Development of a 1 x N Fiber Optic Sensor Array for Carbon Sequestration Site Monitoring

Project Number: DE-FE0001858

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National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and Building the Infrastructure for CO₂ Storage
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Presentation Outline

• Program and Project Benefits
• Technical Status
  – Brief Introduction to integrated path differential absorption concentration measurements
  – 1 x N fiber sensor array description
  – Experimental results
• Program accomplishments and summary
Benefit to the Program

- **Program Goals Addressed:**
  Develop and validate technologies to ensure 99% storage permanence.

- **Project Benefits**
  The research project is developing a scalable, cost effective, reconfigurable fiber sensor array for large sub-surface monitoring of CO$_2$. This technology contributes to the Carbon Storage Program’s effort to ensure 99% CO$_2$ storage permanence.
The project objectives for the proposed work include the development, testing, and deployment of a 1 x N fiber sensor array for subsurface CO$_2$ monitoring.

- Relates to the development of technologies to demonstrate that 99% of CO$_2$ remains in the injected zones.
- Success criteria: Demonstration of instrument from a laboratory setting.

Testing of the instrument will be conducted to determine the performance of the fiber sensor array at the Zero Emission Research Technology (ZERT) field site during a controlled release experiment and at the Big Sky Carbon Sequestration Partnership Site.

- Relates to conducting field tests for site operations.
- Success criteria: Demonstration of instrument during a ZERT controlled release experiment and for a one month deployment at the BSCSP site.
The number density for carbon dioxide is related to the amount of light absorbed as a function of wavelength.

Working near the 2 µm wavelength provides strong absorption features which allow subsurface CO₂ concentration measurements to be made in as little as 0.5 m.

Measuring the normalized transmission allows one to calculate the number density.

Using the line strength and line shape parameters, the concentration can be calculated from the IPDA equation:

\[
C = \frac{-\ln(T)}{S_g(v - v_0)[N_L(296/T_a)]P_TL'}
\]
Technical Status: Instrument Design

- Current Temperature Controller
- Reference Detector
- Fiber Splitter
- DFB Laser
- Multichannel Voltmeter
- Transmission Detector
- Circulator
- 1 x N Fiber Optic Switch
- Computer
- Ground Level
- Fiber Probes
- Detectors
- Diode Mount
- Diode Controller
- DAQ
Technical Status: Probes

Solidworks CAD drawing of the probe design. The probe was designed to contain all passive optical components and is inexpensive to manufacture.
Technical Status: Data Acquisition Software
Technical Status: Field Experiment

Aerial view of the ZERT controlled release site.

Electronics and optics packaged in a weatherproof enclosure for field studies.

Instrument deployed at the ZERT site with sun shade.
## Technical Status: ZERT Field Data

<table>
<thead>
<tr>
<th>Wavelength (µm)</th>
<th>Linestrength $10^{-21}$ molecules/cm</th>
<th>Normalized Lineshape Cm</th>
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<tr>
<td>2.001 102 0</td>
<td>0.811 2</td>
<td>1.160 0</td>
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<td>2.001 557 7</td>
<td>0.931 6</td>
<td>1.151 6</td>
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<td>2.002 025 5</td>
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<td>2.004 548 2</td>
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</table>

### Graphs

- **Top Graph:** Transmission vs. Wavelength ($\mu$m)
  - 2,000 PPM
  - 10,000 PPM
  - 60,000 PPM

- **Bottom Graph:** Normalized Transmission vs. Wavelength (nm)
  - HITRAN
  - Instrument Sample
Technical Status: ZERT Field Data

Concentration (PPM)

1p.m. 7/6
1p.m. 7/5
1p.m. 7/7
1p.m. 7/8
1p.m. 7/9

Probe 1
Probe 2
Probe 3
Probe 4
Technical Status: ZERT Field Data

![Graph showing CO2 concentration over time with different probes]

- **Probes:**
  - Probe 1
  - Probe 2
  - Probe 3
  - Probe 4

**Axes:**
- **Y-axis:** CO2 Concentration (PPM)
- **X-axis:** Time (Days)

**Legend:**
- **Start** and **Stop** markers indicate the duration of the data collection.

**Observations:**
- The graph illustrates the fluctuation of CO2 concentration over a period of 60 days.
- Each probe shows a unique pattern of concentration variation.
- The concentration peaks and troughs are evident throughout the time span.

**Note:** For a detailed analysis, the specific data points and methodologies used are essential for accurate interpretation.
Technical Status: BSCSP Field Data
A commercial 1 x 100 fiber optic switch allows up to 100 probes to be deployed. Using standard telecommunications fiber, these 100 probes can be located up to 1 km away from the central electronics box.

Because the cost of the probes is kept low, scaling to 100 probes will not greatly increase the cost providing a cost effective sensor array.
Accomplishments to Date

• A 1 X N fiber sensor array architecture has been developed.
• Subsurface CO$_2$ concentration measurements have been made continuously for over 40 days.
• Instrument has been demonstrated at the ZERT field site where the elevated subsurface CO$_2$ concentration from the subsurface release is clearly evident.
• Instrument has been successfully deployed at the BSCSP site.
Summary

• The fiber sensor array has been successfully deployed at the ZERT controlled release experiment.
• The fiber sensor array offers a scalable, reconfigurable, cost effective monitor for large area coverage with autonomous operations.
• Future Plans
  – Include a second DFB laser for sensing oxygen to provide the potential to distinguish sources of subsurface CO$_2$.
  – Working with Integrated Optical Systems on transfer technology of fiber sensors into the commercial market.
Thanks Kindly for Your Time
• Kevin Repasky: (PI) responsible for overall project.
  John Carlsten: (Co-PI) work with Dr. repasky to manage project and students.
  Lee Spangler: Head of ZERT and BSCSP. Coordinate field work
  Laura Dobeck: Coordinate ZERT field experiments.
## Appendix: Gantt Chart

<table>
<thead>
<tr>
<th>Month</th>
<th>3</th>
<th>6</th>
<th>9</th>
<th>12</th>
<th>15</th>
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<td><strong>Phase 2</strong> Development and initial testing of a 1 x 4 fiber sensor array</td>
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• Presentations:

• Papers: