MEG ENERGY
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Emission Reduction And SEquestration (ERASE) FEED Study Non-Confidential Final Report

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Prepared for:
Alberta Innovates

Prepared by:
MEG Energy Corp.

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1. PROJECT INFORMATION:

Project Title:	**Emission Reduction And SEquestration (ERASE) FEED Study**
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AI Project Advisor:	Sanah Dar

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The ERASE project was supported with funding from Alberta Innovates.

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A. EXECUTIVE SUMMARY

MEG is an Alberta company focused on sustainable *in situ* development and production. MEG's current bitumen production capacity at the Christina Lake Regional Project (CLRP) is approximately 110,000 bbls/day. MEG's long-term emissions reduction goal is to reach net zero Scope 1[1] and Scope 2[2] GHG emissions by 2050.

MEG believes the McMurray saline aquifer in the southern Athabasca region could be used for commercial CO_2 sequestration. This Emission Reduction And SEquestration (ERASE) Front-End Engineering & Design (FEED) study is a necessary step to advance the prospect of commercial scale Carbon Capture and Storage (CCS) in the McMurray saline aquifer. A successful pilot, which is outside the scope of this project, will provide the basis to justify long-term CO_2 containment, and confirm the subsurface viability of a commercial project. The successful implementation of this technology or use of the knowledge generated could result in:

- Improved environmental performance and global competitiveness for Alberta's energy industry;
- A long term sustainable industry that contributes to social programs for future generations via royalties and taxes;
- Significant employment opportunities; and
- Policy development to allow for CO_2 sequestration in the McMurray aquifer.

The ERASE FEED study achieved the project Key Performance Indicators (KPIs), which were as follows:

- Completed geoscience and reservoir simulation studies supporting the viability of a commercial sequestration project;
- Completed a reservoir simulation for the selected pilot location;
- Completed a 3D seismic program for the selected pilot location; and
- Finalized the pilot scope and the Measurement, Monitoring and Verification (MMV) plan.

[1] Scope 1 refers to direct GHG emissions from sources that are owned or controlled by the Corporation.
[2] *Scope 2 refers to indirect GHG emissions that result from the generation of purchased electricity, heating, cooling or steam consumed at assets owned or controlled by the Corporation.*

B. INTRODUCTION

Sector Introduction

This project is advancing the prospect of CCS in the McMurary saline aquifer, which could support emissions reduction goals for thermal bitumen producers as well as other industrial sectors where CO_2 sequestration is required, particularly where they are far away from CO_2 trunklines and high-pressure CO_2 sequestration is not feasible.

Knowledge Gaps

The main challenge this innovation aims to address is to demonstrate the long-term viability and security of CO_2 sequestration within the McMurray saline aquifer. In particular, one of the key challenges to overcome is the CO_2 sequestration depth restrictions outlined in the Alberta Carbon Sequestration Tenure Regulation. The Tenure dictates that CO_2 must be sequestered in a deep subsurface reservoir, defined as deeper than 1,000 m below the surface of the land. The McMurray saline aquifer is at a depth of 300-400 m below the surface and is capped with regionally extensive marine shale that was deposited during an extensive marine flooding event and acts as the primary cap rock for *in situ* operations. This cap rock is consistent and relatively flat in structure, varying in thickness from 8.5 m to 12.1 m over MEG's CLRP development area. The cap rock extends north and east of MEG's CLRP and is believed to be adequate to contain CO_2 in the region identified for potential commercial CO_2 sequestration. The shale has demonstrated to be both an effective gas trap and competent cap rock for *in situ* operations; however, injecting CO_2 into the McMurray saline aquifer for the purpose of sequestration has not been done before.

C. PROJECT DESCRIPTION

Technology Description

The McMurray formation in the CLRP area has a large saline aquifer, which has been identified as a potential location for long-term geologic CO_2 sequestration, and is currently not being utilized for CO_2 sequestration. A successful pilot will provide the basis for justification of long-term CO_2 sequestration in the McMurray saline aquifer and confirm the viability of a commercial scale project. The proposed project is a FEED study for the pilot. This study will include all the key activities required to sanction a pilot, and some pre-pilot preparations.

The McMurray Formation is overlain by a number of regional marine shales of the Wabiskaw Member and Clearwater Formation. The McMurray sands are primarily bitumen saturated on MEG's CLRP lease and become water saturated north and east of the CLRP lease. The McMurray is underlain by tight limestone of the Beaverhill Lake Group. The Christina Lake local stratigraphic column is illustrated in Figure 1.

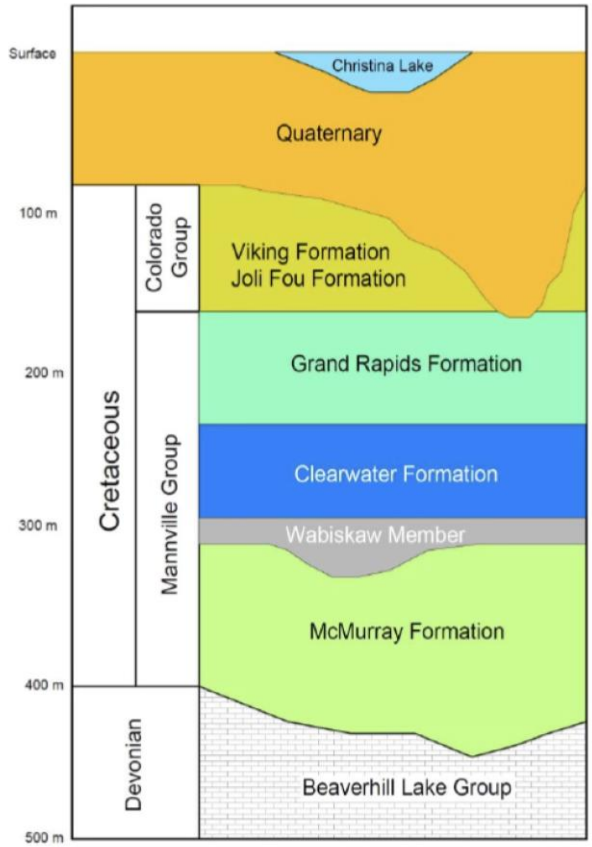

Figure 1 – Christina Lake local stratigraphic column.

Figure 2 illustrates the CO_2 Phase Diagram. Most CO_2 sequestration projects to date have targeted deep formations where the pressures are greater than 7 MPa. This allows the CO_2 to be stored in a dense phase, as a supercritical fluid, a liquid, or a hydrate, reducing the risk of gas phase leakage and increasing the storage efficiency. McMurray formation conditions do not allow for dense phase storage because of the relatively low pressure. When CO_2 is injected in gas phase, the low density of the gas phase makes CO_2 storage inefficient. For example, at 15 °C and 2.5 MPa, CO_2 density is 54.5 kg/m^3. This is relatively small in comparison to 468 kg/m^3, the density of CO_2 at its critical point (31 °C and 7.4 MPa). When water absorbs CO_2, its density increases and it sinks to the bottom of the aquifer, pushing fresher water (undersaturated with CO_2) up to continue contacting CO_2. The CO_2 gas cap is expected to eventually disappear completely under the natural reservoir conditions. This process, however, would take time and gas phase containment is critical. An alternative solution would be to mix the CO_2 with water and inject it already dissolved in the water. In this option, a significant CO_2 gas cap is not formed at any time. Figure 3 illustrates the solubility of CO_2 in water at different temperatures and pressures.

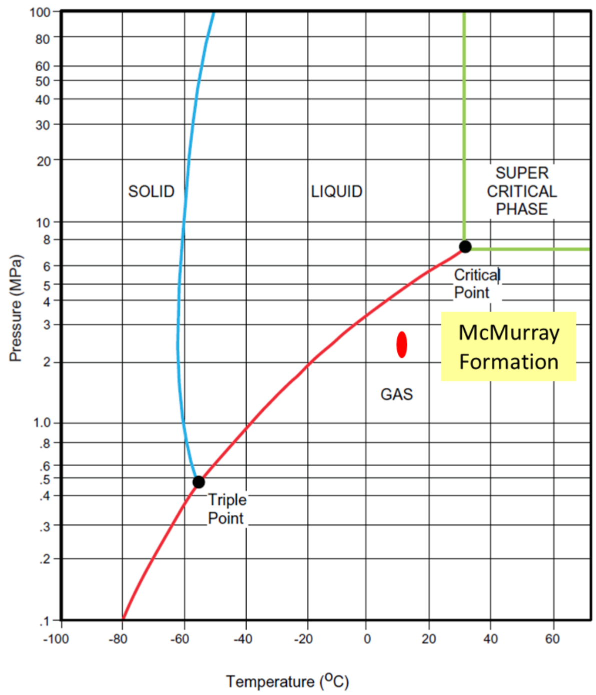

Figure 2 – CO_2 Phase Diagram, From Bachu et al, "Suitability of the Alberta Subsurface for Carbon-Dioxide Sequestration in Geological Media", EUB Earth Science Report 00-11, p8.

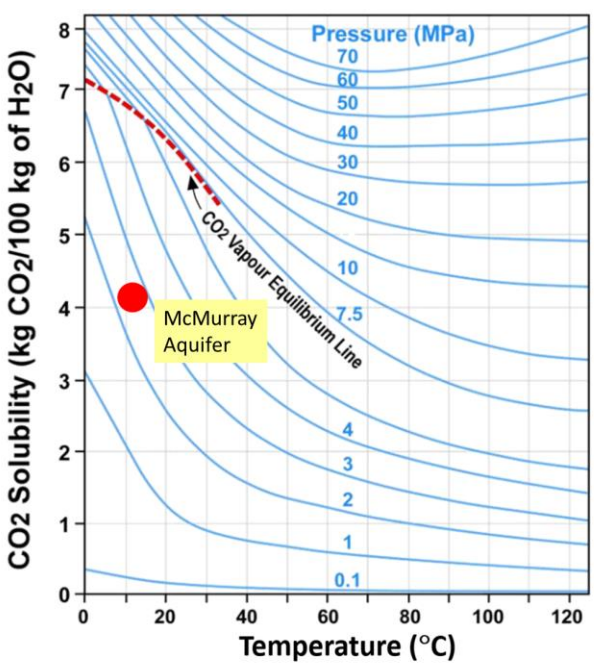

Figure 3 – Solubility of CO_2 in pure water as a function of temperature and pressure [From Ernie Perkins, Fundamental Geochemical Processes Between CO_2, Water and Minerals]. Red dot represents the range of conditions in McMurray aquifer.

Project Objectives

The objectives of the ERASE FEED study did not change throughout the project and the KPIs are as follows:

- Demonstrate the geoscience and reservoir simulation studies support the viability of a commercial sequestration project;
- Complete a reservoir simulation for the selected pilot location;
- Complete a 3D seismic program for the selected pilot location; and
- Finalize the pilot scope and the MMV plan.

D. METHODOLOGY

MEG is taking a phased approach to prove up and commercialize CCS in the McMurray saline aquifer. This project, which was the first step to advance towards commercialization, focused on the McMurray aquifer in the vicinity of MEG's CLRP and included the following:

- Geoscience studies: seismic, geology, hydrogeology, geochemistry;
- Reservoir simulation studies;
- Well design evaluations;
- Surface facility considerations;
- Interviews/discussions with experts and pioneers in CCS to support prioritization of feasibility studies and evaluation of different sequestration options.

A successful pilot, which is outside the scope of this project, will provide the basis to justify long-term CO_2 containment, and confirm the subsurface viability of a commercial project.

E. PROJECT RESULTS

Below are the KPIs (in ***italics***) for the ERASE FEED study project, with key results:

- ***Demonstrate the geoscience and reservoir simulation studies support the viability of a commercial sequestration project***.
  - Preliminary geoscience studies, including siesmic, geological, hydrogeological and geochemical, support the concept of long-term CO_2 storage in the McMurray aquifer.
  - Preliminary reservoir simulations suggest the aquifer is suitable from both a capacity and containment perspective.
- ***Complete a reservoir simulation for the selected pilot location***.
  - Completed with sensitivity studies.
- ***Complete a 3D seismic interpretation for the selection of pilot location***.
  - 3D seismic work completed in the potential area of commercial development.
- ***Finalize the injection strategy, pilot scope and MMV plan***.
  - An initial pilot plan is finalized. The plan includes pilot location, well configuration, monitoring strategy and design, production-mixing-injection strategy, surface facilities & infrastructure, and a numerical reservoir modelling strategy that is incorporated into the monitoring strategy.
  - A conceptual commercial scale MMV strategy and plan has also been completed.

F. KEY LEARNINGS

The key learnings of this project include:

- Preliminary studies suggest that the McMurray saline aquifer is suitable for CO_2 storage.
- Direct injection of CO_2 in gas phase is technically feasible. However, the containment risk is relatively high.
- CO_2 dissolved in saline water prior to injecting into the aquifer may be the preferred option, due to lower containment risks.
- Both options require low pressure CO_2. This could provide significant compression energy savings relative to pipeline transportation, which requires much higher pressure.

G. OUTCOMES AND IMPACTS

The McMurray saline aquifer has been used as a water source, as well as the disposal sink, in *in situ* operations. With adequate distance between the source and the sink, there would be no contamination issues in the source water. A similar question will arise for carbonated water injection, given that water for mixing with CO_2 is expected to be sourced from the same McMurray saline aquifer as it would be disposed with CO_2.

For commercial scale volumes of carbonated water containing about 2 MTPA CO_2 over 20 years, the total cumulative volume of saline water required is estimated to be approximately 1 billion tonnes. This translates, for the McMurray aquifer of 50 m in thickness, into an underground footprint of 67 square kilometers, or 72% of a township. For 20 MTPA (the approximate total emission rate of all thermal projects in the vicinity of McMurray saline aquifer) over 20 years, the underground footprint within the McMurray saline aquifer would be approximately 7 townships.

Preliminary economic and energy consumption analysis indicates that injecting gas is more cost effective relative to injecting carbonated water, while the latter simplifies subsurface considerations and has much lower containment risk. In addition, the process of injecting CO_2, either in gas phase or in carbonated water, into shallow aquifer generates less additional CO_2, mainly due to lower compression requirements, relative to sending CO_2 via pipeline to where deeper reservoir for storage is available. A relative comparison of three CO_2 storage options in term of capital cost, energy cost and containment risk suggests that injecting carbonated water for CO_2 storage could potentially be a viable alternative to deep reservoir sequestration via pipeline.

Based on this, MEG has developed a pilot plan to test sequestration of carbonated water to continue to advance towards commercial scale development.

H. BENEFITS

This project supported employment, including training and retention of highly qualified and skilled personnel (HQSP), in Alberta while advancing towards commercial CO_2 sequestration and supporting the path to net zero emissions.

A detailed economic analysis has not been performed for a commercial sequestration project. However, if successful, it is expected to provide significant value, including:

- Improved environmental performance and global competitiveness for Alberta's energy industry;
- A long term sustainable industry that contributes to social programs for future generations via royalties and taxes; and
- Significant employment opportunities.

I. RECOMMENDATIONS AND NEXT STEPS

This project was a necessary component of the technology development required to advance the prospect of commercial scale CO_2 sequestration in the McMurray saline aquifer. A pilot demonstration is also believed to be a key next step to support policy development and commercialization.

The objectives of the future pilot are anticipated to be:

- Assess the dissolution rate of CO_2 in McMurray aquifer;
- Assess MMV techniques in the Christina Lake geologic setting;
- Assess migration of CO_2 in the McMurray aquifer (dissolved and gaseous); and
- Determine the feasibility of injection strategy and CO_2 storage at commercial scales.

At the end of the pilot, it is anticipated that this innovation would be technically ready for commercialization.

J. KNOWLEDGE DISSEMINATION

The intended end-users of the knowledge generated from this project are MEG and other *in situ* operators in the Southern Athabasca region, as well as other industrial sectors where CO_2 sequestration is required, particularly where they are far away from CO_2 trunklines and high-pressure CO_2 sequestration is not feasible. This project involves collaboration and knowledge-sharing with the public sector (AI) with reports containing results from the project, including this non-confidential report.

K. CONCLUSIONS

The ERASE FEED study achieved the project KPIs, which were as follows:

- Completed geoscience and reservoir simulation studies supporting the viability of a commercial sequestration project;
- Completed a reservoir simulation for the selected pilot location;
- Completed a 3D seismic program for the selected pilot location; and
- Finalized the pilot scope and the Measurement, Monitoring and Verification (MMV) plan.

A pilot demonstration is also believed to be a key step prior to commercialization, but outside the scope of this project. At the end of the pilot, it is anticipated that this innovation would be technically ready for commercialization. The successful implementation of this technology or use of the knowledge generated could result in:

- Improved environmental performance and global competitiveness for Alberta's energy industry;
- A long term sustainable industry that contributes to social programs for future generations via royalties and taxes;
- Significant employment opportunities; and
- Policy development to allow for CO_2 sequestration in the McMurray aquifer.