laboratory Testing and Field Trials
WHOC12 Paper	WHOC12-194	Sept. 2012	M.A. Dawson, T. J. Boone ExxonMobil Upstream Research Company M. Kwan Imperial Oil Resources	Progressing a Cyclic Solvent Heavy Oil Recovery Process to the Field Trial Stage
WHOC12 Paper	WHOC12-412	Sept. 2012	T. J. Boone & K. Sampath ExxonMobil Upstream Research Company D. E. Courtnage Imperial Oil Resources	Assessment of GHG emissions associated with in-situ heavy oil recovery processes

Table 3: List of CSP related patents filed by Imperial

Canadian Patent No.	Year Filed	Status	Title
CA 2349234, US6769486	2001	Granted	Cyclic Solvent Process for In-situ bitumen and heavy oil production
CA 2645267, US8455405	2008	Granted	Solvent for extracting bitumen from oil sands
CA 2703319, US 20110272152	2010	Granted	Operating Wells in Groups in Solvent-Dominated Recovery Processes
CA 2688392, US20120325467	2009	Abandoned	Method of Controlling Solvent Injection to Aid Recovery of Hydrocarbons from an Underground Reservoir
CA 2705643, US 8899321	2010	Granted	Optimization of solvent-dominated recovery (Method of distributing a viscosity reducing solvent to a set of wells)
CA 2701422, US 20110264373	2010	Abandoned	A Method for the Management of Oilfields Undergoing Solvent Injection
CA 2707283, US 20110303423	2010	Granted	Viscous Oil Recovery Using Electric Heating and Solvent Injection
CA 2696638, US 8684079	2010	Granted	Use of a solvent-external emulsion for in situ oil recovery
CA 2693640, US 8752623	2010	Granted	Solvent separation in a solvent-dominated recovery process
CA2693036, US 8602098	2010	Granted	Hydrate control in a cyclic solvent-dominated hydrocarbon recovery process
CA 2734170, US 20120234535	2010	Granted	Method of injecting solvent into an underground reservoir to aid recovery of hydrocarbons
CA 2741916, US 20140069641	2011	Granted	Integration of Viscous Oil Recovery Processes
CA 2738364, US 20140034305	2011	Granted	Method of enhancing the effectiveness of a cyclic solvent injection process to recover hydrocarbons
CA 2781273	2012	Granted	Diluting Agent for Diluting Viscous Oil
CA 2804521	2013	Filed	Bitumen Recovery Using Dual Duty Diluting Agent
CA 2836528, US 9488040	2013	Granted	Cyclic solvent hydrocarbon recovery process using an advanced retreat movement of injectant
CA 2837471	2013	Filed	Improving recovery from a hydrocarbon reservoir
CA 2872120	2014	Filed	Method of injecting solvent into an underground reservoir to aid recovery of hydrocarbons
CA 2898943	2015	Granted	Methods of performing cyclic hydrocarbon production processes
CA 2893221	2015	Granted	Mobilizing composition for use in gravity drainage process for recovering viscous oil and start-up composition for use in a start-up phase of a process for recovering viscous oil from an underground reservoir
CA 2900178	2015	Granted	Recovering Hydrocarbon from an Underground Reservoir
CA 2900179	2015	Granted	Recovering Hydrocarbon from an Underground Reservoir
CA 2972203	2017	Granted	Chasing Solvent for Enhanced Oil Recovery

FIGURES

Figure 1: Layout of CSP Pilot Wells

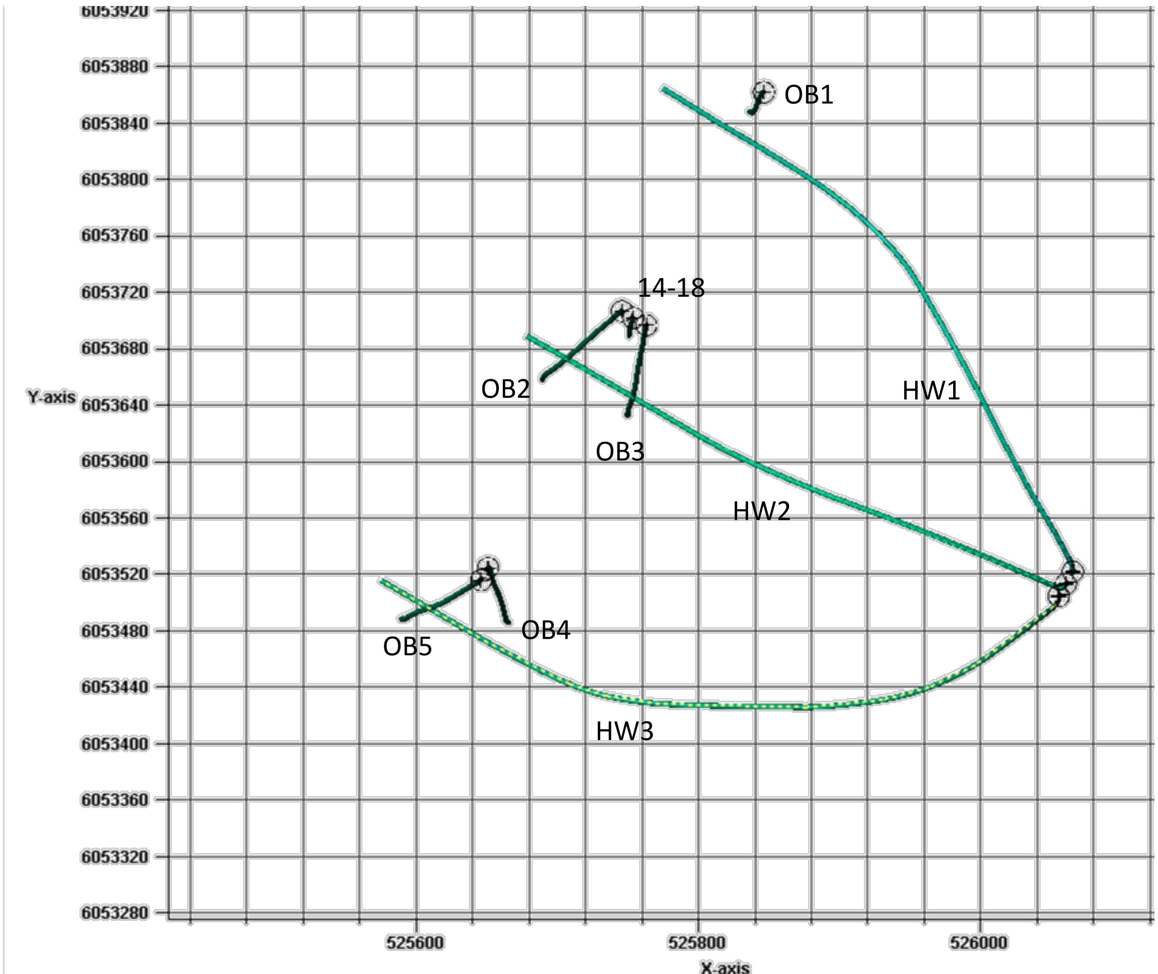

Figure 2: Pad Locations of CSP Pilot Wells

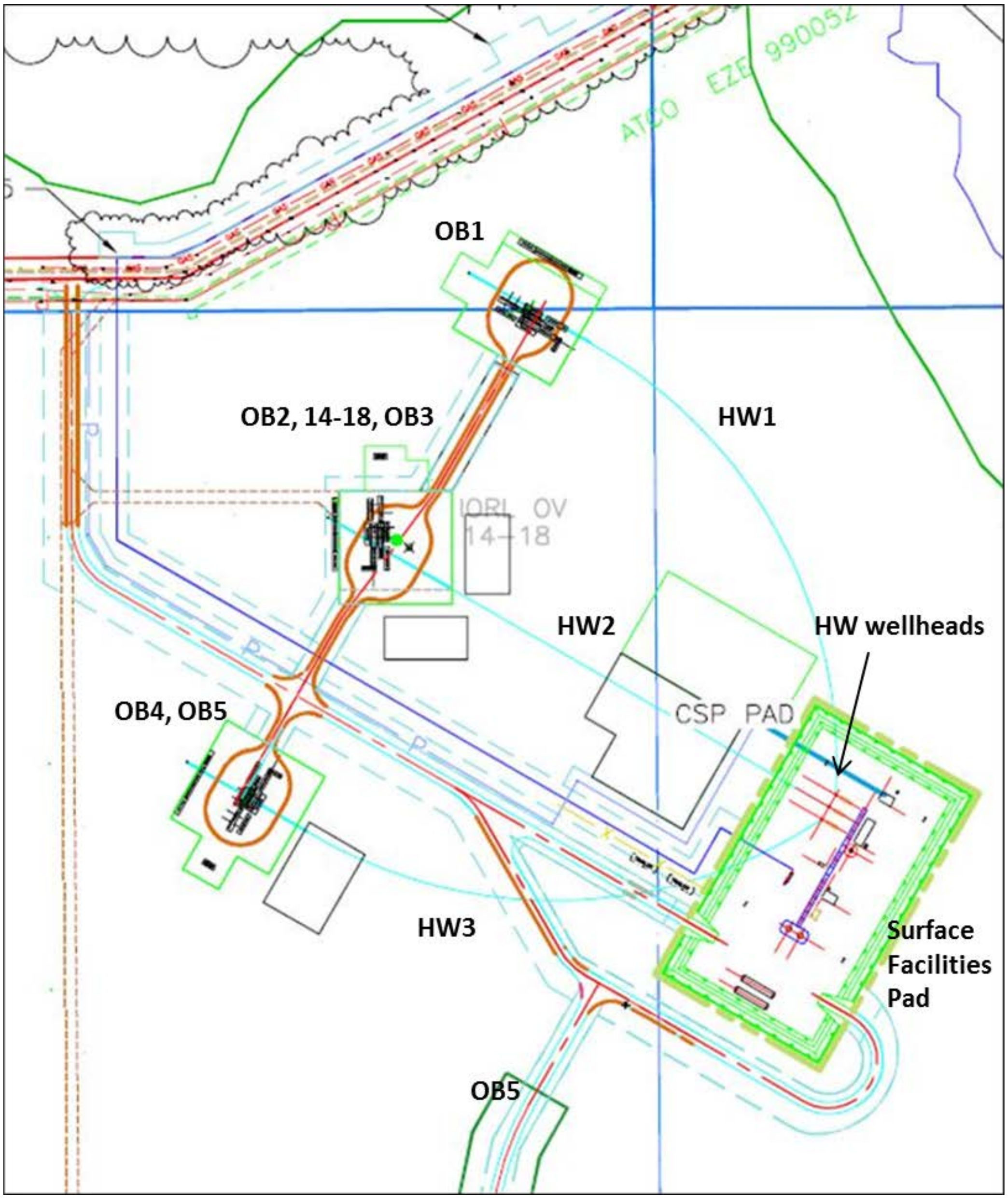

Figure 3: OB well layout at the CSP Pilot

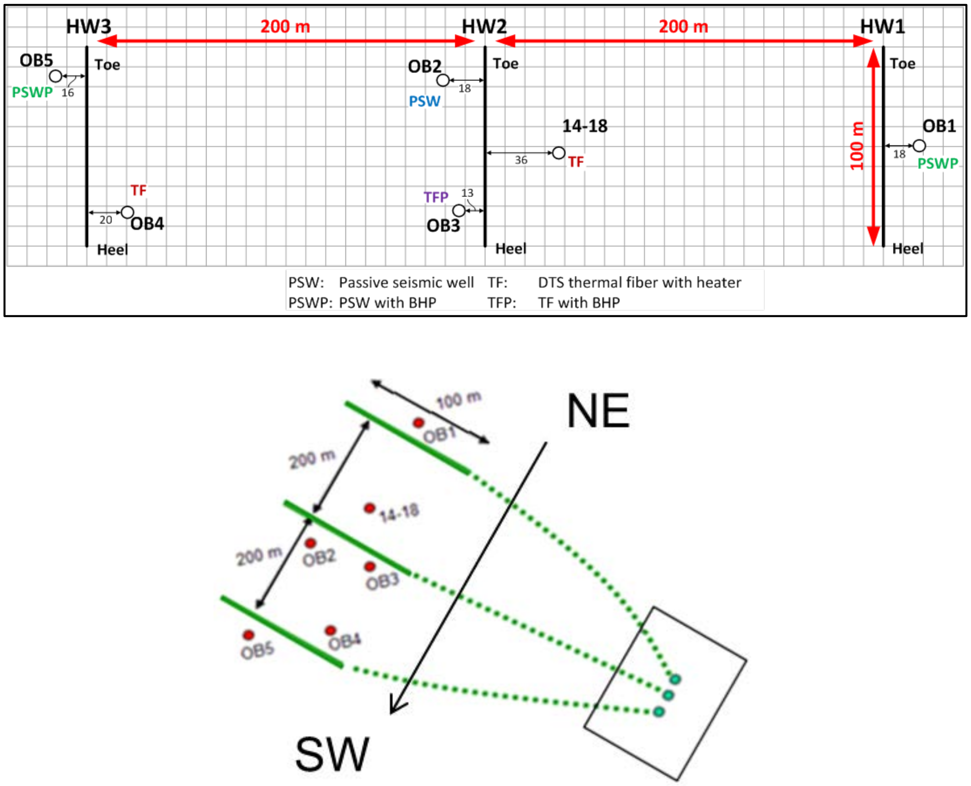

Figure 4: CSP Pilot surface liquid production lines

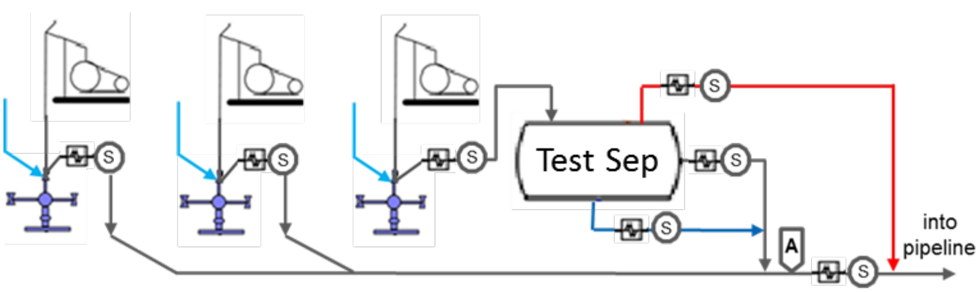

Figure 5: CSP Pilot Schedule