IEAGHG WEYBURN-MIDALE CO_2 MONITORING & STORAGE PROJECT

RESPONSE TO A SOIL GAS STUDY PERFORMED BY PETRO-FIND GEOCHEM LTD.

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RESPONSE TO THE PETRO-FIND GEOCHEM LTD. STUDY

Major efforts worldwide have been underway since the mid-1990's to explore all facets of the geological storage of CO_2. These efforts range from small-scale injection pilots, which are designed to improve our scientific understanding of subsurface CO_2 injection, migration, and monitoring, to large-scale demonstration projects that involve all aspects of the CCS chain. As one of the larger-scale international efforts, the IEAGHG Weyburn-Midale CO_2 Monitoring and Storage Project, was established in 2000 to study the science of geological CO_2 storage using, as the research field site, Cenovus's Weyburn CO_2 – Enhanced Oil Recovery (EOR) project in SE Saskatchewan. The IEAGHG Research Project has focused on the application of scientific procedures and techniques to assess integrity of the geological storage system and to explore the range of measurement and monitoring technologies suitable for the verification of effective long-term storage of CO_2. Along with extensive site characterization, these technologies include near-surface sampling techniques, wellbore monitoring, and deep subsurface imaging.

To this end, more than 30 internationally recognized research organizations – and more than one hundred leading researchers from across North America and Europe – have deployed numerous methods to monitor CO_2 in the deep subsurface where it is injected, and test for any evidence of anthropogenic CO_2 at the surface. One of the many on-going studies is an extensive soil gas monitoring program conducted by a self-funded European Union Group including the British Geological Survey (BGS-UK), Bureau de Recherches Géologiques et Minières (BRGM-France), Istituto Nazionale di Geofisica e Vulcanologia (INGV-Italy) and the University of Rome. Research results provided by the various project teams have been subject to rigorous internal peer- and project-reviews, with the ultimate goal of publication in the open scientific literature.

Based on the extensive scientific research conducted by the IEAGHG Weyburn-Midale CO_2 Monitoring & Storage Project, no results have been found that would support the recently reported conclusion that CO_2 injected as part of the CO_2-EOR Project has migrated through the geological storage system to the surface.

A recent report, *Geochemical Soil Gas Survey*, *A site investigation of SW30-5-13-W2M Weyburn Field, Saskatchewan,* by consultant Paul Lafleur of Petro-Find Geochem Ltd., describes results from a soil gas sampling survey conducted July 7, 2010 on the Kerr property. This property is located at the southern margin of the Weyburn oil field, over 2 km away from the nearest CO_2 injection wells. In this study, soil gas samples were collected from approximately 1 m depth using an aluminum probe and hand drill; 26 soil gas samples were analysed for CO_2 and light hydrocarbon concentrations, and six samples (higher concentrations only) selected for stable isotope analyses. The Petro-Find report concludes that the source of high CO_2 soil-gas concentrations on the property is clearly leakage of the CO_2 injected into the Weyburn reservoir. The following summary points list the conclusions of Petro-Find and challenge their use of data and conclusions.

SUMMARY POINTS

The following points address Petro-Find's claim that "the source of the high concentrations of CO_2 in soils of the Kerr property is clearly the anthropogenic CO_2 injected into the Weyburn reservoir".

Petro-Find states that the high CO_2 concentrations in soils of the Kerr property are clearly anthropogenic because their stable carbon isotope compositions approximate those of the CO_2 being injected into the Weyburn reservoir.

Carbon isotopic compositions of soil gases collected on the Kerr property are similar to those found in prairie soils elsewhere. Published, peer-reviewed studies have shown these compositions to be produced by biological processes. Thus, the reported carbon isotopic signature of soil gas from the Kerr property is not anomalous and does not fingerprint leakage from the Weyburn oil reservoir. Furthermore, stable carbon isotopic analyses of lower CO_2 concentration samples were not conducted, thus depriving the study of critical local controls.

Petro-Find claims that a major shift in the isotopic composition of CO_2 in soil gases at the Kerr property has occurred since CO_2 injection began at Weyburn.

There is no evidence for a change in carbon isotope concentrations in soil gases due to CO_2 injection at Weyburn in the sampling performed by Petro-Find. In fact, Petro-Find incorrectly uses baseline values from a deep geologic formation to infer near-surface soil gas baseline values.

Petro-Find states that CO_2 concentrations in soil gases at the Kerr property are anomalously high and suggest leakage from the Weyburn reservoir.

The concentrations of CO_2 in soil gases collected by Petro-Find are similar to those found in prairie soils in the vicinity of Weyburn. Natural biogenic CO_2 concentrations in prairie soils are generally higher during the summer and in moist, low-lying areas similar to sampling sites at the Kerr property. Thus, soil-gas CO_2 concentrations reported for the Kerr property are not anomalous and do not provide a signal for leakage from the Weyburn oil reservoir.

Petro-Find infers a link between soil gas CO_2 concentrations and threshold atmospheric limits for health concerns.

CO_2 concentrations that would be of concern in the air above ground are actually quite normal in soil gas at a depth of 1 m. There are no data in the Petro-Find report demonstrating dangerous levels of CO_2 in the atmosphere.

Petro-Find suggests that open "deep-seated faults/fractures" provide the only explanation for CO_2 to rapidly migrate over 2 km south to the Kerr property.

There is no credible evidence that the surface lineaments proposed by Petro-Find indicate a 1.5 km deep open fault.

Petro-Find invokes that a breach of the cap rock of the Weyburn reservoir must have occurred in their scenario.

The anhydrite cap has retained over 1.4 billion barrels of oil in the Weyburn reservoir for millions of years. Moreover, for leakage to reach the surface this would require breaching a further 1,500 m of strata, including 5 major geological barriers totaling 800 m in thickness. In addition, for CO_2 to migrate 2 km south it would have to move counter to mapped formation-water flow and the natural tendency of CO_2 to migrate up dip, north and away from the Kerr property.

The Petro-Find report reaches a conclusion that is unsubstantiated by the limited data in their study. The report contains technical errors, invokes undocumented data, and provides minimal to no information on their scientific methods or analytical techniques.

In summary, there is no substantiated evidence in the Petro-Find report to support their claim that "the source of the high concentrations of CO_2 in soils of the Kerr property is clearly the anthropogenic CO_2 injected into the Weyburn reservoir." The phenomena observed at the Kerr property can be explained by near surface processes including microbial generation of soil CO_2 and methane.

DISCUSSION

The report *Geochemical Soil Gas Survey* by Petro-Find Geochem Ltd. describes results from a soil-gas sampling program on the Kerr property, which is located at the southern margin of the Weyburn oil field, but over 2 km away from any CO_2 injection wells. The report concludes that the source of high CO_2 soil-gas concentrations on the property is clearly leakage of the CO_2 injected into the Weyburn reservoir based on:

1) stable carbon isotope values of CO_2 sampled in the soils being similar to the composition of the CO_2 injected into the oil reservoir and being different than biogenic CO_2; and
2) a major shift in baseline isotope values of the soil gas at the Kerr site following the commencement of CO_2 injection at Weyburn.

Petro-Find's basic premise that they can *clearly* identify CO_2 leaking from the Weyburn reservoir is not supported by their data on either point.

The following sections provide additional detailed discussions and support for the summary points provided above.

<u>Carbon isotopic compositions of soil gases collected on the Kerr property are similar to those found in prairie soils elsewhere.</u>

The Petro-Find report claims that the isotopic composition of carbon in soil gas CO_2 (6 samples which average -22.1 per mil) clearly indicates leakage from the Weyburn reservoir because it "approximates" the isotopic composition of the injected CO_2 (-20.4 per mil). The difference between soil gas and anthropogenic gas compositions is suggested by Petro-Find to indicate that there is also biogenic soil CO_2 present in the samples, but this is not a precise match. More importantly, the assertion that these values represent a unique fingerprint cannot be supported because the isotopic composition of soil gas naturally present in prairie soils is also similar to that of the injected CO_2 (e.g., Keller and Bacon, 1998; Hendry, 1999). Based on reference to a single university thesis (Wang, 1997), the Petro-Find report states that the typical carbon isotopic composition of biogenic CO_2 in soil gas is between -27 and -28 per mil (these are actually measurements of solid organic matter, not soil gas as Petro-Find states). Soil gas isotopic values, however, will be similar to the organic matter from which they are generated or slightly higher (that is, less negative) if diffusion in the soil takes place (Cerling, 1984, 1991). Wang (1997) determined the predominant soil type in the Weyburn area is Dark Brown Chernozemic with soil organic matter having carbon isotopic ratios of -25.4 to -21.8 per mil. In fact, there is an extensive and established scientific literature that has long demonstrated a much wider range of isotopic compositions in organic matter. C3 plants (most local plants including crops such as wheat) produce CO_2 between about -19 and -31 per mil, whereas C4 plants (the minority of species) range between about -9 and -18 per mil. A detailed study into soil respiration in a pasture region in central Saskatchewan with no oil production or CO_2 flooding determined carbon isotopic compositions of soil gases averaging -23 per mil (Hendry et al., 1999); values which are similar to those of the Petro-Find study. Other studies that infer or measure the carbon isotopic composition of soil-gas CO_2 in Saskatchewan indicate a range between -28 to -18 per mil (e.g., Cerling and Quade, 1993; Wang, 1997, Wang and Anderson, 1998). In this

instance, carbon isotopic compositions cannot distinguish between ubiquitous, indigenous biogenic soil gas and anthropogenic gas because of the overlap in the carbon isotopic signatures of biogenic soil-gas CO_2 and the Weyburn-reservoir CO_2.

There is no evidence for a baseline change in carbon isotope concentrations in soil gases.

Petro-Find also claims that an observed major shift in baseline isotopic compositions of soil gas CO_2 lends support to their argument. This claim is factually incorrect because they erroneously assume isotopic baseline values of -12 to -14 per mil represent the initial composition in the soil gases prior to the start of injection (Petro-Find, Table 2). The -12 to -14 per mil carbon isotope compositions cited by Petro-Find actually are measurements of CO_2 in the Weyburn oil reservoir prior to anthropogenic CO_2 injection (Johnson et al., 2009). The Petro-Find report incorrectly uses the carbon isotopic values of naturally occurring CO_2 in an oil reservoir at 1.5 km depth to represent initial values of CO_2 in soils at surface. As such, the argument for a dramatic shift in isotopic composition is technically flawed.

The concentrations of CO_2 in soil gases collected by Petro-Find are similar to those found in prairie soils in the vicinity of Weyburn

Annual soil-gas monitoring surveys were conducted by a European Union research group during five consecutive years from 2001 to 2005 (Riding and Rochelle, 2009). (An additional survey planned for 2010 has been postponed to 2011). The surveys included sampling a 360-sample grid within the CO_2-EOR area and a smaller 35-sample grid at a "background" site approximately 10 km away from the oilfield. These areal surveys were supplemented by examination of vertical profiles at two abandoned well sites and profiles over other localized areas. Measurements were made for soil-gas chemical and isotopic compositions, chemical concentrations, CO_2 fluxes, and gamma-ray spectroscopy. In addition, continuous electronic radon sensors were installed at 1.9 m depth for up to one year at a time. These studies have established a complex and highly variable near-surface soil gas environment, but no evidence has been found to relate soil-gas compositions or chemical concentrations in the Weyburn area to the escape of injected CO_2 from the EOR project in the underlying oilfield.

Petro-Find reports chemical analyses of soil-gas samples collected from the Kerr property in a single survey during July 2010. They express concern with the average CO_2 concentration of 2.3% and especially with a single value of approximately 11% measured in the shallow subsurface. However, these average and extreme values are well within the range of EU results from their July-2001 survey, during which a maximum value of 12% was measured and many areas within the main and background grids showed values in excess of 3% (Riding and Rochelle, 2009). The higher soil-gas CO_2 concentrations measured by the EU researchers were strongly related to depressions and low-lying areas such as sloughs and ponds, which also occur on the Kerr property. In fact, the "major anomaly" of CO_2 content in soils noted in the Petro-Find report fringes the "major slough" on the Kerr property. It may also be noted that the summer of 2010 was one of the wettest on record, with rain and hot weather occurring over several days preceding the Kerr survey. Elevated soil gas CO_2 values are well known (e.g., Hendry et al., 1999) to be produced by root and microbiological respiration, and this shallow biological production of CO_2 is much more prevalent in the summer. For comparison, EU soil gas surveys conducted in late

autumn (Oct 2003, Oct 2004, Oct 2005) on the main grid were around 2.5%. **Thus the soil gas CO_2 concentrations from the Kerr property are comparable to those observed in EU surveys, and cannot be considered, by themselves, to be indicative of leakage of CO_2 from depth.**

Petro-Find suggests open "deep-seated faults/fractures" provide the only explanation for CO_2 to rapidly migrate over 2 km south to the Kerr property

Petro-Find suggested that only a deep-seated fault open from the reservoir to the surface could explain how CO_2 could move from the reservoir to the Kerr property that is over 2 km away from the CO_2-EOR operation. They indicate an open fault could provide the mechanism for upward flow fast enough that CO_2 contents in the soils could change daily related to changes in the deep reservoir.

Petro-Find uses surface lineaments (linear surface landforms or patterns of generally unknown origin) and contours of soil gas contents at surface to infer the presence of faults and fractures at depth. Although no methodology is described, it would seem the lineaments used in this study were drawn from a topographic map whereas standard methods use high resolution air photos and satellite imagery. Characterization work conducted as part of the IEAGHG Weyburn-Midale Project, and other studies, have shown that most lineaments are not fault related and reflect near surface processes often related to glaciation. To establish a direct link with any deeper feature requires integration with seismic data, detailed geological mapping, high-resolution aeromagnetic data, and petrophysical log analyses.

The existence of an open fault is highly unlikely given the long-term existence of oil in the Weyburn reservoir. An open fault to the Weyburn Reservoir would almost certainly transmit other fluids including hydrocarbons and potentially brines. No oil shows have ever been noted above the 1325 m deep Watrous Formation (the major stratigraphic trap in the area) in the thousands of wells drilled in the area, and hydrogeological data from the IEAGHG Weyburn-Midale Project (Wilson and Monea, 2004) show water compositions of major flow units are distinct with no indication of cross-formational flow above the Watrous Formation. It is exceedingly improbable that an open fault would have developed recently as there are no identified active faults in the Weyburn area and no earthquakes above magnitude 4 prior to 1965 or above 2.5 since 1965 have been identified within 40 km of the injection site on the Canadian National Seismograph Network. **The Petro-Find report concludes that the high CO_2 concentrations must originate from the CO_2 injected into the reservoir and that the gas must then have travelled up deep-seated faults or fractures. Neither of these conclusions is warranted by the data presented.**

SUMMARY

The Petro-Find report for the Kerr Property (SW/30-5-13W2M) is missing key scientific documentation relating to sampling methods, analysis, supporting data, and repeatability, and does not provide a discussion on alternative, and more plausible, interpretations of the data. Many of the geochemical signals identified in this report can be explained by near surface processes including the biogenic production of soil gas CO_2. There is no evidence presented in this report that can support the far-reaching and definitive statements made about the source of CO_2 on the Kerr property.

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