PTAC
PETROLEUM TECHNOLOGY ALLIANCE CANADA

# Economic Benefits of Gas Injection in Steam-Assisted Gravity Drainage (SAGD) Wind Down

**Final Report**
**March 31, 2016**

# Executive Summary

Several issues may arise during the wind down process that would require attention, which are analyzed as part of this project to generate reservoir engineering information and solutions that will allow SAGD operators to propose process options to the Alberta Energy Regulator (AER) after the economic life of SAGD operations. Left unattended, depleted SAGD reservoirs could become thief zones for adjacent producing reservoirs, negatively affecting their performance and increasing associated greenhouse gas emissions.

This project looks at the Steam Assisted Gravity Drainage (SAGD) Wind Down process and identifies data gaps, through review of available and usable data, and summarizes newly generated laboratory data to fill the gaps initially identified.

A workshop was held on April 13, 2015 to discuss the merits of various technologies in wind down and maintenance modes. Discussions included thoughts around implementing non-condensable gas (NCG) injection, or electrical heat to maintain the pressures in depleted areas. The event was by invitation only and included representation from oil sands producers and government regulatory bodies. Oil sands producers delivered presentations reviewing their current experiences, strategies, challenges, and concerns followed by a question and answer period. The potential for mitigation was to be evaluated by comparing alternatives such as gas injection and flue gas in terms of their technical, environmental and economic benefits and determine the cost and energy efficient method to fill in depleted reservoirs.

Stage 1 of the project encompassed a review by CMG of the data available for computer simulations, specifically related to SAGD Wind Down operations. Reservoir simulation is a critical first step because it evaluates and screens potential solutions at a far lower cost and greater speed than field testing. The purpose of this study was to address concerns raised by stakeholders about the quality and completeness of existing data sets used for simulation. As with any computer simulation, the value of the output critically depends on the accuracy of the inputs and thus validates the need for this study. CMG identified areas lacking experimental data and recommended methodologies to improve those areas. This review by CMG found that most of the required technical information was already available in public and private sources and enabled participating oil sands companies to update their numerical models.

Using the conclusions and recommendations from Stage 1 to provide direction (which indicated that a smaller than anticipated scope of work was required for Stage 2), the second stage of this project focused on testing and obtaining data to fill the main gap identified by CMG, which concerned the dissolution and ex-solution rates of methane in the laboratory and to determine how temperature affected these rates.

Originally, the final stage of this project was to complete a numerical simulation study on behalf of all participating SAGD operators, which would have used the newly generated laboratory data to provide an assessment of the SAGD process at a substantially lower cost and environmental impact than a field trial. It was determined that the smaller scope of Stage 2 did not warrant the expenditures of resources in Stage 3. After completion of the Project, the oil sands companies in the PTAC Phoenix Network will be able to perform numerical simulations individually, according to their own models and specific reservoir configurations, using the information

generated in Stages 1 and 2. These simulations will provide the foundation for the identification of the preferred wind down strategy, which may include NCG injection such as methane, $CO_2$ and flue gas in a manner that reduces costs and environmental impact.

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# 1 Introduction

This report provides a final account of the project: Technical and Economic Benefits of Gas Injection in Steam-Assisted Gravity Drainage (SAGD) Wind Down undertaken by PTAC Petroleum Technology Alliance Canada (PTAC) in collaboration with Devon Energy, Husky Energy, Nexen, Statoil Canada, Suncor Energy, Alberta Innovates Technology Futures (AITF), and Computer Modelling Group (CMG). The project took place from April, 2015 to March 31, 2016.

The purpose of this project was to study the SAGD Wind Down process and the mitigation strategies to minimize the negative impact of a depleted SAGD reservoir on adjacent producing SAGD well pairs. The 3 stages of the project were originally identified as:

1. Review of Available and Useable Data
2. Laboratory Work
3. Numerical Simulation

However, due to the conclusions reached in Stages 1 and 2, Stage 3 was not undertaken. This report will describe the methodology and results of the project as performed.

# 2 Background

SAGD is the dominant technology for in situ oil sands production. After approximately 10 years, the production from a well pair (injection and production wells) declines and it may become uneconomic to continue production. SAGD operations would then proceed to a wind down phase and well pairs would be taken off steam injection and production at that time. However, several issues may arise that would require attention:

- The steam chamber of a shutdown well pair may act as a thief zone and affect production and steam to oil ratio (SOR) in neighboring producing well pairs. This would lead to increased environmental impact. Pressure maintenance may be required for a long period of time, requiring a large volume of non-condensable gas.
- Companies may elect to specify buffer zones between well pairs or projects in the same oilfield. This buffer may be as wide as 200 meters and represents a loss of reserves. New containment methods may require far less buffer spacing.
- Enhanced recovery may be possible from the application of a secondary recovery technology. For example, in situ combustion could be implemented to recover the approximately 40% oil in place not recoverable by SAGD. However, it is not known if flue gas from in situ combustion would negatively impact adjacent well pairs that are still producing in SAGD mode.

It is therefore crucial to generate the reservoir engineering information and solutions that will allow SAGD operators to propose process options to the AER after the economic life of SAGD operations.

# 3 Objectives

The objective of the project was to study the SAGD Wind Down process (i.e. the end of life of a SAGD well pair) and the mitigation strategies to minimize the negative environmental and cost impact of a depleted SAGD reservoir on adjacent producing SAGD well pairs.

## 3.1 Objective 1 – Improving Numerical Simulation of the Impact and Mitigation Strategies for SAGD Wind Down

- The objective was to summarize the available data for pressure, volume, and temperature (PVT) and special core analysis (SCAL) to identify data gaps for the effective numerical simulation of SAGD Wind Down processes in bitumen and heavy oil reservoirs.
- The information collected for this study indicated a lack of experimental data and methodology in the following areas:
    - Phase behavior of bitumen and gas mixtures
    - Phase behavior for water/bitumen/gas systems
    - Pure gases at high temperature conditions
    - Relative permeability of gas/oil
    - Relative permeability measurements of preserved core and reservoir fluids (versus available data obtained from lab studies of relative permeability measurements using sand packs and/or extracted cores and mineral oil)
- The phase behavior gaps listed above pertained particularly to the dissolution and ex-solution of methane into bitumen.

## 3.2 Objective 2 – Measurement of Rate-Dependent Dissolution and Ex-solution Behavior

- The objective was to first measure the dissolution rate of methane into Athabasca bitumen as a function of time at varying temperatures and fixed pressure. Secondly, the objective was to also measure the ex-solution rate of methane from a live-oil mixture (Athabasca bitumen saturated with methane) as a function of time at varying temperatures and fixed pressure.
- Ex-solution tests at higher temperature led to ex-solution of a higher volume of methane, which is consistent with a lower solubility of methane at a higher temperature.

## 3.3 Objective 3 – Numerical Simulation Using Data Sets from Preceding Project Stage

- The objective was to use the data, which was defined and generated from the previous project stages, to run a series of numerical simulations to establish a base case of operating SAGD, SAGD in process of wind down, shut-in SAGD, and selected mitigation strategies.
- This objective was omitted because stage 3 was not undertaken.

# 4 Results of Project

## 4.1 Project Achievements

### 4.1.1 Achievement 1 - Identification of Data Gaps to Improve Numerical Simulation of Impact and Mitigation Strategies for SAGD Wind Down – Executed by CMG

This portion of the project provided direction for the remaining project tasks by identifying key areas of focus for future data measurement. The content of the CMG report was used to define the laboratory tests for the following project phase.

### 4.1.2 Achievement 2 - Laboratory Data Measurement to Fill Identified Data Gaps – Executed by AITF

The laboratory tests measuring dissolution and ex-solution were successfully completed as stated in the contract deliverables. The results yield data sets to fill gaps identified in Stage 1 of this project.

## 4.2 Benefits

### 4.2.1 Benefit 1 – Identification and Filling of Data Gaps Related to SAGD Reservoirs

This project identified areas of weakness with respect to data availability for SAGD Wind Down operations and generated scientific information from laboratory testing that could lead to minimization of economic losses for stakeholders during SAGD operations. If methane injection is used to prevent depleted SAGD reservoirs becoming thief zones for adjacent production wells, it will result in high costs to the oil and gas industry and there is a need to understand the behavior of the methane in these reservoirs. Given the very large number of existing and future SAGD wells, all stakeholders in the oil sands industry would benefit from this project and will reduce the costs incurred during the SAGD Wind Down phase.

### 4.2.2 Benefit 2 – Impact on Canada

The project will potentially reduce GHG emissions from the Canadian oil and gas industry especially during SAGD operations due to the high energy efficiency of the proposed mitigation strategies. Canada would be able to produce hydrocarbon products from oil sands and heavy oil sources to address particularly the global market needs while mitigating impacts to the environment.

## 4.3 Technology/Knowledge Development Objectives

**Methodology**

The project involved several major steps: (1) review of available and usable data by CMG, which involved both public and private data sources, (2) laboratory work completed by AITF to obtain the necessary data to fill gaps identified in the previous project stage, and (3) numerical simulation to establish base cases for SAGD operations and selected mitigation strategies.

**Review of Available and Usable Data**

The Project issued a Request for Proposals (RFP) and selected CMG's as the best proposal. CMG reviewed available data from public sources such as scientific journals published by the Society of Petroleum Engineers (SPE), but also information from private sources/consortium projects provided under confidentiality agreements, to assess the usability of data sets for numerical simulation, and advise on data gaps and methods to close such gaps. Thus contributing directional information as to where future studies should focus to satisfy needs where industry is lacking.

**Laboratory Work**

The Project issued an RFP for Stage 2 and selected AITF's as the best proposal. The results from the laboratory tests contribute to data sets for input into simulators. More detailed and accurate data sets allow for more accurate simulation studies, which help oil sands operators improve efficiency in SAGD wind down operations by better understanding how the reservoir behaves.

**Numerical Simulation**

This portion of the project was not undertaken.

## 4.4 Challenges and Barriers

### 4.4.1 Barrier/Challenge 1 – Complexity of the Technical Problem

The SAGD Wind Down phase is poorly understood because SAGD is a relatively new production technology and few reservoirs have reached the wind down phase. Industry experts participated heavily in technical meetings spanning from April 2015 – January 2016 to take the appropriate steps forward with this project.

A SAGD Wind Down Strategy Workshop was held on April 13, 2015 to launch the Project and discuss the merits of various technologies in wind down and maintenance modes. Discussions included thoughts around implementing NCG injection (air, $O_2$, $CO_2$, $CH_4$), or electrical heat to maintain the pressures in depleted areas. The workshop provided a unique opportunity to learn various strategies and maximize value from old and mature SAGD reservoirs. The event was by invitation only and included representation from oil sands producers and government regulatory bodies. Oil sands producers Husky Energy Inc., Devon Energy Corporation, Statoil Canada Ltd., and Nexen each delivered a presentation reviewing their current experiences, strategies, challenges, and concerns followed by a question and answer period. Attendees brainstormed challenges and created a list of potential joint industry projects. Lastly, there was a time period dedicated to asking the AER questions. The potential for mitigation was to be evaluated by comparing alternatives such as gas injection (methane, nitrogen, carbon dioxide ($CO_2$) and flue gas (primarily nitrogen and $CO_2$) in terms of their technical, environmental and economic benefits and determine the cost and energy efficient method to fill in depleted reservoirs.

Participating oil sands companies contributed significant time of their reservoir engineering and numerical simulation experts in workshops, team meetings, RFP preparation and selection and review of final technical reports from CMG and AITF. In total, the Project documented 531 hours contributed by oil sands companies and technical experts spent to understand technical issues and make appropriate technology management decisions.

### 4.4.2 Barrier/Challenge 2 – Need for Field Testing

The Project only addressed numerical simulation of the technical context and of possible solutions such as methane and flue gas injection. To achieve solutions implemented by industry on a wide scale, field testing will be required which will either validate the numerical models or raise new issues.

# 5 Conclusion and Follow-up

Overall, this project aimed to identify and close data gaps by generating data from laboratory work to enable the effective numerical simulation of SAGD wind down in bitumen and heavy oil for impacts and mitigation strategies. The technology readiness level of gas injection into SAGD Wind Down progressed from 1 to 2 during the course of this project.

The results from Stage 1 determined areas lacking sufficient experimental data to be used as inputs for simulation studies to better understand SAGD reservoir behavior. These results helped guide the direction of the second stage of the project.

The results from Stage 2 produced new data to satisfy the gaps identified by CMG, which can be used in future simulation studies.

Although the third stage, identified in the original scope, was not completed, Stages 1 and 2 produced information to enable the numerical simulation portion of the project to move forward at a later date by the involved companies individually.

## 5.1 Next Steps

This project was performed in the context of PTAC’s Phoenix Network and it is expected that the project will lead to follow-on projects.

At the present time, participating companies may update their numerical models with the new information generated by the Project and perform numerical simulations specific to their context and reservoirs. This would lead to the identification of a short list of preferred solutions which will need to be field tested and proven before wide scale deployment.