Real-time in-situ CO_2 Monitoring ($RICO_2M$) Network for Sensitive Subsurface Areas in CCS

Project Number DE-FE0012706

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Intelligent Optical Systems, Inc.

U.S. Department of Energy

National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and
Infrastructure for CCS

August 12-14, 2014

Real-time in-situ CO_2 Monitoring ($RICO_2M$) Network for Sensitive Subsurface Areas in CCS

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INTELLIGENT OPTICAL SYSTEMS, INC.

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Outline

- Benefit to the Program
- Project Overview
- Technical Status
  - Technology
  - Progress
- Project Summary
  - Accomplishments
  - Future work
- Appendix

Benefit to the Program

- Carbon Storage Program goal being addressed:
  - Develop and validate technologies to ensure 99 percent storage permanence.

- Benefits Statement:
  - The project will develop a **sensor network based on distributed fiber optic sensors for in-situ and real-time monitoring of geochemical parameter in groundwater.** 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 sensitive areas. This technology contributes to the Carbon Storage Program's effort of ensuring 99 percent CO_2 storage permanence (Goal).

Project Overview: Goals and Objectives

- **Phase I Objective: Develop a multi-parameter system** for highly sensitive and accurate detection of CO_2 in groundwater.

- **Phase II Objective:** Perform large scale **deployment and demonstration in the field** of intelligent real-time in-situ network (RICO_2M Net).

Project Overview:
Goals and Objectives

Research Plan

- **PHASE I:** **Develop a multi-parameter system** for highly sensitive and accurate detection of CO_2 in groundwater.
  - Generate system requirements
  - Select existing sensors (developed by IOS) for dissolved CO_2
  - Develop fiber optic sensors for pH
  - Develop fiber optic sensor for salinity
  - Build and validate a monitoring system incorporating sensors for CO_2, pH, salinity, and temperature.

Project Overview: Goals and Objectives

Research Plan

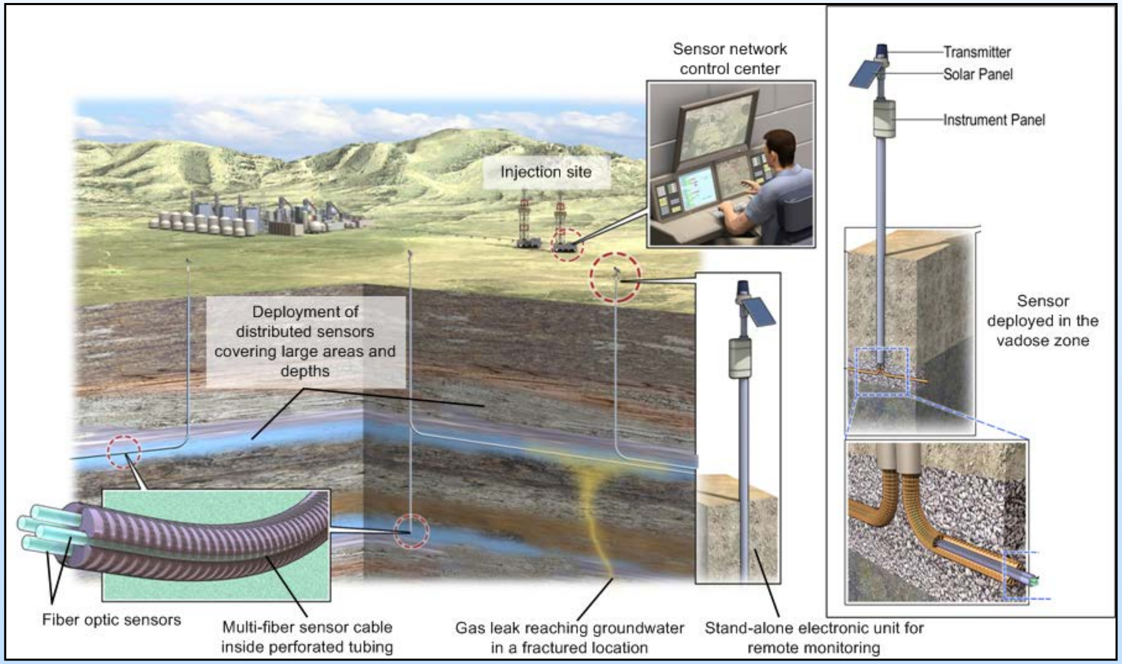
- **PHASE II:** Perform large scale **deployment and demonstration in the field** of intelligent real-time in-situ network (RICO_2M Net).
  - Fabricate the monitoring sensor network
  - Deploy and continuously monitor geological parameters in groundwater (10-15 units for one year)
  - Validate results with established monitoring techniques
  - Controlled-release of CO_2 (measuring low concentrations of CO_2 with high accuracy)

Technical Status
Technology

Distributed Intrinsic Chemical Fiber Optic Sensors

Unique Characteristics

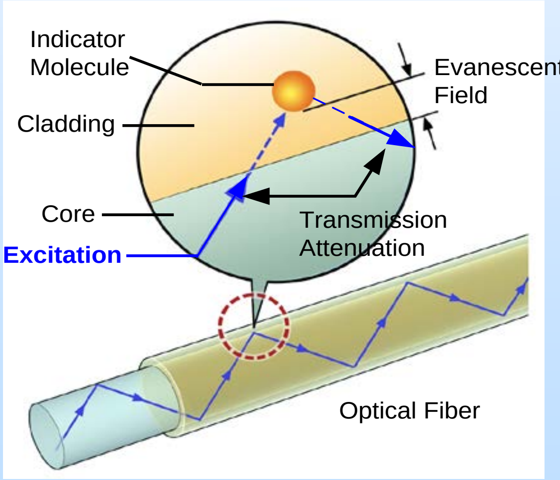
- The entire length of the fiber is a sensor
- Direct detection of dissolved CO_2
- A single cable may include CO_2, pH, salinity and temperature sensors.



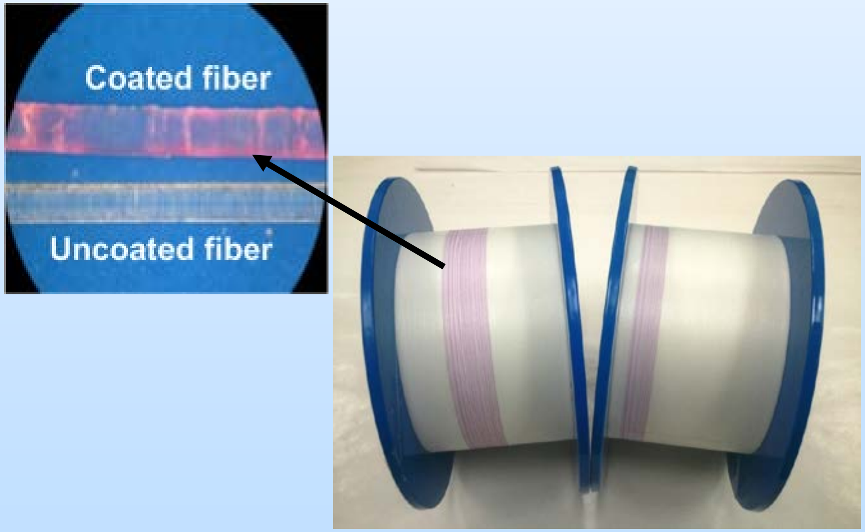
Technical Status

Technology

- A silica glass core is coated with a polymer cladding containing a colorimetric indicator
- Upon exposure of any segment of the fiber, the CO_2 (H_3O^+) diffuses into the cladding and changes its color
- A change in fiber attenuation at wavelengths relating to the color change is detected.



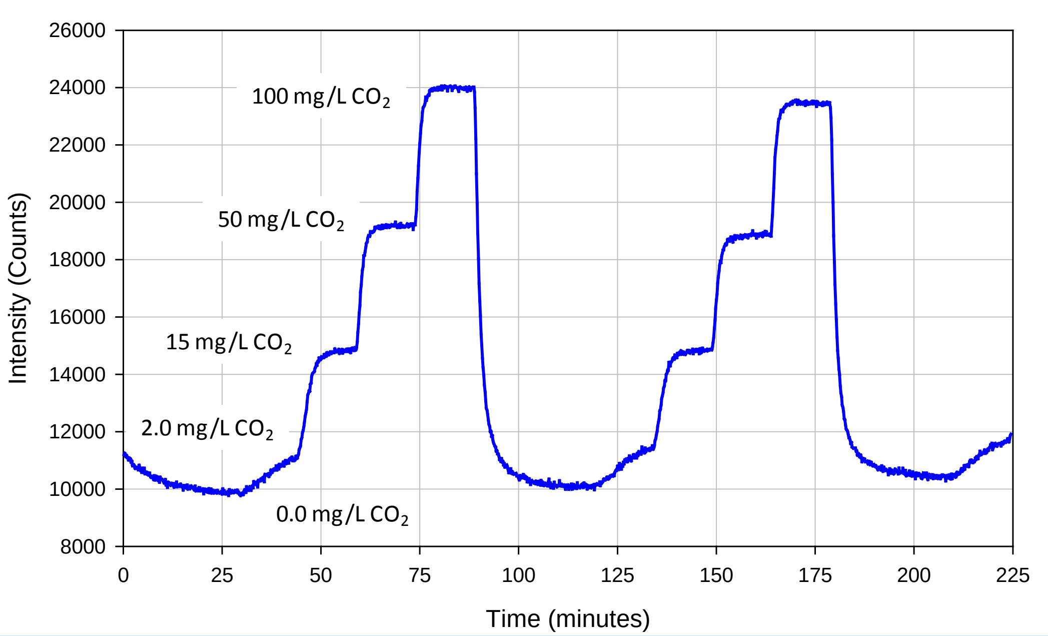
Fiber structure of colorimetric distributed fiber optic sensors



Fiber optic sensor for CO_2 rolled on a spool. Microscopic detail shows fibers uncoated and coated with the sensitive polymer.

Technical Status
Technology

- The change in the fiber attenuation is **proportional** to the CO_2 concentration, and is **reversible**.

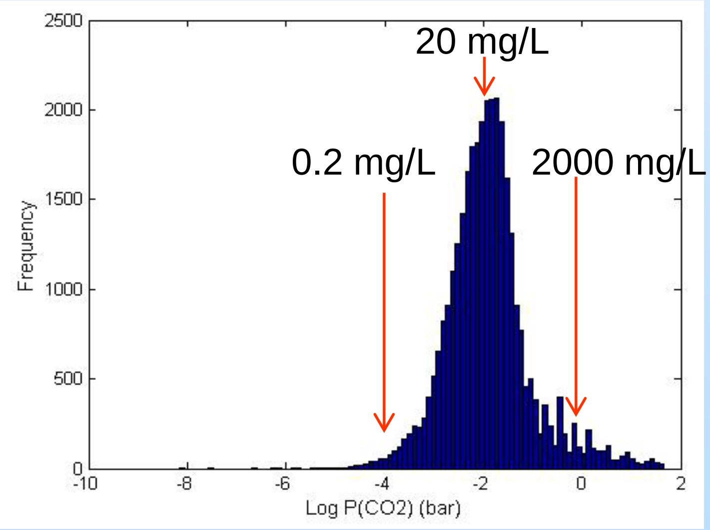


Technical Status

Progress: System Requirements

Basic Analytical Requirements for CO_2

Req. ID	Requirement	RICO$_2$M version 1.0	Product
FR1.1	**Measurement range (10 m exposed)**	**0 mg/L to 1,750 mg/L**	0 mg/L to 1,750 mg/L
FR1.2	**Resolution (10 m exposed)**	**1 mg/L or 1% of reading**	1 mg/L or 1% of reading
FR1.3	Accuracy	Better than 10%	Better than 7%
FR1.4	Response Time (t_{90})*	5 minutes for 10 mg/L variation	5 minutes for 10 mg/L variation



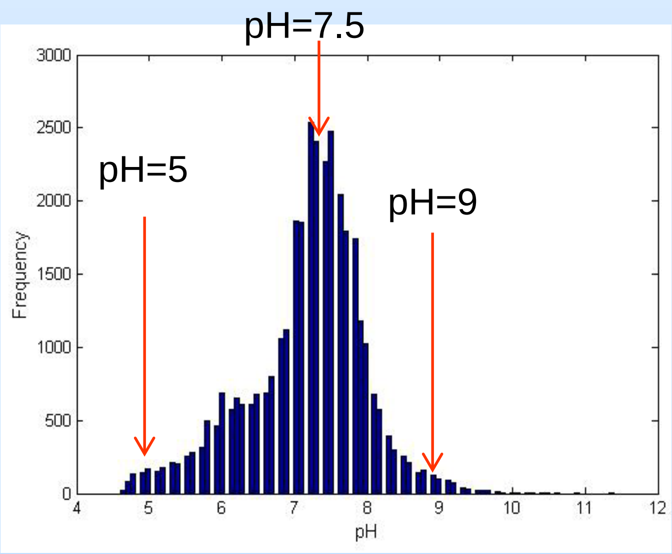
Distribution of calculated pCO_2 of more than 35,000 groundwater analyses selected from the NWIS Database.

Technical Status

Progress: System Requirements

Basic Analytical Requirements for pH

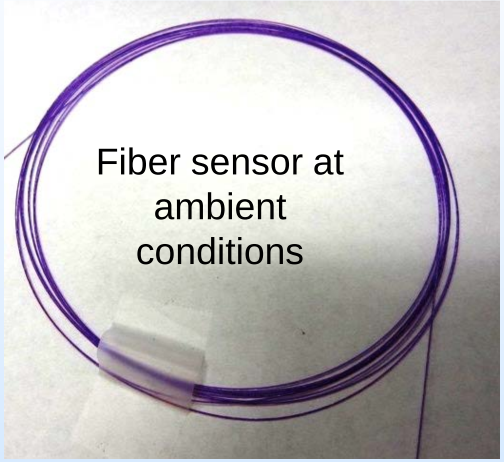
Req. ID	Requirement	RICO$_2$M version 1.0	Product
FR2.1	**Measurement range (10 m exposed)**	**5 to 9 pH**	4 to 10 pH
FR2.2	**Resolution (10 m exposed)**	**0.2 pH**	0.1 pH
FR2.3	Accuracy	Better than 10%	Better than 7%
FR2.4	Response Time (t_{90})*	5 minutes for 1 unit pH variation	5 minutes for 1 unit pH variation

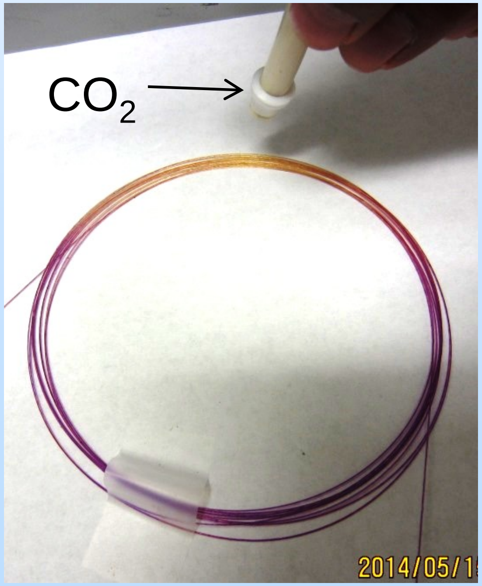


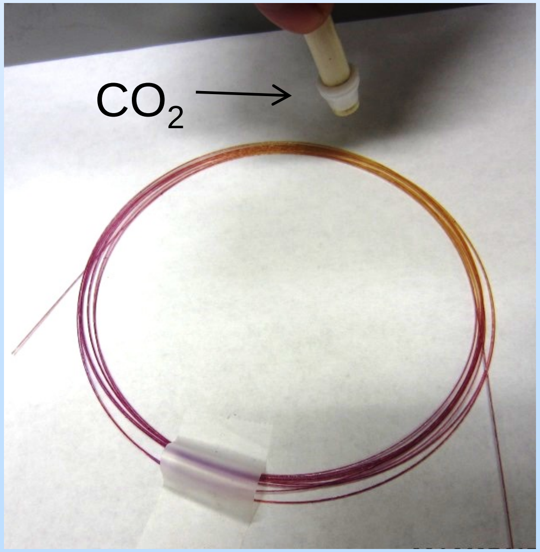
pH distribution of more than 35,000 groundwater analyses selected from the NWIS Database.

Technical Status

Progress: Existing CO_2 Sensor



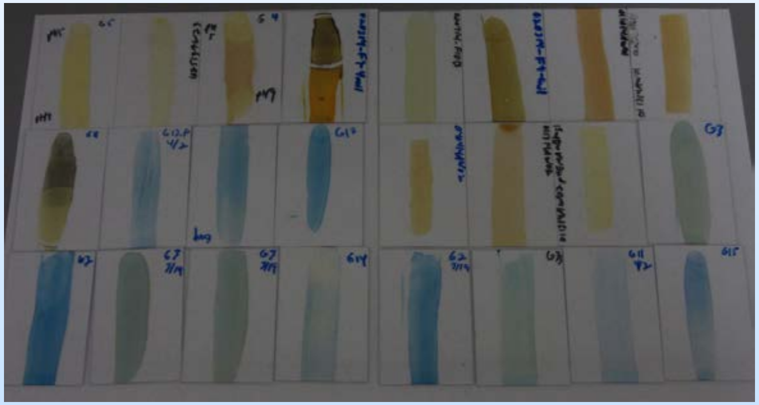




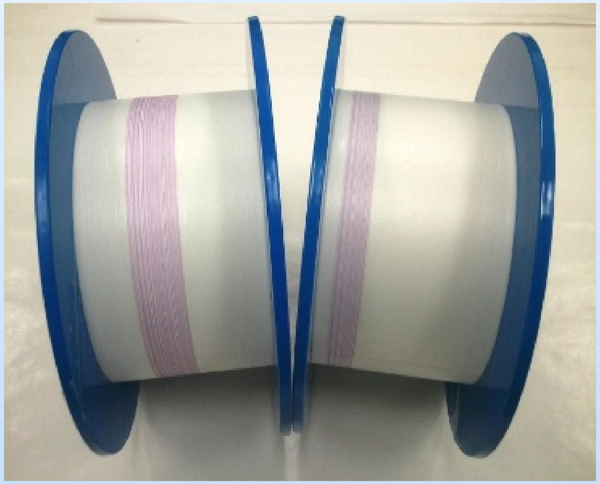
Technical Status

Progress: Develop Distributed pH Sensors

Cladding materials coated on glass slides

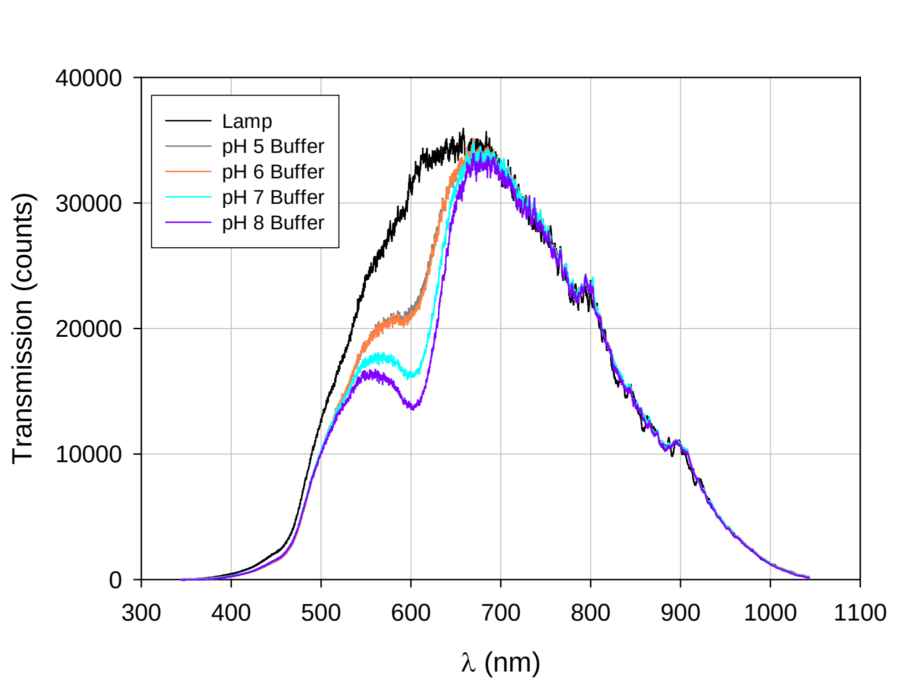


Prototypes of optical fibers fabricated at IOS



Technical Status

Progress: Develop Distributed pH Sensors



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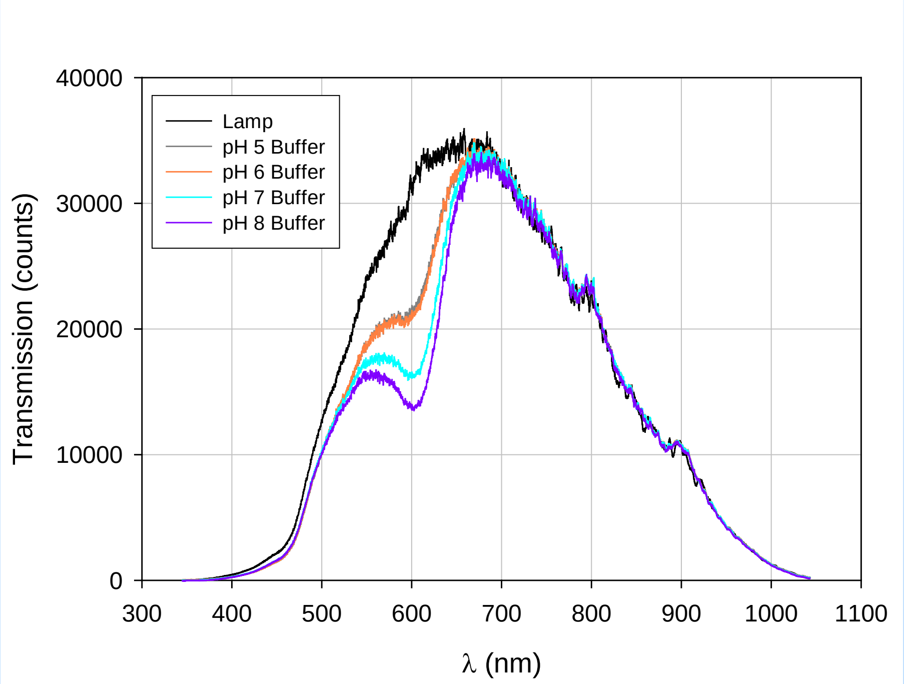

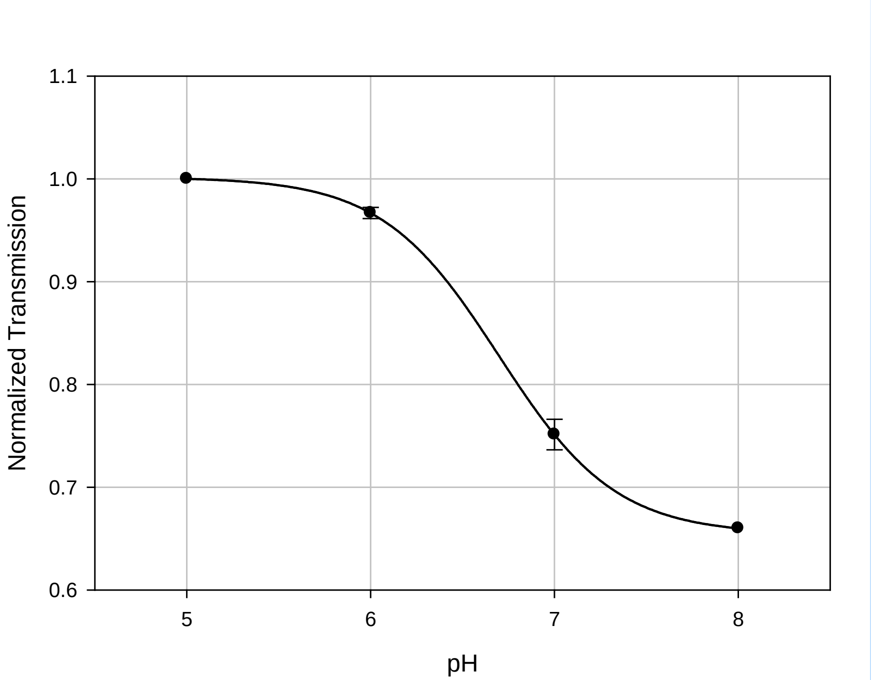

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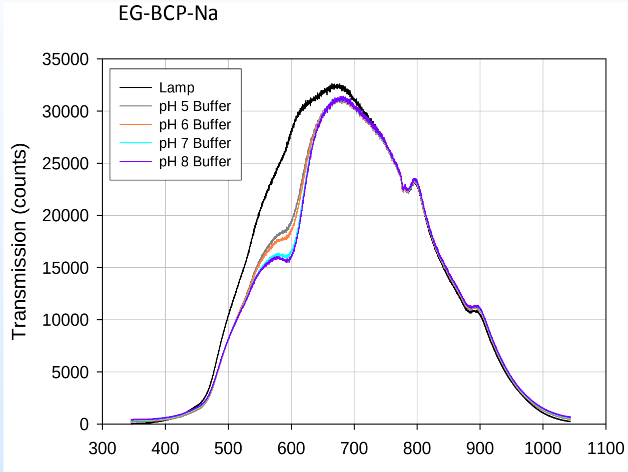
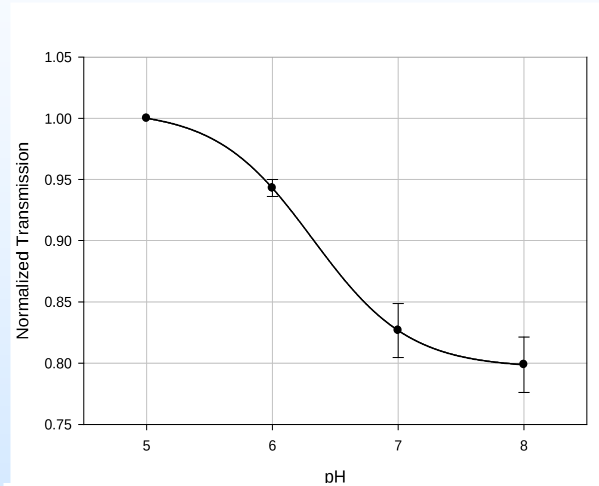
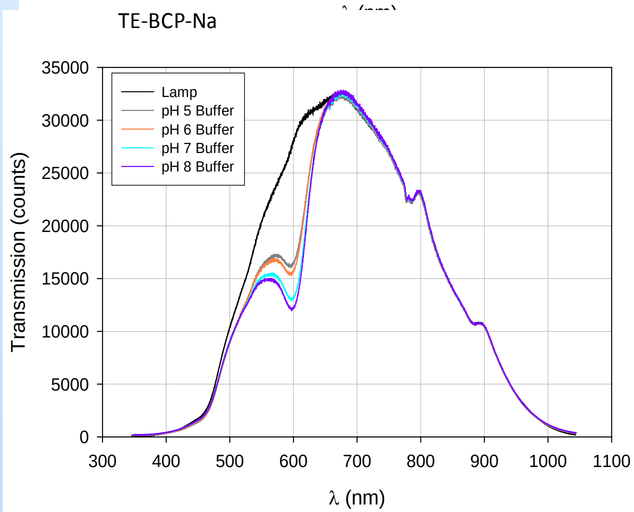
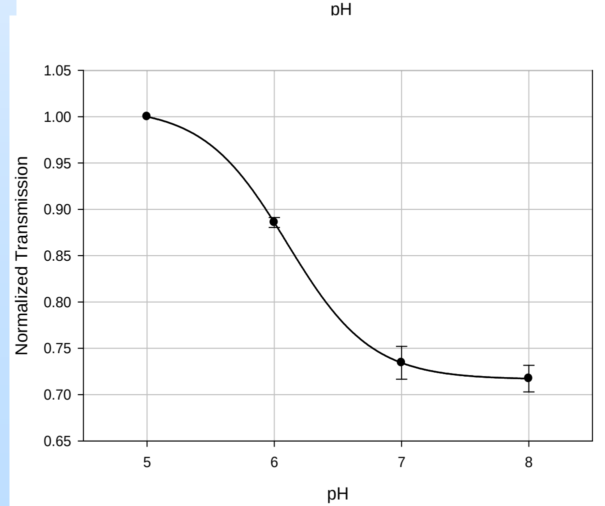


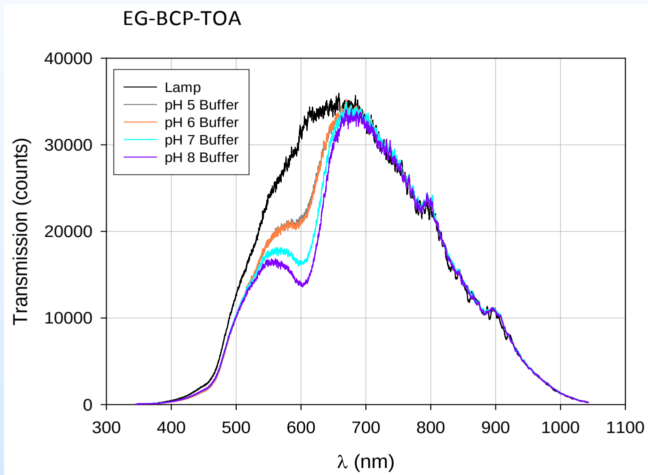


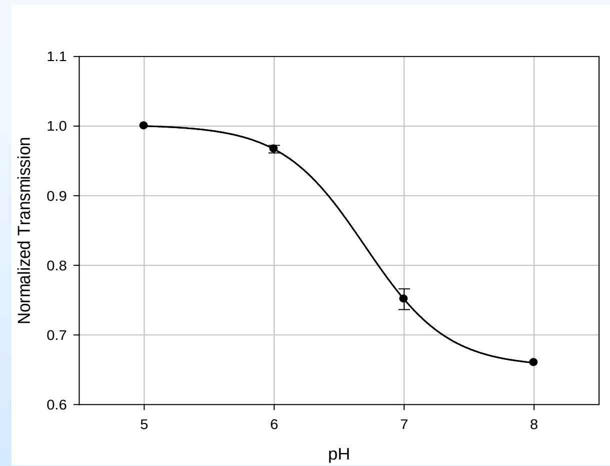


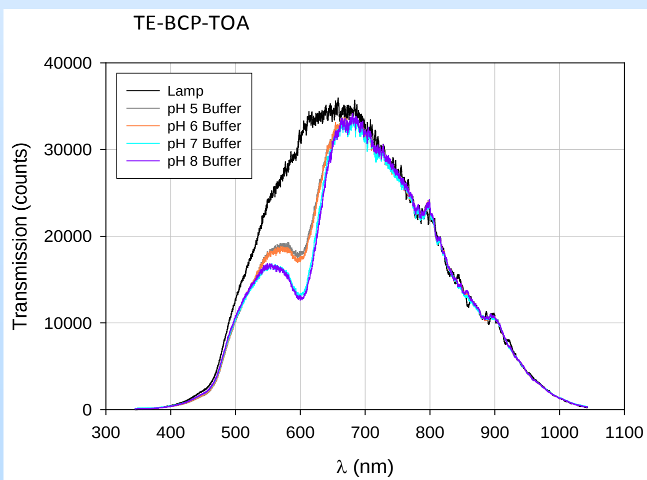


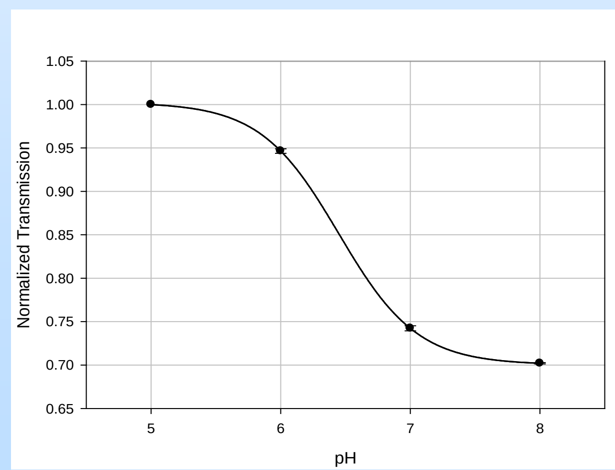
Technical Status

Progress: Develop Distributed pH Sensors



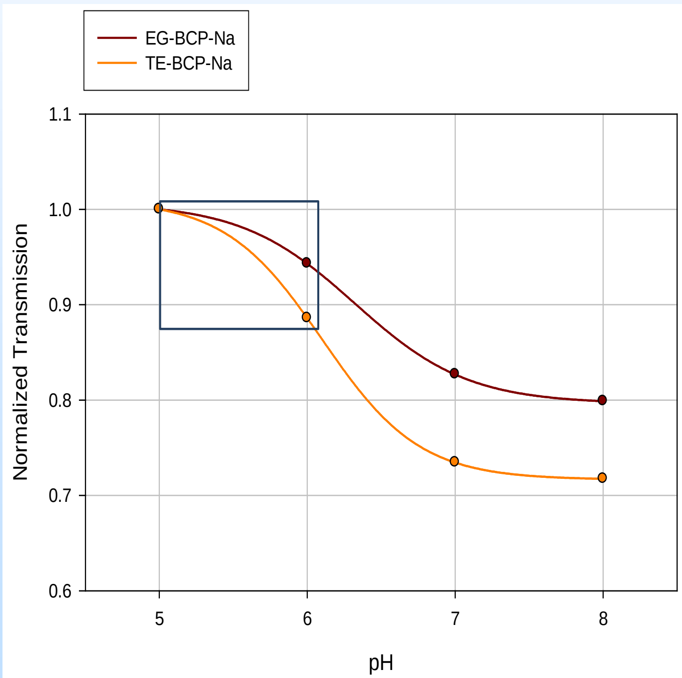


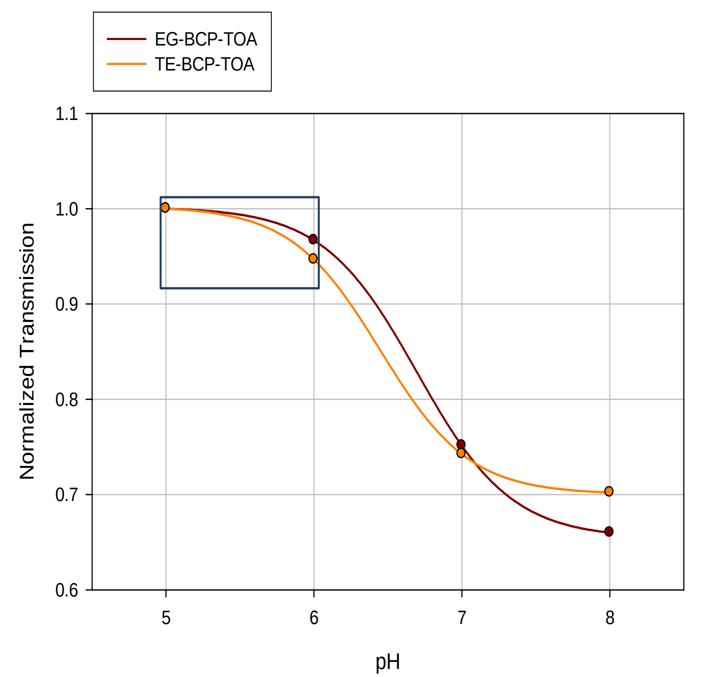




Technical Status

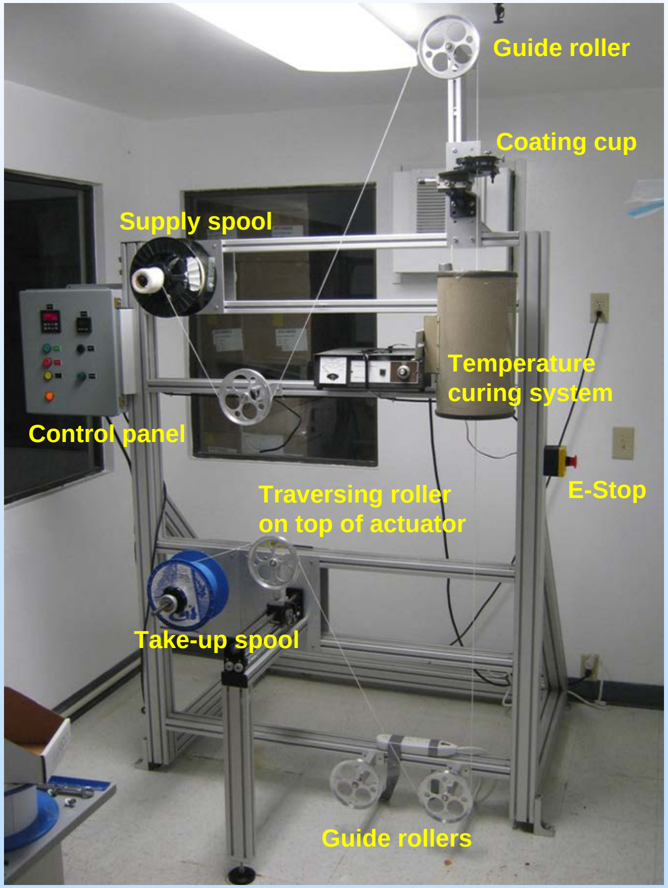
Progress: Develop Distributed pH Sensors

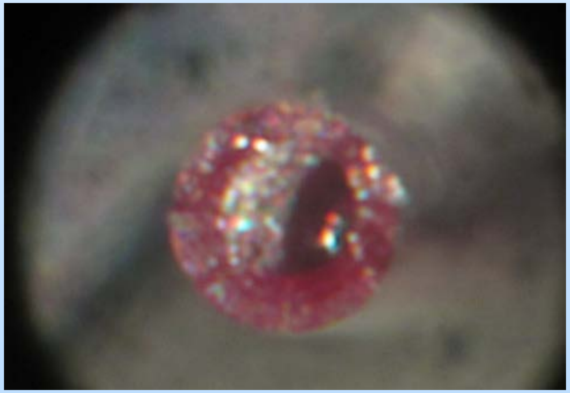




Technical Status

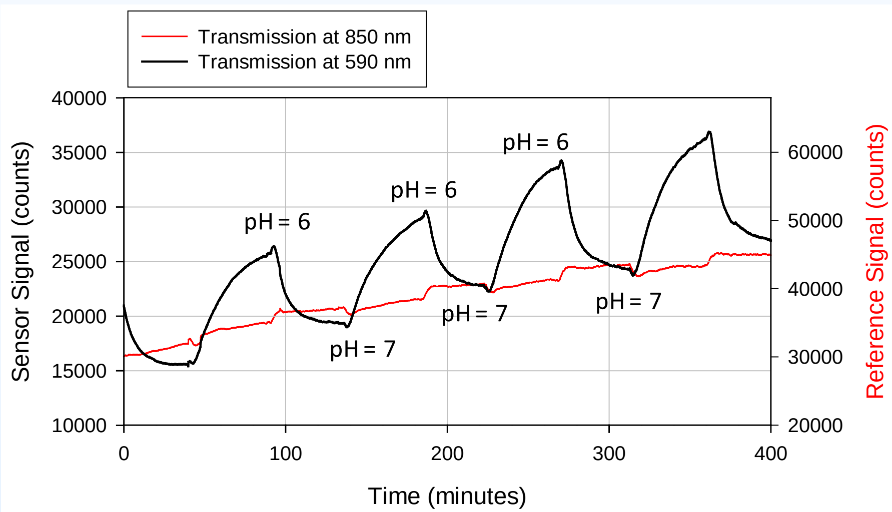
Progress: Develop Distributed pH Sensors

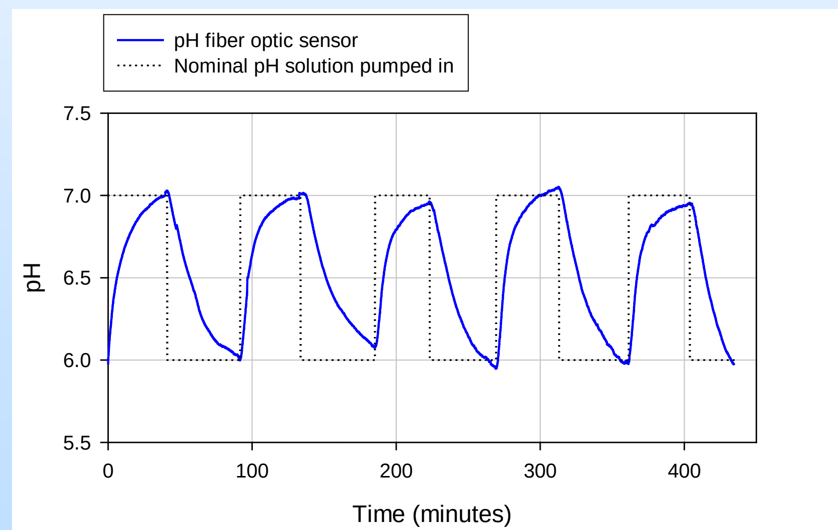




Technical Status

Progress: Develop Distributed pH Sensors

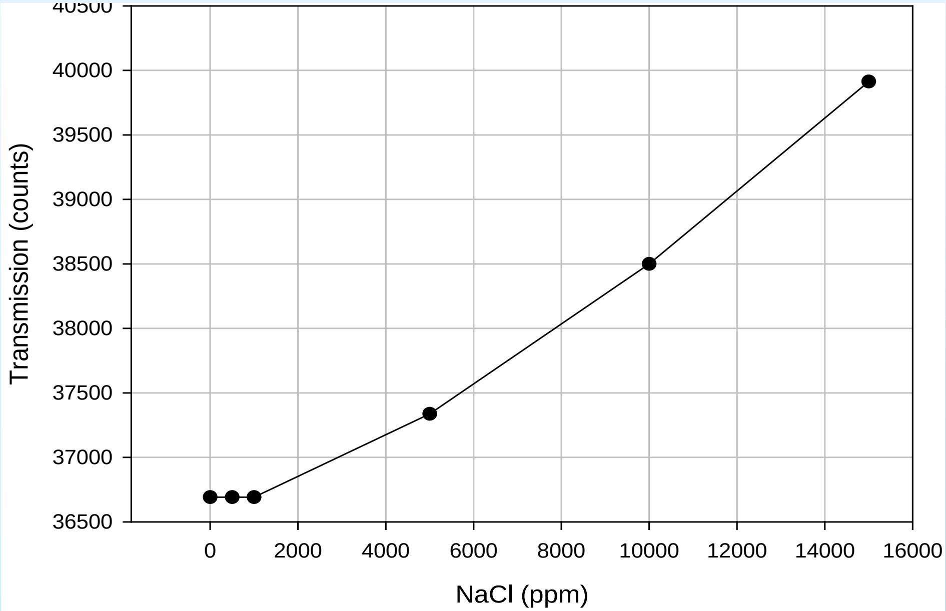




Basic Sensor Characteristics
Measurement range: 5 to 8.5 pH
Resolution (precision): 0.04 (@ 7 pH)
Temperature range: 5° to 30°C
Temperature compensation: 1.4%/°C

Technical Status

Progress: Develop Distributed Salinity Sensors



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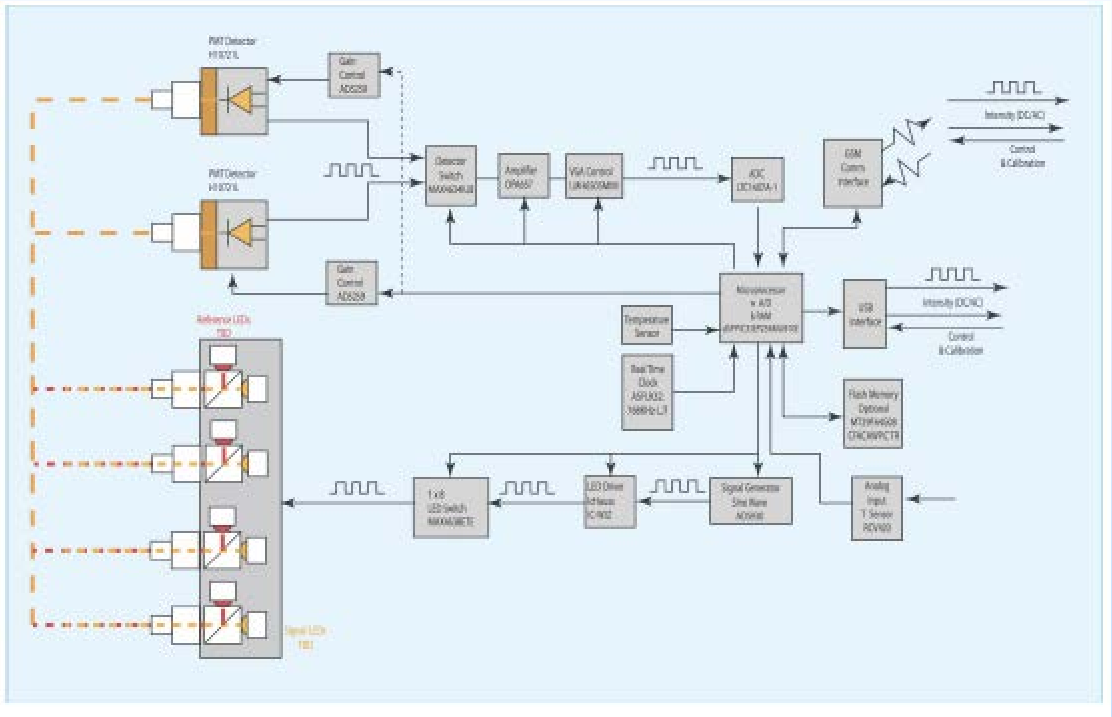
Technical Status

Progress: Design Multiparameter Monitor



Summary
Accomplishments to Date

- Novel distributed fiber optic sensor for pH developed.
- Distributed pH sensors characterized, and sensor requirements met.
- First distributed fiber optic sensor for salinity developed.
- High level design of the multi-parameter monitoring system established, including sensor cables and electronic unit (estimated fabrication cost ≤$5,000).

Summary
Future Work

- Assemble multi-parameter monitoring system, including sensor cables and electronic unit
- Install first-generation system in the field (review design)
- Monitor performance of system in the field for at least one year (determine maintenance requirements)
- Demonstrate detection of CO_2 leaks by controlled release tests (determine sensitivity)
- Perform comparison with established analytical techniques (determine accuracy)
- Advance and validate reactive transport modeling for CO_2 by comparison with continuous monitoring.

System READY for serving in sequestration projects.

Acknowledgments

- **Intelligent Optical Systems, Inc.: Sensor development**
  Jesús Delgado Alonso and Robert A. Lieberman
- **Bureau of Economic Geology at UTA: Sensor field validation and modeling**
  Changbing Yang
- **GeoMechanics Technologies: Downhole sensor deployment**
  Michael S. Bruno
- **Benson Laboratory at Stanford University: Sensor laboratory testing**
  Prof. Sally Benson and Ferdinand F. Hingerl
- **Montana State University (ZERT): Sensor field validation**
  Kevin Repasky

NETL Department of Energy

Barbara Carney, Robie Lewis, Robert Noll, **Joshua Hull**

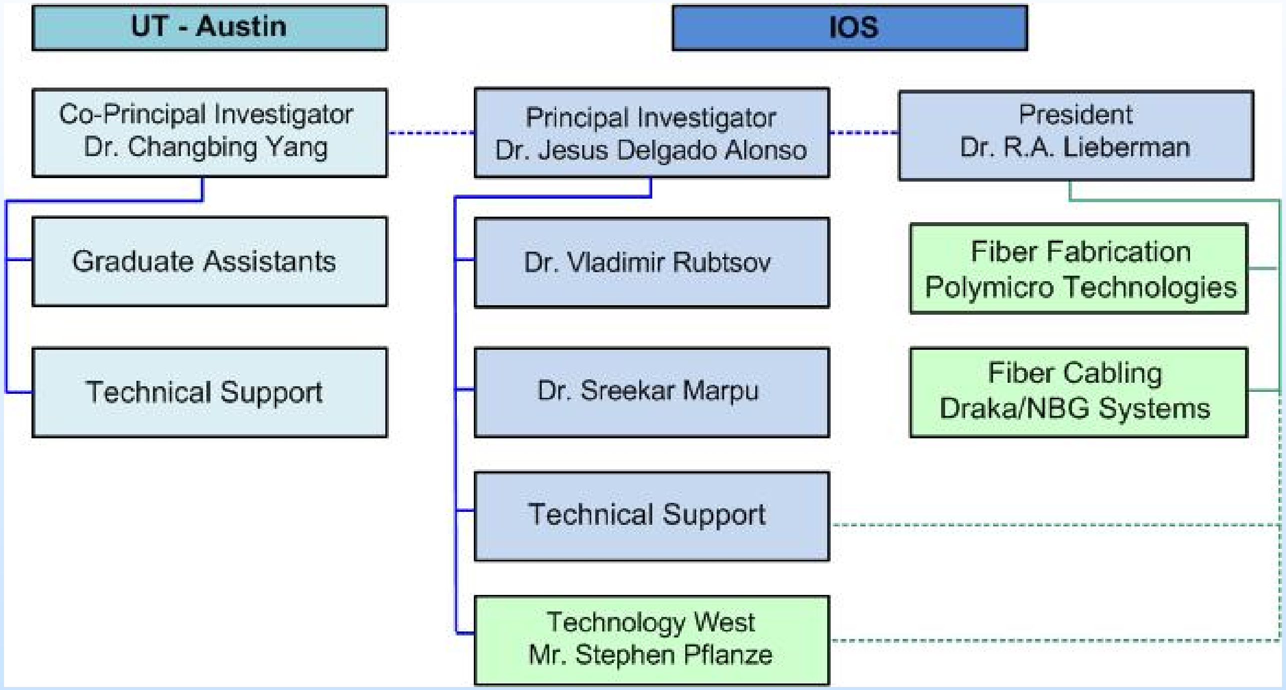
Synergy Discussion

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

- Organization Chart
- Project Schedule
- Bibliography

Organization Chart

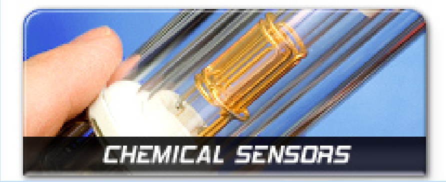


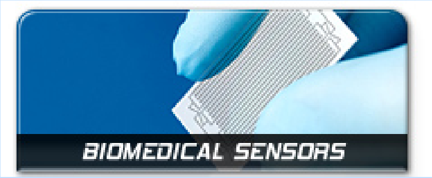
As the prime contractor for this project, IOS will carry out all activities related to the design, fabrication, and testing of the distributed CO_2 sensor network, and will provide field support to the University of Texas at Austin (UT-Austin) throughout the system Phase II field trials.

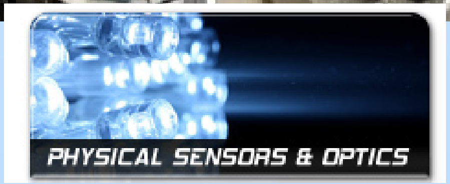
UT-Austin will manage all aspects of CO_2 sensor system field testing, and will provide valuable technical guidance in Phase I, assuring that the system design meets the rigorous demands of the subsurface environment found at the CCUS test site.

Organization Chart:
Intelligent Optical Systems, Inc.

- Founded in 1998
- Business focus:
  - **Chemical sensors**
  - Biochemical sensors
  - Advanced light sources & detectors
- 25 employees; 9 PhDs
- 11,500 sq. ft. -- labs, clean rooms, offices
- $8M in laboratory equipment



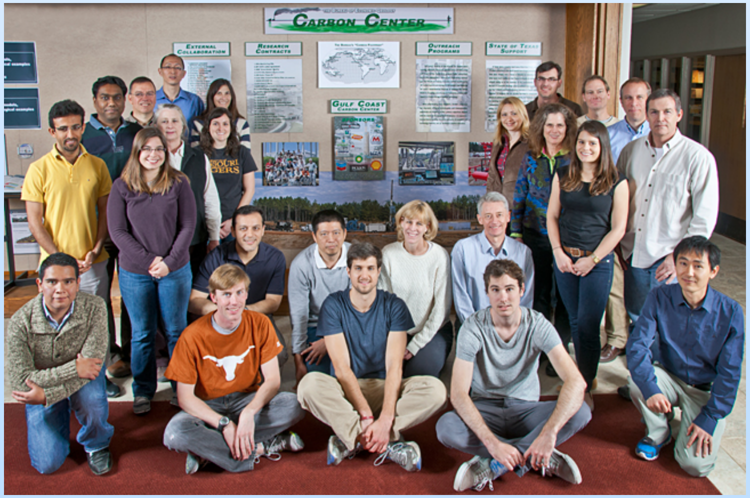




Organization Chart:
The University of Texas at Austin

Bureau of Economic Geology (BEG)

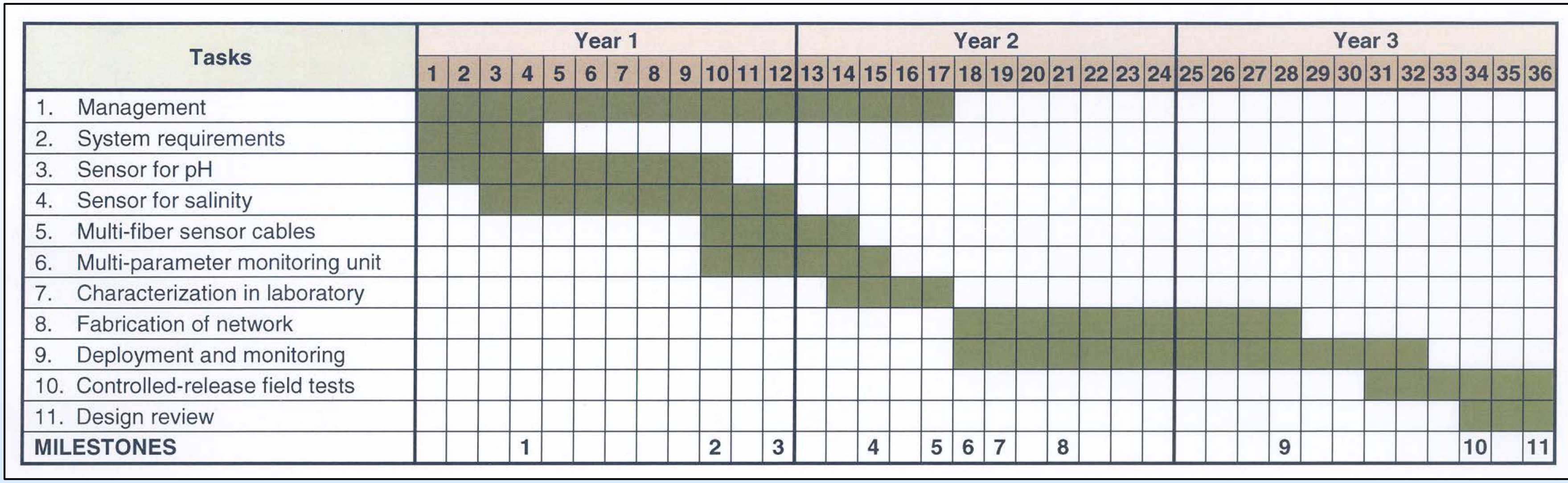
- Established in 1909, BEG is the oldest research unit at The University of Texas at Austin
- Provide research and advice related to energy and environmental issues, and perform State Geological Survey functions as requested by the State Legislature.



Gulf Coast Carbon Center (GCCC)

- Seeks to impact global levels of atmospheric carbon dioxide by:
  - **Conducting** studies on geological sequestration of CO_2 in the deep subsurface
  - **Educating** the public about risks that might limit deployment of geological sequestration and measuring the retention of CO_2 in the subsurface
  - **Enabling** the private sector to develop an economically viable industry to sequester CO_2 in the Gulf Coast area.

Project Schedule



PHASE I: Develop a multi-parameter system

Milestone 1. System Functional Requirement Document (FRD) generated.

Milestone 2. Fiber optic distributed sensor for pH fabricated and characterized in the laboratory.

Milestone 3. Fiber optic distributed sensor for salinity fabricated and characterized in the laboratory.

Milestone 4. Monitoring system assembled and system operation verified in accord with FRD.

Milestone 5. Multi-parameter monitoring system characteristics established.

PHASE II: Perform large scale field validation

Milestone 6. Groundwater chemistry survey, using the traditional method, conducted.

Milestone 7. First series of multi-parameter monitoring system fabricated.

Milestone 8. First Intelligent Real-time in-situ CO_2 Monitoring Network ("RICO_2M Net") deployed.

Milestone 9. Revised multi-parameter monitoring systems fabricated and deployed.

Milestone 10. RICO_2M Net detects presence (or absence) of CO_2 in sensitive subsurface locations.

Milestone 11. System design reviewed.