DATA REVIEW

SOIL GAS CHEMISTRY DATA CONDUCTED BY TRIUM FOR CENOVUS ENERGY

(WEYBURN OIL FIELD SW30-5-13-W2M)

Prepared for

Petroleum Technology Research Centre

DATA REVIEW

WELL INTEGRITY WORK CONDUCTED BY CENOVUS ENERGY

(WEYBURN OIL FIELD SECTION SW30-5-13-W2M)

By

MDH ENGINEERED SOLUTIONS
Member of the SNC-LAVALIN Group

Executive Summary

This report summarises a review, organised by the Petroleum Technology Research Centre (PTRC), of a site investigation (SI) undertaken by Trium Inc. on behalf of Cenovus Inc. The SI was conducted over several days in both August and September, 2011, and comprised sampling and analysis of soil gas, shallow groundwater and surface water at site SW30-5-13W2M, an investigation site near Weyburn, Saskatchewan. Additional well water analyses were undertaken at the Thakeray Farm immediately adjacent to the investigation property. The SI was undertaken to investigate previous claims by residents at the investigation site that CO_2 from the enhanced oil recovery operations at the Weyburn oilfield, operated by Cenovus, had contaminated groundwater and soils. Soil gas samples were obtained from a second site (a control site) located 10 km NW of the oilfield operational area to provide background control for data comparison. Samples of the CO_2 injection stream at the oilfield operations were also analysed for comparison. In addition, the review panel also considered data from oilfield wells located within the investigation site, comprising records of well construction and history, integrity logging tools, surface casing vent flow statistics and fluid analyses undertaken by Cenovus.

The PTRC review was held on 9th November, 2011. A panel of 3 experts from the IEAGHG Weyburn-Midale CO_2 Monitoring and Storage Project (WMP), assisted by a consultant from MDH Engineered Solutions (MDH), reviewed the SI methodology and data.

Key findings of the review panel can be summarised as follows:

- The design, methodology and execution of the gas and water sampling conducted in the SI were agreed to be robust and thorough;
- The range of measured CO_2 concentrations in soil gas samples were found to be typical of soils of the prairies region during summer months, as shown by correlation with data from the control site and previous extensive monitoring undertaken as part of the WMP;
- The data consistently showed an inverse relationship between the detected concentrations of CO_2 and O_2 in all soil gas samples, with the concentration of N_2 remaining stable – this relationship being strongly indicative of a near-surface, biogenic origin for the CO_2 and being consistent with background data previously published from the WMP;
- One ‘outlying’ data point from the August soil gas sampling programme, of 17% CO_2, was within the expected range that can be present due to biogenic activity during summer conditions and also was matched by a corresponding decrease in O_2 with stable N_2 concentrations, as described above. Moreover, the same sampling point in September yielded a CO_2 concentration of under 5%, indicative of an expected seasonal decrease in biogenic activity;

- Analyses of soil gas samples revealed presence of the unstable Carbon-14 isotope, confirming a recent, biogenic origin for all of the CO_2 present. In contrast, Carbon-14 is absent from the CO_2-EOR injection stream, indicative of the 'old' fossil fuel origin of that CO_2;

- Analyses of soil gas samples also documented stable Carbon-13 isotopic signatures that were consistent with those of natural prairie soils;

- Groundwater samples showed no evidence of contamination from CO_2. Very low concentrations of light hydrocarbons were detected in some samples, at levels near to analytical limits of laboratory detection, which could be due to a variety of minor sources including surface spillages;

- The work on well integrity undertaken by Cenovus was found to be appropriate and indicative of sound well integrity, in accordance with appropriate industry standards.

In summary, the review panel found the investigations of soil gas and groundwater undertaken by Trium, and the well integrity investigations undertaken by Cenovus, were appropriate and robust. The panel further concluded that the results show no evidence of any CO_2 leakage from the oilfield CO_2-EOR operations to the site.

TABLE OF CONTENTS

1.0 INTRODUCTION

This document provides a third-party review performed by experts from the IEA Greenhouse Gas R&D Programme Weyburn-Midale Carbon Dioxide (CO_2) Monitoring and Storage Project (henceforth in this report WMP), with support from MDH Engineered Solutions Inc. (MDH), of (i) the site investigation (SI) conducted by Trium Inc. (Trium), an environmental consultant, undertaken on behalf of Cenovus Inc. (Cenovus), a Canadian oil company, and (ii) well integrity analyses conducted by Cenovus. The Trium SI included field sampling and laboratory analyses of soil gas and groundwater conducted at Weyburn Oilfield section SW 30-5-13-W2M (the "investigation site"), the adjacent Thakeray Farm water well, and the long-term WMP project control site (the "Minard Farm") henceforth referred to as the "control site". The review involved a technical evaluation of the adopted sampling and analyses techniques and protocols, reported compositional, concentration, and isotopic data, and their limited interpretation.

2.0 BACKGROUND

Cenovus' Weyburn field, located in southeast Saskatchewan, Canada, hosts a CO_2 Enhanced Oil Recovery (CO_2-EOR) operation. That CO_2-EOR operation, in turn, is host to an accompanying independent research project, the IEAGHG Weyburn-Midale CO_2 Monitoring and Storage Project (WMP), which is studying the geological storage of CO_2. As part of the WMP, extensive measurement, monitoring and verification studies, including soil gas surveys, have been carried out since 2000.

MDH was contacted by Petroleum Technology Research Centre (PTRC) in November 2011 to assist in the production of a third-party review report on the field sampling methodology, sample analyses, and data interpretation conducted by Trium on behalf of Cenovus in August and September 2011. The work by Trium was conducted to investigate claims of CO_2 leakage from the Weyburn CO_2 EOR operations to the surface and near-surface environment on the investigation site, which is located in the southwest of the Weyburn field and outside the CO_2-EOR operational area.

3.0 DATA REVIEW

The sampling methodology, analyses, and interpretation conducted by Trium are reviewed below for soil gas (sections 3.1.1 to 3.1.4), carbon isotopes (sections 3.2.1 and 3.2.2) and groundwater (section 3.3). An additional four sections (4.1.1 to 4.1.4) offer a review of the well integrity investigation conducted by Cenovus.

3.1 *Soil Gas*

For the control site, a total of 28 soil gas samples were collected at a depth interval of 0.8 to 1.0 m using a post-run tubing (PRT) system for the first and second sampling events. All samples were analyzed for CO_2 and CH_4 in the field in real-time by coupling the PRT to a fast greenhouse gas analyzer (FGGA). For the first sampling event, duplicate samples were collected for 50% of those locations based on the highest CO_2 concentrations, using Summa canisters, for certified lab analyses of CO_2, CH_4, and fixed gases (He, H_2, Ar, O_2, N_2, CO, C1-C6, C_2H_4). Additionally, duplicate samples for sulfur compounds were collected from 25% of the locations based on the highest CO_2 concentrations. For the second sampling event duplicate samples for CO_2, CH_4, and fixed gases were collected from the same 25% of locations where sulfur compounds were analyzed in the first sampling event (Trium SI Report; Section 5.2).

For the investigation site, a total of 54 and 78 sample locations were collected from in the first and second sampling events, respectively, at a depth interval of 0.8 to 1.0 m using a PRT system. All samples were analyzed for CO_2 and CH_4 in the field in real-time using an inline FGGA. For both sampling events 50% of the samples were collected in duplicate for laboratory analyses of CO_2, CH_4, and fixed gases and 25% of the samples were collected in duplicate for sulfur compound analyses. Additional samples were also collected from areas of relatively high CO_2 observed in the first sampling event (Trium SI Report; Section 5.3).

Overall, the reviewers concluded that the design, methodology and execution of the gas and water sampling conducted in the SI were agreed to be robust and thorough.

3.1.1 CO_2

Of the total 132 field measurements undertaken in the investigation site, the reviewers noted only a single data point (Location 8 in August) where the measured CO_2 value (17%) was significantly higher than the remaining soil gas sample results from the investigation site and 56 samples from the control site. However, the same sample location yielded a CO_2 measurement of < 5 % during the sampling event one month later, indicative of a biogenic origin. This interpretation is supported in Section 3.1.2 below.

The reviewers concluded that the overall range of CO_2 concentrations encountered at both investigation and control sites were consistent with previous soil gas investigations undertaken over several years of the IEAGHG Weyburn-Midale project.

3.1.2 CO_2 versus O_2/N_2

The relationship of measured O_2 and N_2 to measured CO_2 were essentially identical between the two sampling events undertaken at both investigation and control sites (e.g. Trium SI Report; Figures 3, 4, 9 and 10). The slope of the O_2 versus CO_2 plot was approximately -1, while the N_2 versus CO_2 plot was nearly zero.

The reviewers concluded that O_2 concentrations were affected by CO_2, while N_2 concentrations were not. Since the biogenic production of CO_2 from O_2 would result in an inverse relationship between the two measured concentrations, while CO_2 from geological sources would result in inverse relationships being observed for both O_2 and N_2, these results indicated that soil gas CO_2 measured in the investigation site samples was the product of natural, biogenic production. Moreover, the peer reviewers noted that the 17 %

CO_2 value and correspondingly low O_2 concentration, observed at investigation site sample point 8 during the first sampling event, correlated with this trend.

3.1.3 CH_4

Methane (CH_4) concentrations were found to be very low or below detection limits (<10 parts per million, ppm) in the majority of field measurements across the investigation site. More accurate laboratory analyses of a subset of the samples (see Section 3.1) confirmed the extremely low levels of methane present. Location 8 recorded a CH_4 concentration of 565ppm (0.06%), accompanying the 17% CO_2 data point, as could be anticipated from a biogenic source.

Sampling of the soil gas at the control site actually revealed a slightly higher proportion of samples where methane could be detected, albeit still at very low concentrations (typically 5 to 6 ppm).

The reviewers concluded that the overall ranges of CH_4 concentrations encountered at both investigation and control sites were consistent with previous soil gas investigations undertaken over several years of the IEAGHG Weyburn-Midale project.

3.1.4 Sulfur

The source and recycle gas samples were characterized by 13 measurable sulfur gas compounds, with hydrogen sulfide accounting for approximately 93 % of all species (Trium SI Report; Section 5.1.3). The control site investigation was characterized by the observation of only three measureable sulfur compounds; dimethyl sulfide, carbon disulfide, and hydrogen sulfide, at low parts per billion (ppb) concentrations in the first sampling event (Trium SI Report; Section 5.2.3). Samples were not collected during the second sampling event due to these extremely low values observed in the initial sampling event. Similar to the control site, measureable but extremely low concentrations of dimethyl sulfide, carbon disulfide, and hydrogen sulfide in the investigation site were detected during the first sampling event; however, no species were detected during the second sampling event (Trium SI Report; Section 5.3.3).

The reviewers indicated that the absence of detectable species in the second sampling event suggested that the extremely low concentrations of sulfur compounds were subject to temporal variations, indicative of a biogenic origin. The peer reviewers noted that potential sources for these sulfur compounds could be considered in further detail.

3.2 Soil Gas Isotopes

For the control site, a total of seven soil gas samples were collected at a depth interval of 0.8 to 1.0 m using a post-run tubing (PRT) system for the first and second sampling events. Each sample was laboratory analyzed for isotopes (^{13}C, ^{14}C, ^{18}O on CO_2) (Trium SI Report; Section 5.2).

For the investigation site, a total of 13 and 19 soil gas samples were collected in the first and second sampling events, at a depth interval of 0.8 to 1.0 m using a PRT system. All samples were laboratory analyzed for isotopes (^{13}C, ^{14}C, ^{18}O on CO_2). Additional samples were also collected from areas of high CO_2 observed in the first sampling event (Trium SI Report; Section 5.3).

3.2.1 ^{14}C on CO_2

Analyses of soil gas samples from the source, Dakota Gasification Company (DGC), and recycle gas samples revealed the presence of the unstable Carbon-14 isotope (^{14}C) at values of approximately 0 pMC (Trium SI Report; Section 5.2.2). At the control site, ^{14}C values of approximately 104 pMC were observed (Trium SI Report; Section 5.2.2). Similarly, all soil gas samples collected from the investigation site were characterized by ^{14}C values of approximately 105 pMC (Trium SI Report; Section 5.3.2) in both the August and September sampling events.

The reviewers concluded that these results provide very firm evidence that CO_2 measured in all surface gas samples were of 'modern' biogenic origin, while the low ^{14}C values observed in the source gas CO_2 were indicative of an 'old' fossil fuel origin.

3.2.2 $\Delta^{13}C$ on CO_2

The $\Delta^{13}C$ values from the control site samples were measured at values between -22 and -23 per mil (Trium SI Report; Section 5.2.2). Similarly, investigation site samples averaged between -22.6 and -23.4 per mil between the two sampling events (Trium SI Report; Section 5.3.2). Conversely, the DGC source gas values were measured at an average of approximately -20.5 per mil (Trium SI Report; Section 5.2.2).

The reviewers indicated that a plot of $\Delta^{13}C$ versus CO_2 concentration would be a good indicator of the origin of measured soil gas CO_2. Soil gas CO_2 originating from EOR "leakage" would plot on a regression line between atmospheric CO_2 (0 to 4% CO_2; approximately -8.0 per mill ^{13}C) and DGC CO_2 (100% CO_2; -20.5 per mil ^{13}C). Conversely, CO_2 originating from biogenic or soil processes would have a mixing signature that starts with the $\Delta^{13}C$ value of the original organic carbon in the soil (approximately -26 to -28 in Saskatchewan). That signature would then need to shift by about 4 per mil due to diffusion between solid carbon and gaseous carbon, and CO_2 concentrations varying with the amount of mixing with air. Therefore, the reviewers concluded that the $\Delta^{13}C$ values measured in both the control and investigation sites do not fall along a regression line between the DGC source gas and atmospheric CO_2. Instead, they plot along a regression line that was indicative of a soil or biogenic process origin.

3.3 Groundwater

Shallow groundwater samples were obtained from two wells at the investigation site, and one well on the Thakeray site, during September 2011.

Groundwater samples showed no evidence of contamination from CO_2. Very low concentrations of light hydrocarbons were detected in some samples, at levels near to the analytical limits of laboratory detection, which could be due to a variety of minor sources including surface spillages. The reviewers noted that there was no evidence for any link between these very low concentrations in shallow groundwater, and CO_2-EOR operations.

4.0 Well Integrity and Pipeline Infrastructure

The reviewers considered the work undertaken by Cenovus to be appropriate and indicative of sound well integrity, but recognised that more detailed examination could be provided for further comfort.

4.1.1 Pipeline Infrastructure

Cenovus personnel undertook a compilation of pipeline infrastructure at the investigation site. This compilation was presented during the review meeting. The reviewers feel that a good amount of recent history has been complied on the integrity of pipeline infrastructure present on the investigation site, encompassing the last 10 to 20 years. This includes a good accounting of recorded spills.

The reviewers indicated that limited records from times preceding this 10-to-20-year period had been collected and recommended that Cenovus should continue research and data collection efforts on this matter. The reviewers also considered that additional history could be collected to better understand the gravel pit and agricultural operations that have occurred on the investigation site. Finally, the reviewers noted that additional historical data on surface infrastructure and land use could provide better context for more detailed interpretation of results presented by Trium.

4.1.2 Well Structure

A substantial amount of work has been conducted to characterize the Cenovus-operated wells located on the investigation site. Included in these wells were two 1960's vintage vertical wells, water injector (101/6-30-5-13W2) and a suspended production well (101/4-30-5-13W2). Also included were two 1990's vintage horizontal producer wells 4-30-5-13W2(91/10-24) and 11-30-5-13W2(91/1-25).

The characterization efforts included a broad array of downhole tools and tests. Significant results presented at the review meeting were: casing and cement evaluation logs (multi-finger calipers, ultrasonic, sonic and magnetic flux tools) for the two horizontal production wells and the suspended vertical production well; and casing integrity (multi-finger calliper and annular pressure test) and injection logging (temperature, flowmeter and radioactive tracer) results for the injection well. The tools chosen are deemed appropriate, and the quality of the data that was presented appears to be good. In terms of assessing the potential for leakage of reservoir fluids to shallow soil horizons, the most important factor to assess is the quality of the cement through the Watrous Formation, which serves as the regional seal in the vicinity of the Weyburn Field. In the case of the horizontal production wells, production casing was set within the Watrous; hence, the lower part of this formation is not cemented. However, the upper portion of the Watrous (approximately 50 metres in thickness) is cased and cemented and the logs gathered suggest that the casing is in good condition and the annulus is filled with cement. In the case of the suspended vertical production well, the logs suggest that the casing is in good condition through the entire Watrous Formation and the annulus is filled with cement. In the case of the vertical injection well, the data indicate that no out-of-zone flow occurred during injection.

In the context of this review, these results collectively suggest that well integrity is not an issue for these four wells. The reviewers considered the techniques applied by Cenovus to meet industry standards and be appropriate for the task at hand.

4.1.3 PennWest Well

An abandoned horizontal oil production well operated by PennWest exists on the investigation site (near Sample Point 8). The limited construction details, operating history, and abandonment procedures used for this well could warrant further investigation. The reviewers noted that production casing was set and cemented fully through the Watrous Formation and down into the Midale Evaporite, and recommended that well abandonment details and well trajectory through the Watrous Formation be determined.

4.1.4 Surface Casing Vent Flow

The 1960's vintage vertical wells (101/4-30-5-13W2 and 101/6-30-5-13W2) both showed liquid flow through the surface casing vent into a barrel, at rates of 1 to 2 barrels per year, during the 2011 monitoring work. The water chemistry of the collected flow indicated pH values > 11.0, Na > 3,000 mg/L, and the presence of > 1000 mg/L OH.

The source of the collected liquid for these two wells is currently undefined. Based on the fact that production casing cement tops were near the base of the Mannville Group in these wells and given the results of previous research to characterize aquifers in the overburden sequence in the vicinity of the Weyburn field, it is likely that the observed surface casing vent flows originate in the Mannville, which is well above the Watrous formation (regional seal) and the Midale beds (CO_2 injection zone). The elevated major ion concentrations and the presence of OH ions suggest that this water is interacting with cement at depth; however, additional testing would be required to better define the source.

5.0 SUMMARY

The following key conclusions were agreed by the reviewers:

- The design, methodology and execution of the gas and water sampling conducted in the SI were agreed to be robust and thorough;
- The range of measured CO_2 concentrations in soil gas samples were found to be typical of soils of the prairies region during summer months, as shown by correlation with data from the control site and previous extensive monitoring undertaken as part of the IEAGHG Weyburn-Midale project;
- The data consistently showed an inverse relationship between the detected concentrations of CO_2 and O_2 in all soil gas samples, with the concentration of N_2 remaining stable – this relationship being strongly indicative of a near-surface, biogenic origin for the CO_2 and being consistent with background data previously published from the WMP;
- One 'outlying' data point from the August soil gas sampling programme, of 17% CO_2, was within the expected range that can be present due to biogenic activity during summer conditions and also was matched by a corresponding decrease in O_2 with stable N_2 concentrations, as described above. Moreover, the same sampling point in September yielded a CO_2 concentration of under 5%, indicative of seasonal decreasing biogenic activity;
- Analyses of soil gas samples revealed the presence of the unstable Carbon-14 isotope, confirming a recent, biogenic origin for all of the CO_2 present. In contrast, Carbon-14 is absent from the oilfield injection stream, indicative of the 'old' fossil fuel origin of that CO_2;
- Analyses of soil gas samples also documented stable Carbon-13 isotopic signatures that were consistent with those of natural Prairie soils;
- Groundwater samples showed no evidence of contamination from CO_2. Very low concentrations of light hydrocarbons were detected in some samples, at levels near to analytical limits of laboratory detection, which could be due to a variety of minor sources including surface spillages;
- The work on well integrity undertaken by Cenovus was found to be appropriate and indicative of sound well integrity, in accordance with appropriate industry standards.

In summary, the review panel found the investigations of soil gas and groundwater undertaken by Trium, and the well integrity investigations undertaken by Cenovus, were appropriate and robust. The panel further concluded that the results show no evidence of any CO_2 leakage from the oilfield CO_2-EOR operations to the site.

6.0 CLOSURE

MDH Engineered Solutions Corp., hereinafter collectively referred to as "MDH", has exercised reasonable skill, care, and diligence in preparing this report. MDH will not be liable under any circumstances for the direct or indirect damages incurred by any individual or entity due to the contents of this report, omissions and/or errors within, or use thereof, including damages resulting from loss of data, loss of profits, loss of use, interruption of business, indirect, special, incidental or consequential damages, even if advised of the possibility of such damage. This limitation of liability will apply regardless of the form of action, whether in contract or tort, including negligence.

MDH has prepared this report for the exclusive use of Petroleum Technology Research Centre (PTRC) and does not accept any responsibility for the use of this report for any purpose other than intended. Any alternative use, reliance on, or decisions made based on this document are the responsibility of the alternative user or third party. MDH accepts no responsibility to any third party for the whole or part of the contents and exercises no duty of care in relation to this report. MDH accepts no responsibility for damages suffered by any third party as a result of decisions made or actions based on this report.

Should you have any questions or comments please contact us.

Regards,

Sean Shaw, Ph.D.

7.0 DISCLAIMER

The information presented in this document was compiled and interpreted exclusively for the Petroleum Technology Research Centre (PTRC). MDH Engineered Solutions Corp. does not accept any responsibility for the use of this report for any purpose other than intended or to any third party for the whole or part of the contents and exercise no duty of care in relation to this report to any third party.

Any alternative use, including that by a third party, or any reliance on, or decisions made based on this document, are the responsibility of the alternative user or third party. MDH Engineered Solutions Corp. accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report.

MDH Engineered Solutions Corp. has exercised reasonable skill, care and diligence to assess the information acquired during the preparation of this report, but makes no guarantees or warranties as to the accuracy or completeness of this information. This report is based upon and limited by circumstances and conditions acknowledged herein, and upon conditions encountered at the time of the writing of this report.

Any questions concerning the information or its interpretation should be directed to MDH Engineered Solutions Corp.

8.0 LIST OF REVIEWERS PRESENT

The review panel consisted of the following technical leaders from the IEAGHG Weyburn-Midale CO_2 Monitoring and Storage Project:

- Dr Ben Rostron, University of Alberta
- Dr Chris Hawkes, University of Saskatchewan
- Dr Jim Johnson, Schlumberger-Doll Research