Real-time in-situ CO₂ Monitoring (RICO₂M) Network for Sensitive Subsurface Areas in CCS

Project Number DE-FE0012706

Jesús Delgado Alonso, Ph.D.
Intelligent Optical Systems, Inc.

U.S. Department of Energy
National Energy Technology Laboratory
Carbon Storage and Oil and Natural Gas Technologies Review Meeting
Mastering the Subsurface through Technology Innovation Partnerships, and Collaboration
August 13-16, 2018
Outline

• Project Overview
• Technical Status
  – Technology
  – Four years of sensor development, from demonstration in the laboratory, to validation in the field, and demonstration at a CCS site
• Project Summary
  – Accomplishments to date
  – Future work
• Appendix
• Acknowledgments
**Phase I Objective:** Develop a multi-parameter system for highly sensitive and accurate detection of CO$_2$ in groundwater

Sensor development and demonstration in the laboratory.

**Phase II Objectives:**
- Perform system deployment and demonstration in the field
- Technology commercial demonstration at a CCS site

Validation in the field, and commercial demonstration.
Distributed Intrinsic Fiber Optic Chemical Sensors

Unique Characteristics

- The entire length of the fiber is a sensor
- Direct detection of dissolved CO$_2$
- A single cable may include CO$_2$, pH, salinity, and temperature sensors.
Technology

- An optical fiber coated with a polymer cladding containing a colorimetric indicator, which absorbs light at a particular wavelength.
- A light source is placed at one end of the fiber and a photodetector at the other end, and light transmission is measured.
Technology

- The coating color varies with the analyte (pH, CO₂…)
- The light transmitted through the fiber at wavelengths absorbed by the indicator varies with the concentration of analyte (pH, CO₂…).
The coating color varies with the analyte (pH, CO\textsubscript{2}…).

The light transmitted through the fiber at wavelengths absorbed by the indicator varies with the concentration of analyte (pH, CO\textsubscript{2}…).
Four Years of Sensor Development

Sensor Materials
- CO₂ sensor materials
- pH sensor materials

Fiber Optic Sensor
- CO₂ and pH fiber sensors in the lab

Instrumentation
- First readout unit

Fiber Optic Sensor
- CO₂ fiber sensors in the field
- CO₂ second generation fiber sensors

Instrumentation
- Second readout unit

Validation in the Field
- CO₂ leak detection
- System performance review

Demonstration at a CCS Site (QUEST)
Four Years of Sensor Development
Demonstration in the lab

Sensor Materials: Cladding material coated onto glass slides

- Indicator dye synthesis
- Polymer formulation
- Testing
- Covalent immobilization by cross linking with vinyl groups in the polymer.
Four Years of Sensor Development
Demonstration in the lab

Fiber Optic Sensor: Glass-core fiber coated with sensitive materials

Cladding material coated onto glass slides

Prototypes of optical fibers fabricated at IOS
Four Years of Sensor Development
Demonstration in the lab

Fiber Optic Sensor: Glass-core fiber coated with sensitive materials

- Glass-core selection
- Core pre-treatment and activation
- Coating process optimization – time, temperature, speed, thickness…
- Cladding material reformulation
- Testing

![Image of uncoated and coated fiber](image1)

![Diagram of fiber optic sensor](image2)
Four Years of Sensor Development
Demonstration in the lab

Fiber Optic Sensor for pH: Analytical characterization

Basic Sensor Characteristics
Measurement range: 5 to 8.5 pH
Resolution (precision): 0.04 at 7 pH
Temperature range: 5°C to 30°C
Temperature compensation: 1.4% / °C
Basic Sensor Characteristics
Measurement range: 0 to 1,500 mg/L
Resolution (precision): ±5% (0 to 100 mg/L); ±10% (100 to 1,500 mg/L)
Temperature range: 5°C to 35°C
Pressure range: 15 to 2,000 psi
Salinity Range: 0 to 35% NaCl
pH range: 2 to 14 pH

Fiber Optic Sensor for CO₂: Analytical characterization

- Testing
- Cladding material reformulation
- Fiber fabrication protocol review
Dual Photodetector System

- 550-850 nm LED
- Photodetector 1: cutoff filter 650 nm
- Photodetector 2: bandpass filter 590 nm

Instrument Development
- High level design
- Detailed hardware and software design

Four Years of Sensor Development
Demonstration in the lab

Instrument Development

Dual Photodetector System

- 550-850 nm LED
- Photodetector 1: cutoff filter 650 nm
- Photodetector 2: bandpass filter 590 nm

Distribution fiber

Sensor segment
Four Years of Sensor Development
Demonstration in the lab

Instrument Development
- PCB design, fabrication, and assembly
- Optical module design and fabrication
Four Years of Sensor Development
Demonstration in the lab

Demonstrator

First Generation

Second Generation
Series fabrication

- System integration
- Testing
- Design review
Four Years of Sensor Development

- CO₂ sensor materials
- pH sensor materials
- Instrumentation
- Fiber Optic Sensor
- Validation in the Field
- Demonstration at a CCS Site (QUEST)

First readout unit

Second readout unit

CO₂ and pH fiber sensors in the lab

CO₂ fiber sensors in the field

CO₂ second generation fiber sensors

CO₂ leak detection

System performance review
Four Years of Sensor Development
Validation in the field

Sensor Probe Fabrication: Protection for fiber sensor

- Mechanical design and assembly
- Calibration, storage, shipping, installation
- Is it practical? Fiber sensor design review.
Four Years of Sensor Development
Validation in the field

Sensor Probe Fabrication: Fiber sensor design review

- Simplifies probe fabrication = lower cost
- Facilitates calibration, storage, and shipment
- Similar performance
Four Years of Sensor Development
Validation in the field

System Assembly for Field Operation

First Generation
RICO2M v2.0 PN003

Second Generation
RICO2M v3.0 PN005

Chassis integrates temperature control module.
Four Years of Sensor Development
Validation in the field

Data Storage and Remote Communication
Four Years of Sensor Development
Validation in the field

System Deployment and Data Collection
Four Years of Sensor Development
Validation in the field

Sensor 1 at BFL2

Sensor 1 at BFL2
Four Years of Sensor Development
Validation in the field

Sensor 1 at BFL2

Sensor 2 at BFL2
Four Years of Sensor Development
Validation in the field

Sensor 1 at BFL2

**Background Average**
\[ \text{CO}_2 = 100 \text{ mg/L} \]

- **Gas Release (10% CO\(_2\))**
  \[ \text{MaxCO}_2 = 120 \text{ mg/L} \]

- **Gas Release (50% CO\(_2\))**
  \[ \text{MaxCO}_2 = 475 \text{ mg/L} \]

- **Gas Release (60% CO\(_2\))**
  \[ \text{MaxCO}_2 = 590 \text{ mg/L} \]

- **Gas Release (100% CO\(_2\))**
  \[ \text{MaxCO}_2 = 1,100 \text{ mg/L} \]
Four Years of Sensor Development
Validation in the field

- Excellent performance detecting small and large gas leaks reaching the aquifer
- Limited accuracy in monitoring CO₂ concentration over time.
Four Years of Sensor Development

- CO$_2$ sensor materials
- pH sensor materials
- CO$_2$ and pH fiber sensors in the lab

Sensor Materials

Fiber Optic Sensor

Instrumentation

First readout unit

CO$_2$ fiber sensors in the field

CO$_2$ second generation fiber sensors

Fiber Optic Sensor

Instrumentation

Second readout unit

Validation in the Field

- CO$_2$ leak detection

Demonstration at a CCS Site (QUEST)

System performance review
The RICO2M system must be capable of detecting CO₂ leaks in groundwater with high reliability, with emphasis on no false negatives, and minimal false positives.

The final objective will be to have a system capable of detecting any leak of gas reaching the aquifer and reporting such an event in real time, which would be followed by water analysis by means of established methods to confirm and quantify the effect on the water chemistry.
Four Years of Sensor Development Demonstration at QUEST
Four Years of Sensor Development
Demonstration at QUEST

Adapt instrumentation for installation at QUEST facilities
Four Years of Sensor Development
Demonstration at QUEST

Fabricate series of distribution cables and probes
Four Years of Sensor Development
Demonstration at QUEST

Generate documentation and obtain approval

- Subcontract agreements
- User manual
- Installation plan and protocol: onsite quality control
- Maintenance plan and protocol
Four Years of Sensor Development

- **Sensor Materials**
  - **CO₂ sensor materials**
  - **pH sensor materials**

- **Fiber Optic Sensor**
  - **CO₂ and pH fiber sensors in the lab**
  - **First readout unit**

- **Instrumentation**
  - **Validation in the Field**
    - **CO₂ leak detection**
    - **System performance review**

- **Fiber Optic Sensor**
  - **CO₂ fiber sensors in the field**
  - **Second readout unit**

- **Instrumentation**
  - **Second readout unit**

- **Series fabricated**
  - **First deployment - August-27-18**

- **Demonstration at a CCS site (QUEST)**
  - **Technology accepted by operator**
Project Summary – Accomplishments to Date

- Developed the RICO2M system, and validated its performance in controlled field studies.
- Established the capability of the RICO2M system to detect large and small leaks of CO₂ before they reach groundwater resources.
- Evolved demonstrators to prototypes, and prototypes to a first series of instrumentation for commercial demonstration.
- Generated the required documentation to perform system demonstration at a QUEST.
Next steps – demonstrate the technology developed under the RICO2M project for groundwater monitoring at a CCS site, and compare performance to off-the-shelf instrumentation and current protocols.
Acknowledgments

NETL Department of Energy

Joshua Hull
Synergy Opportunities

The project will develop a sensor network based on distributed fiber optic sensors for geochemical parameter monitoring in the subsurface. The system will be capable of covering large areas and measuring very low concentrations of CO$_2$ with high resolution, detecting small changes from background concentrations in sensitive areas. This technology contributes to the Carbon Storage Program’s effort of ensuring 99 percent CO$_2$ storage permanence (Goal).
Appendix

• Benefit to the Program
• Project Overview
• Organization Chart
• Project Schedule
• Acknowledgments
Benefit to the Program

• Carbon Storage Program goal being addressed:
  – Develop and validate technologies to ensure 99% storage permanence.

• Benefits Statement:
  – The project will develop a sensor network based on distributed fiber optic sensors for in-situ, real-time monitoring of geochemical parameters in groundwater. The system will be capable of covering large areas and measuring very low concentrations of CO₂ with high resolution, detecting small changes from background concentrations in sensitive areas. This technology contributes to the Carbon Storage Program’s effort of ensuring 99% CO₂ storage permanence (Goal).
Benefit to the Program

- Monitoring dissolved carbon dioxide is the most direct way to detect and quantify a leak reaching underground sources of drinking water.
- Current methods for detecting CO₂ leakage in groundwater are adapted from traditional groundwater quality studies – water samples are collected periodically and analyzed in the laboratory.
  - This is not cost-effective for long-term monitoring of large areas
  - De-gassing during the sampling process can degrade accuracy
  - Very poor spatial coverage
  - Intermittent monitoring can miss changes in the geochemical parameters of groundwater

Monitoring groundwater in-situ and in real time.
Project Overview – Goals and Objectives

• **Phase I Objective:** Develop a multi-parameter system for highly sensitive and accurate detection of CO$_2$ in groundwater

  Sensor development and demonstration in the laboratory.

• **Phase II Objectives:**
  – Perform system deployment and demonstration in the field
  – Technology commercial demonstration at a CCS site

  Validation in the field, and commercial demonstration.
Organization Chart

University of Texas, Austin
Dr. Changing Yang*
Technical Support

Intelligent Optical Systems
Dr. Jesus Delgado Alonso
Principal Investigator

Narciso Guzman
Marvin Lav
Technical Support

Redondo Optics
Dr. Edgar Mendoza

UCLA/NxEco
Dr. Li Liang
Technical Support

Golder Associates
Neil Barnsdall
Technical Support

CCS Site Operator
Project Schedule

Gantt Chart related to technology demonstration at a CCS site