New Approach to
Soil Gas Monitoring

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Monitoring Carbon Storage Sites

- Require integration of many techniques and tools at various depths from the reservoir to the atmosphere.
Soil Gas Monitoring

- Demonstrate protection of natural resources
- Demonstrating the requirement that CO$_2$ has been stored with respect to the atmosphere.
- Address landowner concerns.

Courtesy of Curt Oldenburg

Gulf Coast Carbon Center • Bureau of Economic Geology • The University of Texas at Austin
The Challenge of Variability

- CO₂ naturally abundant and reactive in the near-surface
- Temporally and spatially variable
  - Rainfall/water flux
  - Barometric pressure
  - Root respiration
  - Microbial activity
- Difficult to identify a release from natural variability

Source: DOE, 1999: Carbon Sequestration Research and Development
Current Approach

- **Concentration-Based-Measure** natural “background” CO$_2$ concentrations over 1 year to explain range of seasonal CO$_2$ variation. Anything different signals a release.
Challenges of Concentration Based Approach

- 1 year cannot capture the full variation in natural CO$_2$.
- Background measurements time, cost, and labor intensive.
- Background concentrations cannot be measured everywhere within the area of concern.

Weyburn soil-gas grid

14 km$^2$ grid 200 m spacing (from Riding and Rochelle, 2009)
Process-Based Approach

- Focus on process to identify the origin of CO$_2$.
- Identifying the processes that have acted on the CO$_2$ will distinguish between background and exogenous gas.
- Processes that act on CO$_2$ will also alter coexisting gases in predictable ways.
- CO$_2$, CH$_4$, O$_2$, N$_2$
Gas Concentration Measurements

- Measured in volume percent.
- Any non-reactive input of a component to a gas mixture will, by definition, decrease the % concentrations of other gases in the mixture.
- Any loss of a gas will, by definition, increase the % concentrations of other gases in the mixture.

Air
- 78% N₂
- 21% O₂
- 1.8 ppm CH₄
- 0.038% CO₂

- N₂ is most abundant and most conservative.
Major Processes

**Background**
- Biologic respiration (plant and microbial)
- Oxidation of methane
- Dissolution of CO₂ into groundwater and reactions with soil carbonate
- Atmospheric exchange

**Leakage**
- Exogenous CO₂ or CH₄ from a storage formation
Natural Processes

**Biologic respiration**

\[ CH_2O + O_2 \rightarrow CO_2 + H_2O \]

**Oxidation of CH\(_4\)**

\[ CH_4 + 2O_2 \rightarrow CO_2 + H_2O \]

Mixture

\[ CO_2 < \text{expected for } O_2 \]

\[ CO_2 > \text{expected for } O_2 \]
Playa Lake Natural Analog

- Broad, gently sloping, circular basins
- Perch surface runoff before infiltration.
- CO$_2$-rich (17% microbial)
- CH$_4$- RICH (2.5% microbial)
- Systematic variations in environmental factors
  - Slope - dry, low organics and CO$_2$, shallow soil carbonate
  - Floor - wet, high organics and CO$_2$, soil carbonate mobilized
  - Annulus- mixture
Background Gas Relationships

\[ \text{CH}_2\text{O} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} \]

\[ \text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} \]
Enrichment of N₂

- CO₂ dissolves and reacts with soil carbonate.
- Total pore pressure drops.
- Advection of air into pore.
- Volume % of N₂ increases.
Application to Industrial Site

Gas Station Locations

12 multi-depth stations
36 wells
6 sampling trips
Sept, 2009 – March, 2011

CH₄ ≤ 34 vol. %
CO₂ ≤ 45 vol. %
N₂ 42-85%
O₂ 2-21%
Morphology of Anomaly

- CO$_2$ and CH$_4$ anomaly concentrated at well 103
- Thermogenic
- Kerogen Type II
- Oil and gas reservoir
- CO$_2$ from oxidation of CH$_4$
Fixed Gas Indicators of Process

**Background**
- Trend indicates carbonate dissolution.
- N₂ enriched by carbonate dissolution.
- Minimal O₂ consumption supporting CO₂ is microbial.

**100 (pad)**
- Trend indicates mostly microbial CO₂.
- N₂ supports mostly microbial with little dissolution.
- Minimal O₂ consumption supporting CO₂ is mostly microbial.

**101 (pad)**
- CH₄ oxidation.
- N₂ diluted by exogenous gas input.

**03 (anomaly)**
- Oxidation of exogenous CH₄.
- N₂ diluted by exogenous gas input.

**105 (pit)**
- Decrease in exogenous CH₄, carbonate dissolution, and microbial CO₂.
- N₂ indicates carbonate dissolution and microbial CO₂.
- Some O₂ consumption identifies minimal CH₄ oxidation.

**Large O₂ consumption confirms oxidation of exogenous CH₄.**
Simple Analysis of Fixed Soil Gas

Oxidation of exogenous CH₄

CO₂ Leak

Background

0 5 10 15 20 25 30
CO₂ (vol %)

0 5 10 15 20 25 30
O₂ (vol %)
Simple Analysis of Fixed Soil Gas

- **Input of Exogenous Gas**
- **Background**

- **CO$_2$**
- **78% atmosphere**
- **N2**

- **78% atmosphere**

- **Exogenous Gas**

- **N2**
Simple Analysis of Fixed Soil Gas

Signifies CO₂ may originate from oxidation of exogenous CH₄
Summary

- Current methods for soil gas monitoring are concentration-based and depend on comparing monitored to background CO$_2$ concentrations.
- Natural CO$_2$ is spatially and temporally variable and makes this approach challenging.
- An alternative process-based approach is presented.
- The process-based approach was developed at a natural analog playa lake and successfully tested at an industrial oilfield site.
- The process-based approach uses relationships among CO$_2$, CH$_4$, O$_2$, N$_2$ to distinguish between natural background processes and a leakage signal. The processes that affect CO$_2$ in the vadose zone will also affect coexisting gases in predictable ways.
- This approach uses simple measurements and may make leakage detection possible without the need for time-intensive and costly background monitoring.
- Controlled release sites are needed for further validation of the method.
Thank You