A Highly Sensitive Real-Time Subsurface Sensor for CO₂ Leakage Monitoring

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Bettergy Corp.
Presentation Outline

1. Project Overview and Bettergy Introduction
2. Background and Concept
3. Technical Status
4. Project Schedule
5. Summary
1.1 Project Overview

• Goals and Objectives
  • Develop a highly stable and highly CO\textsubscript{2} sensitive material
  • Design and fabricate the sensor structure
  • Integrate the material into the as-fabricated sensor platform for CO\textsubscript{2} sensing
  • Demonstrate the sensor’s capability of real-time detection of low concentration CO\textsubscript{2} flow
1.2 The Company

Bettergy develops and commercializes innovative energy and environmental technologies, with expertise in nanopore engineered membranes and advanced battery technologies

- **Talented Team**
  - 16 employees and consultants, including 7 PhDs, with a broad range of expertise

- **Intellectual Property**
  - 6 issued U.S. Patents and 7 pending U.S Patent applications

- **$16M** in grants and contracts
  - From DOE, ARPA-E, DoD, NASA, NIH, NSF and NYSERDA

- **Commercialization Experience**
  - Spin out of a battery and membrane technology now in full-scale prototyping stage

- Numerous academic collaborators
1.3 Project Organization Chart

Program Manager
Natalie Iannacchione

Bettergy Corp.
PI: Shixuan Zeng

Research Team

Commercialization and Marketing

University of Cincinnati
Prof. Junhang Dong

Material Development
Sensor Evaluation

Characterization Center
Joint Material Development
1.4 Benefits of the Program

**Project Benefits**
- A “plug-and-play” sensor will assist the existing and future CO₂ injection process
- Advancing carbon capture and storage (CCS) technology, helping to achieve “Carbon Free”
- Significant impact on the market adoption of downhole monitoring sensors

**Program Objectives**
- Increasing private sector commercialization of our sensor technology
- Stimulating technological innovation of subsurface sensors in the private sector
- Improving the return on investment from DOE-sponsored SBIR project
- Creating new, highly skilled jobs for the nation
2.1 Background

➢ Subsurface CO₂ Monitoring --- Problems

DOE SBIR Solicitation FY2021, Topic 24c.

• Innovative technologies to measure *plume location, pressure front and leakage conditions* are sought

• Bettergy proposed a real-time CO₂ leakage sensor for CCS applications
2.1 Background

➢ Injection Well Leakage Detection

*** The space between CO₂ injection casing and bore hole wall is very limited (~35 mm), making it very challenging for sensor implementation.
### 2.1 Background

#### State-of-the-art Subsurface CO₂ Sensing and Challenges

<table>
<thead>
<tr>
<th>Leakage Detection Techniques</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser-based Optical Sensor¹</td>
<td>Signal accuracy; complicated packaging; stability issue; cost</td>
</tr>
<tr>
<td>Shallow 2D Seismic Sensor²</td>
<td>Dissolved CO₂ or low-saturation CO₂ detection near well; sensitivity; cost</td>
</tr>
<tr>
<td>Soil gas monitoring³</td>
<td>Localized leakage detection; analysis and sampling time; use of tracers; cost</td>
</tr>
<tr>
<td>Groundwater monitoring⁴</td>
<td>Analysis and sampling time; potential use of tracers; cost</td>
</tr>
<tr>
<td>Reservoir Fluid Monitoring⁵</td>
<td>Analysis and sampling time; labor-intensive; cost</td>
</tr>
</tbody>
</table>

1. DE-FOA-0001258, Richard Wainner
5. Freifeld and Trautz 2006
2.2 Sensor Concept

**Proposed Subsurface CO₂ Leakage Sensor**

Sensor requirements (Pain points)
- Physically and chemically robust
- Small in size
- Highly sensitive to CO₂
- In-situ, real-time signal response
- Subsurface environment
- Low manufacturing cost, low O&M cost

*** System level projection for our proposed sensor in underground CO₂ leakage detection and/or plume migration monitoring.

Coaxial cable sensor is the solution
2.2 Sensor Concept

What is a coaxial cable sensor?

A Typical Coaxial Cable

By analyzing Reflecte, Transmitted or Interfered signals\(^1\), the coaxial cable sensor can detect:

Physical parameters: e.g. temperature\(^2\), torsion.
Chemical changes: e.g. gas, liquid.

1. J. Huang, Sensors, (2013)
2.2 Sensor Concept

➢ Previous work on coaxial cable sensor

Resonant frequency: \[ f_N = \frac{Nc}{2d\sqrt{\varepsilon_r}} \quad (N=1,2,3,...) \]

1. Temperature sensor\(^1\)
2. Torsion sensor
3. Pressure sensor
4. Liquid level sensor

Existing physical sensors

Material property change will introduce resonant frequency shift\(^2,3\)

New materials for building chemical sensors

• Example of the microwave interference spectrums detected by CC-FPI upon the liquid analyte composition changes\(^1\).
• Resonant frequency shift.

2.2 Sensor Concept

Proposed work

We propose to develop a highly CO$_2$ sensitive material and integrate it with a CC-FPI sensor for real-time detecting low concentration CO$_2$.

Sensor requirements for subsurface CO$_2$ leakage detection:
✓ Physically and chemically robust
✓ Small in size
✓ In-situ, real-time signal response
✓ Scalable
✓ Low manufacturing cost, low O&M cost
➢ Highly sensitive to CO$_2$ (this work)

Based on our previous work, we can conclude that this CC-FPI:
• has demonstrated chemical sensing capability
• is highly robust against harsh conditions
• has high resolution for low concentration analyte detection
• has the potential in scaling-up applications
• is made of low-cost, off-the-shelf commodities
• is easy to manufacture
3. Technical Status

➢ **Expected Outcomes**

1. A novel CO\textsubscript{2} adsorbent will be developed with high CO\textsubscript{2} adsorption capacity, fast diffusion rate, high stability and low cost.
   - Potential CO\textsubscript{2} adsorbent with higher carbon removal efficiency
   - Special CO\textsubscript{2} affinity will advance carbon separation processes
   - Understanding fundamental gas diffusion mechanism in the material

2. A novel coaxial cable sensor for real-time detecting low concentration CO\textsubscript{2} will be demonstrated.
   - A future sensor platform technology for chemical detection
   - Specially designed for harsh environment applications
   - Combine sensor device development with fundamental material research
3. Technical Status

 Tasks and Accomplishments

 Task I. Material Synthesis and Characterization
 ✓ Explore and optimize the material synthesis procedure
 ✓ Characterization and material performance results will be delivered

 Task II. Sensor Fabrication
 ✓ Explore sensor functionality with different structures
 ✓ Fabricate sensor with different materials

 Task III. Sensor Evaluation
 ✓ Evaluate the as-fabricated sensor with a lab apparatus
 ➢ Sensor’s sensitivity, response time and detection limit will be tested
 • Use sensor data to guide material development

 Current Work

 Task IV. Preliminary System Design and Cost Analysis
 ✓ Sensor system design based on practical applications
 • Preliminary technical economic analysis (TEA) will be provided
3. Technical Status

➢ Selected Results

Bettergy’s CC-FPI CO₂ sensors

35 sensors fabricated, more on the way...

S11 cycling tests, Cco₂ = 250 ppm and 600 ppm, 4 cycles with air regeneration
3. Technical Status

➢ Selected Results

Signal response of sensors made of different adsorbent material --- new fundamental study.
### 3. Technical Status

#### Challenges and strategies

<table>
<thead>
<tr>
<th>Research Challenges</th>
<th>Mitigation Strategies</th>
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<tbody>
<tr>
<td>Material synthesis issues</td>
<td>Modify synthesis conditions such as temperature, time or composition.</td>
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<tr>
<td>Sensor assembling issues</td>
<td>Design and fabricate new sensor structure that works the best.</td>
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<tr>
<td>Sensor test issues</td>
<td>Modify sensor testing conditions, adjust testing instrument methods, using advanced control systems from the vendor.</td>
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<td>Environment factors impact</td>
<td>Calibration, multiple experiments.</td>
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### 4. Project Schedule

#### Project Timeline

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<tbody>
<tr>
<td>Month</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
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<tr>
<td>Task I. Material Synthesis and Characterization</td>
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<tr>
<td>Task II. Sensor fabrication</td>
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<td>X</td>
<td>X</td>
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<tr>
<td>Task III. Sensor evaluation</td>
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<tr>
<td>Task IV. Preliminary System Design and Cost Analysis</td>
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<td>Final Report</td>
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4. Project Schedule

➢ Milestones and plans (next quarter)

**Milestone I.** CO₂ sensitive material development, *Aug. 2021*
➢ Material properties are optimized for this sensing application.

**Milestone II.** More Sensors fabricated, *Sep. 2021*
➢ The as-fabricated sensor shows well-defined signals.

**Milestone III.** CO₂ detection tests, *Oct. 2021*
➢ Sensor parameters such as sensitivity, response time, detection limit will be monitored and further optimized.

**Milestone IV.** Sensor’s economic feasibility demonstrated, *Nov. 2021-Jan. 2022*
➢ TEA analysis, market research (interviews, future customers).
5. Summary

This program aims at developing a cost-effective sensor technology that can real-time monitor CO$_2$ leakages for CCS applications.

- A novel CO$_2$ sensitive material was developed
- A new sensor configuration for harsh environment chemical sensing was proposed and fabricated
- The sensor was demonstrated for real-time, low concentration CO$_2$ detection
- The sensor’s reusability was demonstrated with multiple sensing cycles
Thank you!
Appendix: Bibliography

Carbon capture and storage (CCS) is the separation and capture of carbon dioxide (CO₂) from the emissions of industrial processes prior to release into the atmosphere and the storage of the captured CO₂ in deep underground geologic formations.

Major CCS Methods
-Saline formations
- Oil and natural gas reservoirs
- Unmineable coal seams
- Organic-rich shales
- Basalt formations
• **Oil/natural gas extraction** leaves a permeable and porous volume for CO₂ storage.

• These “reservoirs” are ideal **geologic storage sites** as they have conditions suitable for CO₂ storage.

• Injecting CO₂ can **push fluids towards producing wells** --- Enhanced Oil Recovery (EOR), Enhanced Coal Bed Methane (ECBM) recovery

https://www.netl.doe.gov/coal.carbon-storage/faqs/carbon-storage-faqs