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

Project Number DE-FE0012706

Sensor Development

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Sensor Field Validation and Modeling

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U.S. Department of Energy

National Energy Technology Laboratory

2015 Carbon Storage R&D Project Review Meeting

August 18–20, 2015

Outline

- Benefit to the Program
- Technology
- Project Overview
- Technical Status
- Project Summary
  - Accomplishments
  - Planned work
- 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 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% CO_2 storage permanence (Goal).

Benefit to the Program

INTELLIGENT OPTICAL SYSTEMS, INC.

Monitoring groundwater in-situ and in real time to detect and measure very low concentrations of CO_2 with high resolution.

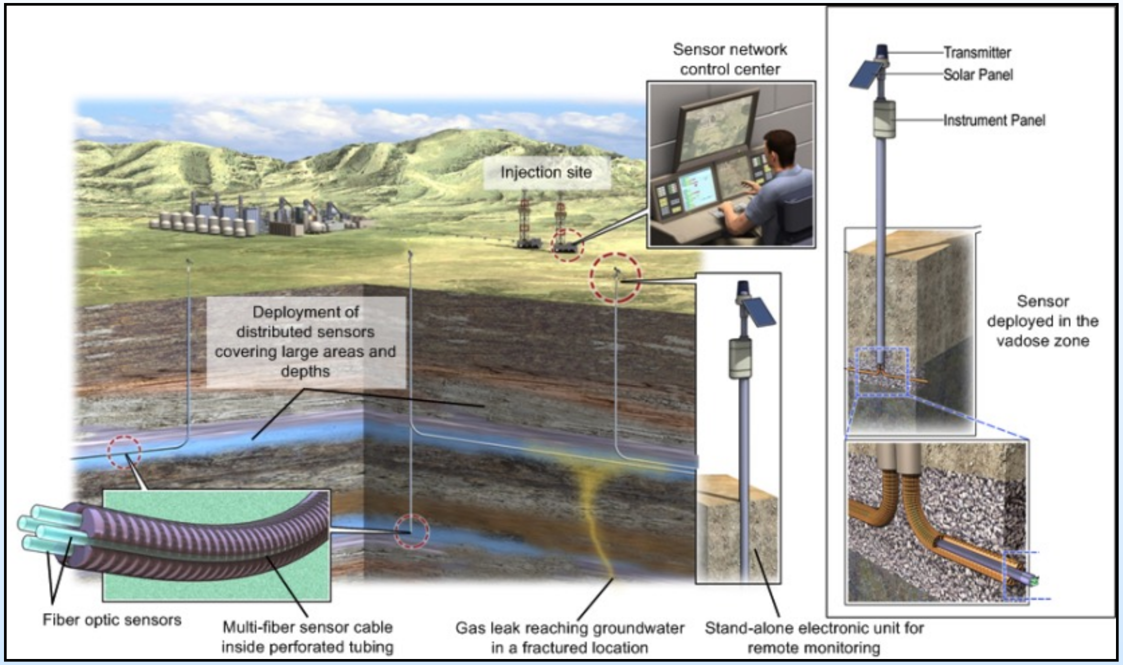
- Monitoring dissolved carbon dioxide is the most direct way to detect and quantify a leak reaching underground sources of drinking water.
- Current methods for detecting CO_2 leakage in groundwater are adapted from traditional groundwater quality studies – water samples are collected periodically and analyzed in the laboratory.
  - 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.

Technology

Distributed Intrinsic Fiber Optic Chemical Sensors

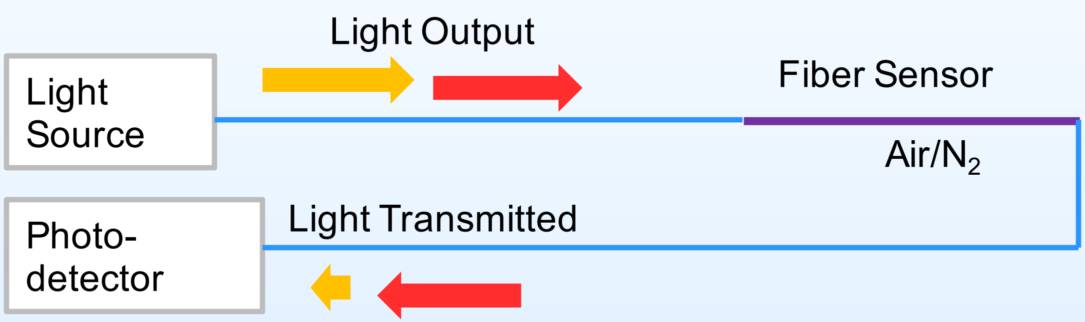
Unique Characteristics

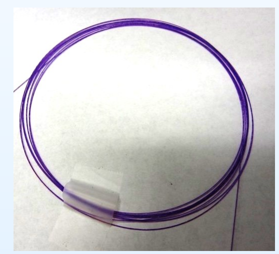
- The entire length of the fiber is a sensor
- Direct detection of dissolved CO_2
- A single cable may include CO_2, pH, salinity and temperature sensors.

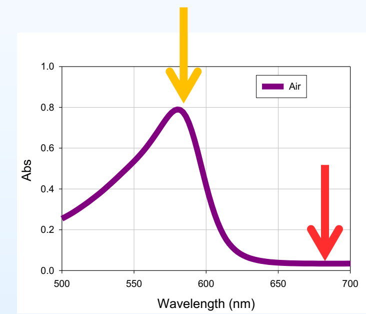


Technology

- A silica glass core fiber is 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.

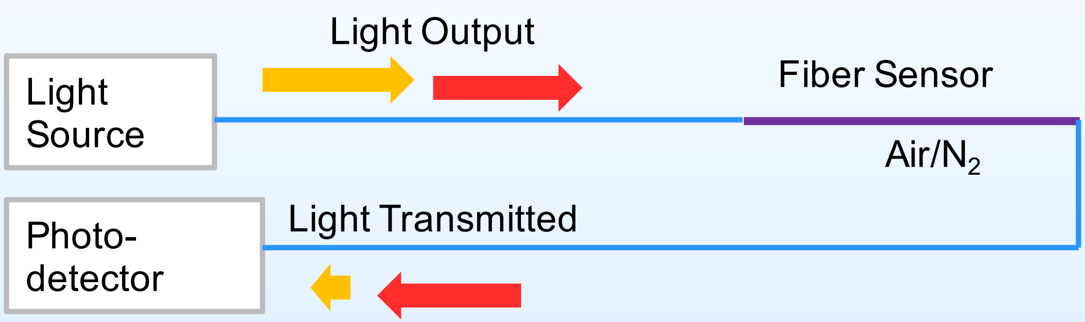


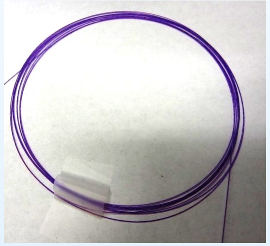


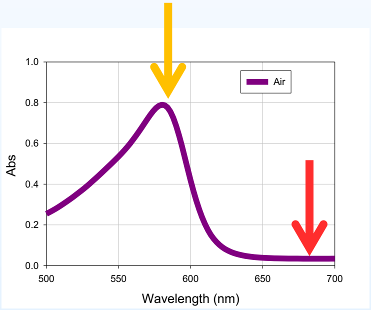


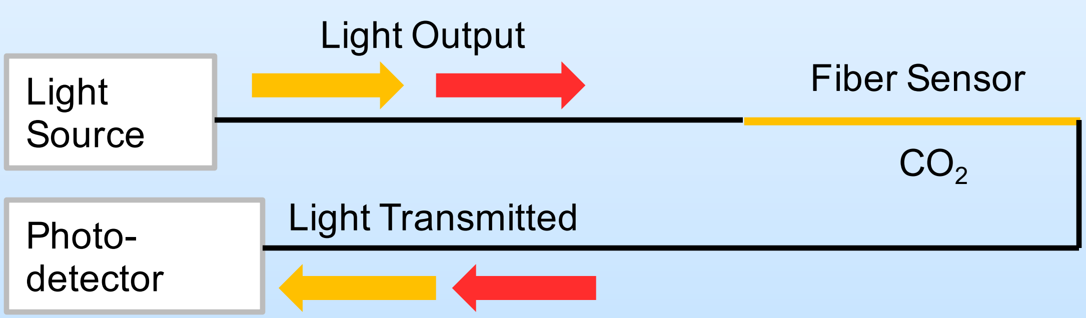
Technology

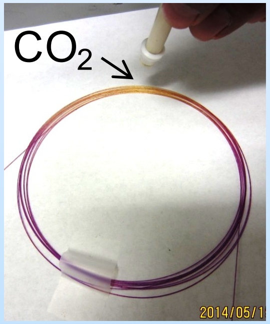
- Upon exposure of any segment of the fiber, the CO_2 diffuses into the cladding and changes color. The light transmitted through the fiber at wavelengths absorbed by the indicator varies with the concentration of CO_2.

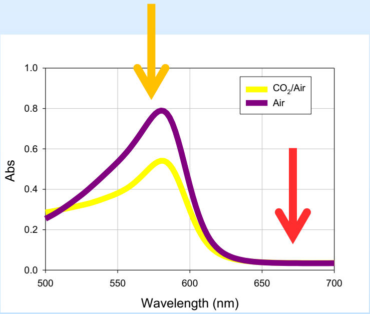






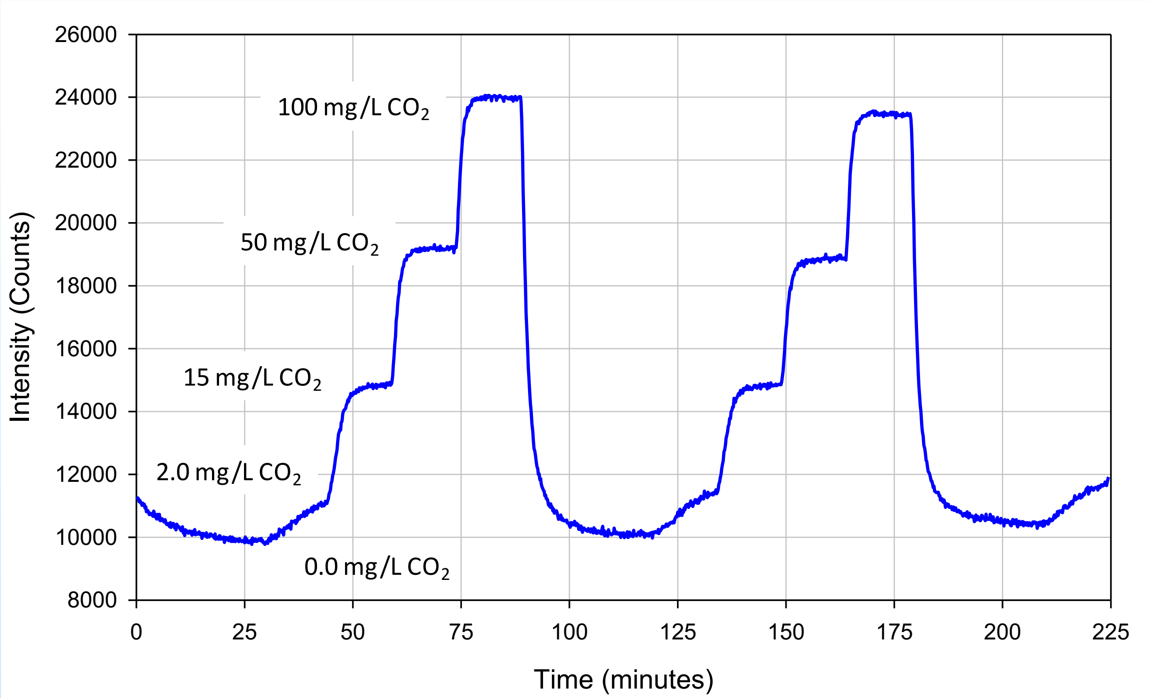






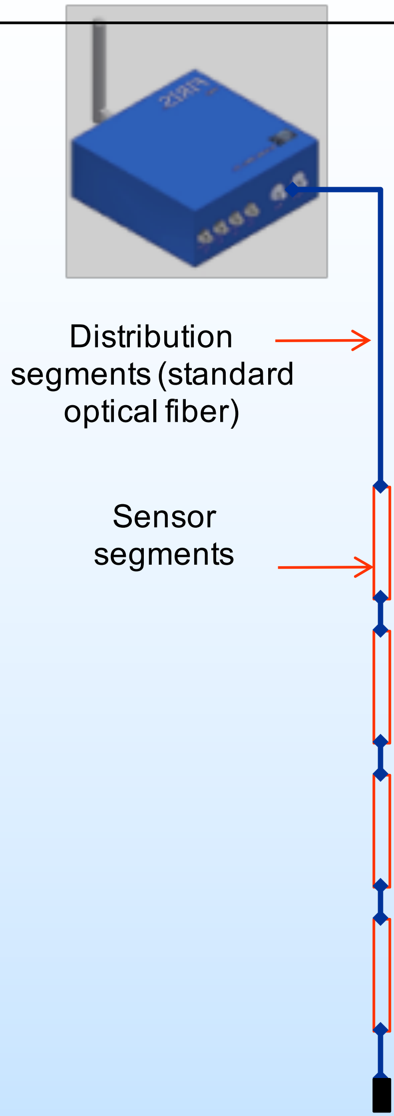
Technology

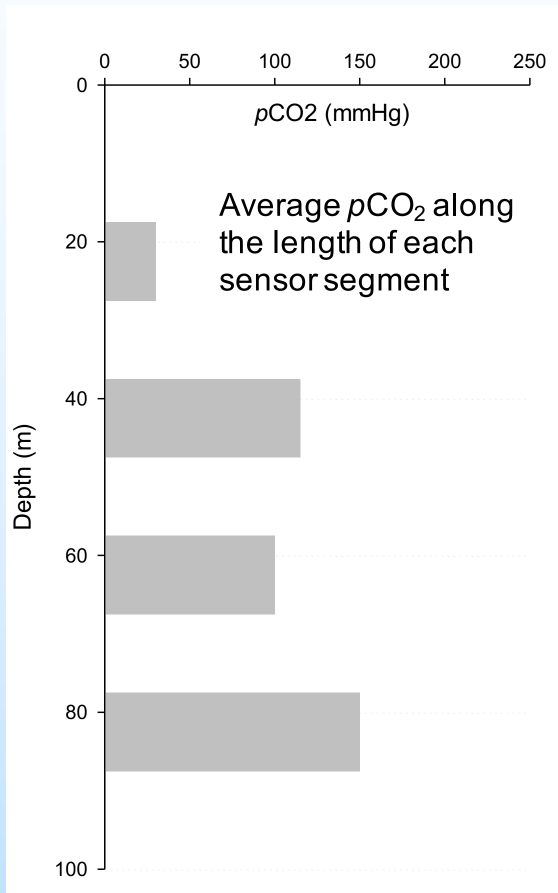
- The change in the fiber attenuation is **proportional** to the CO_2 concentration, and is **reversible**.

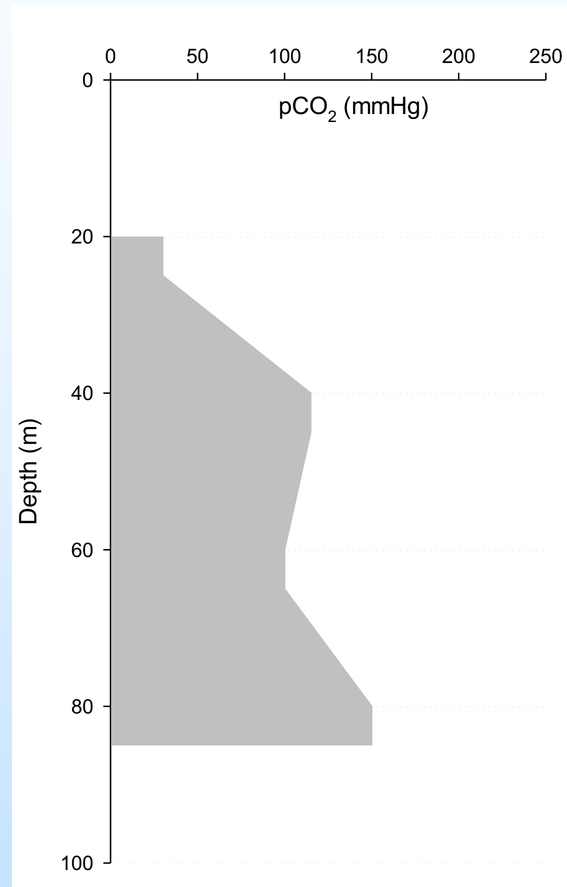


Technology

- **Zone-by-zone** monitoring using a sensor cable with multiple sensor segments.







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 **field deployment and demonstration** of intelligent real-time, in-situ monitoring network (RICO_2M Net).

Project Overview
Goals and Objectives

Research Plan

- **PHASE I: Develop a multi-parameter system**
  - 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 in the laboratory.

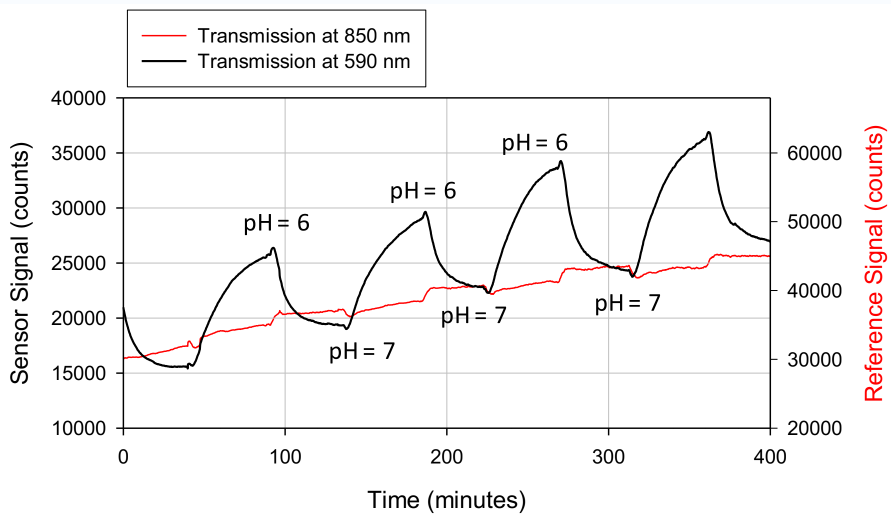
Project Overview
Goals and Objectives

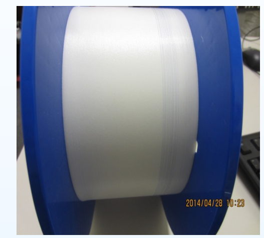
Research Plan

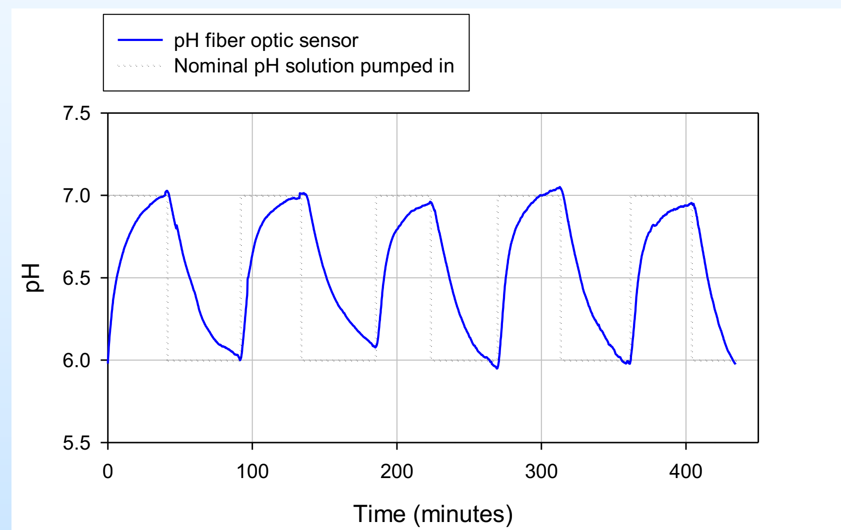
- **PHASE II:** Perform **deployment and demonstration in the field**
  - Fabricate the monitoring sensor network
  - Deploy and continuously monitor geological parameters in groundwater (10-15 units for one year)
  - Validate results with established monitoring techniques
  - Perform controlled-release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

Technical Status

Progress: *Develop Distributed pH Sensors*





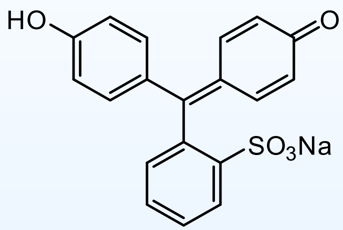


Basic Sensor Characteristics

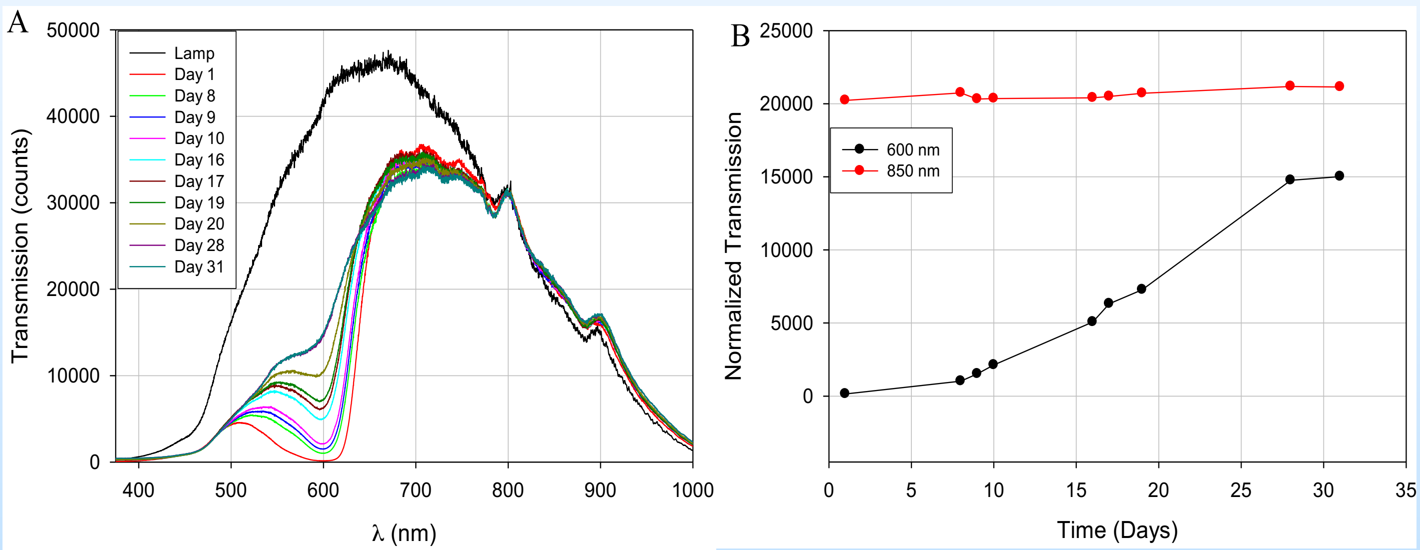
- Measurement range: 5 to 8.5 pH
- Resolution (precision): 0.04 (at 7 pH)
- Temperature range: 5°C to 30°C
- Temperature compensation: 1.4%/°C

Technical Status

Progress: *Develop Distributed pH Sensors*
Indicator Retention in the Polymer



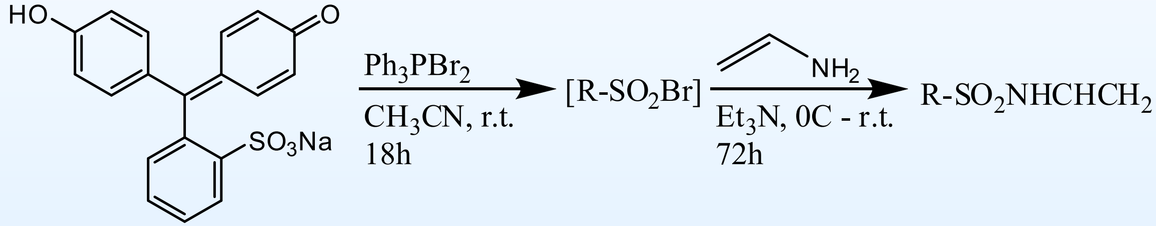
- Electrostatic retention by interaction with cationic groups in the polymer
- Under high water flow rate we observe indicator migration to the water



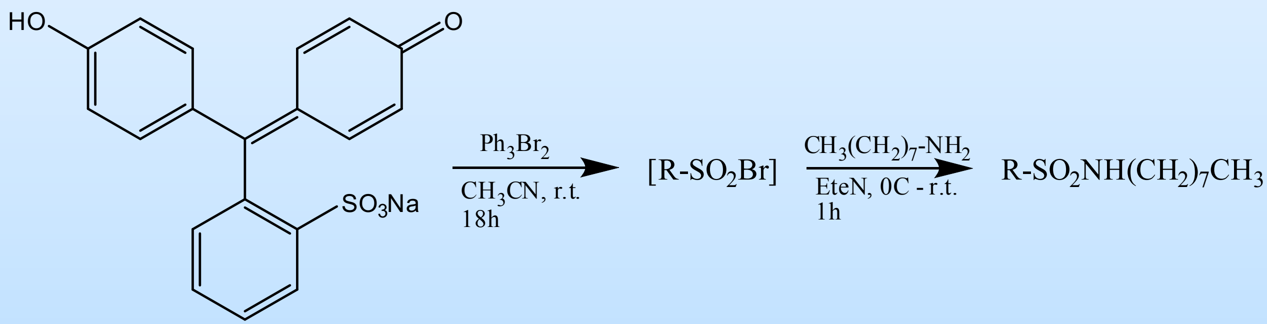
Technical Status

Progress: *Develop Distributed pH Sensors*
Indicator Retention in the Polymer

- Covalent immobilization by cross linking with vinyl groups in the polymer.



- Indicator dye with very low solubility in water by incorporating a long alquil chain.

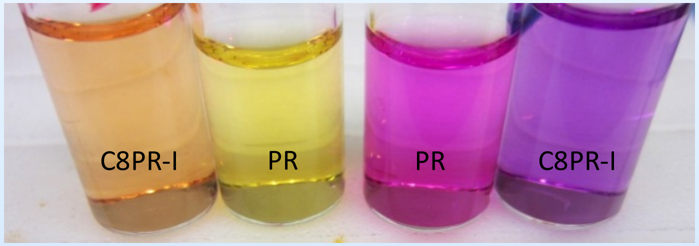


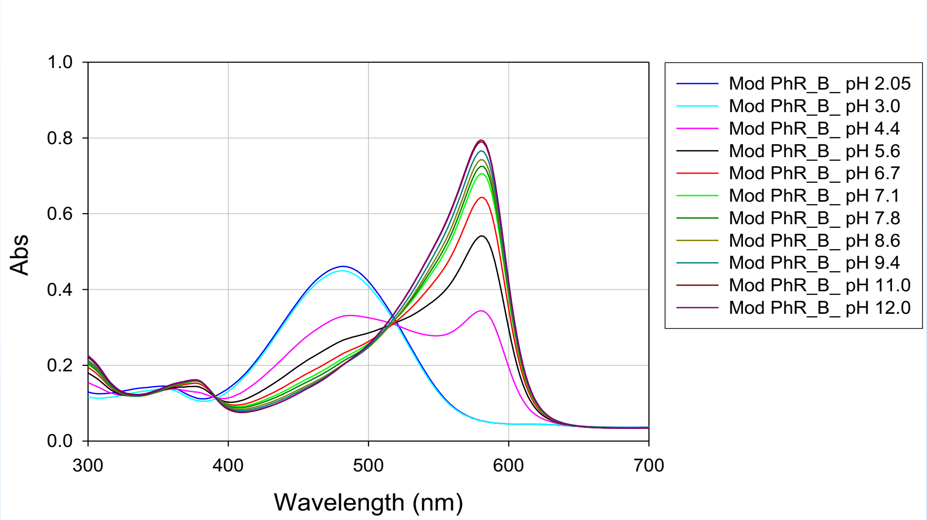
Technical Status

Progress: *Develop Distributed pH Sensors*
Indicator Retention in the Polymer

- Indicator dye with very low solubility in water by incorporating a long alquil chain.

Acid form Basic form





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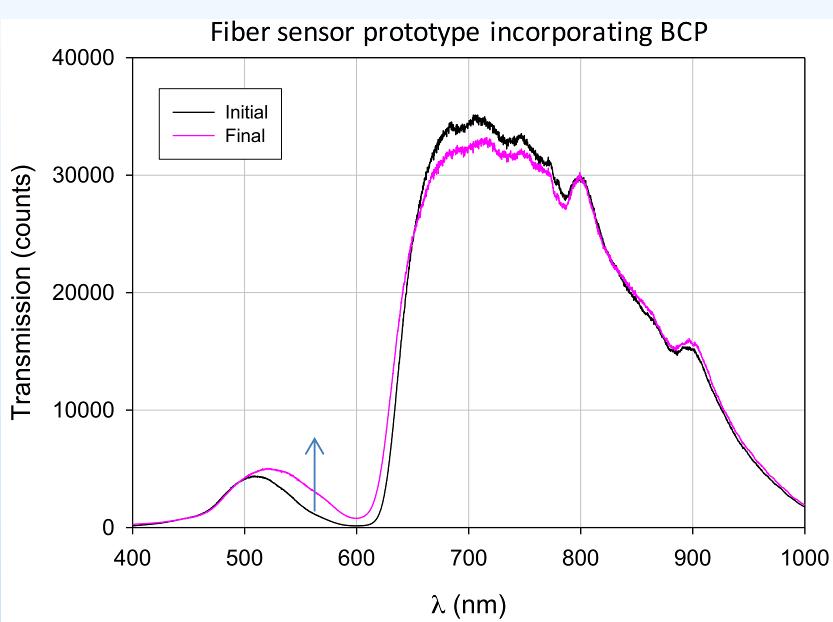
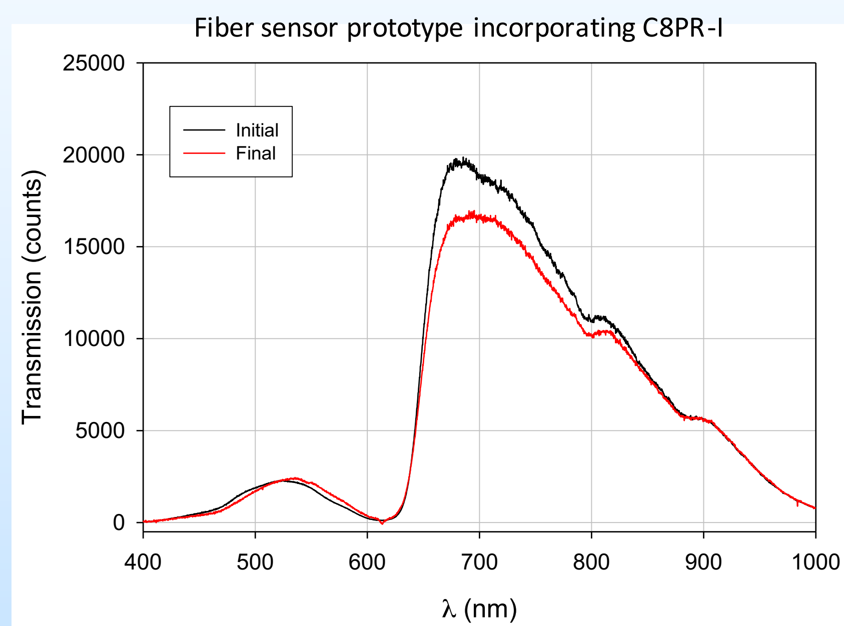
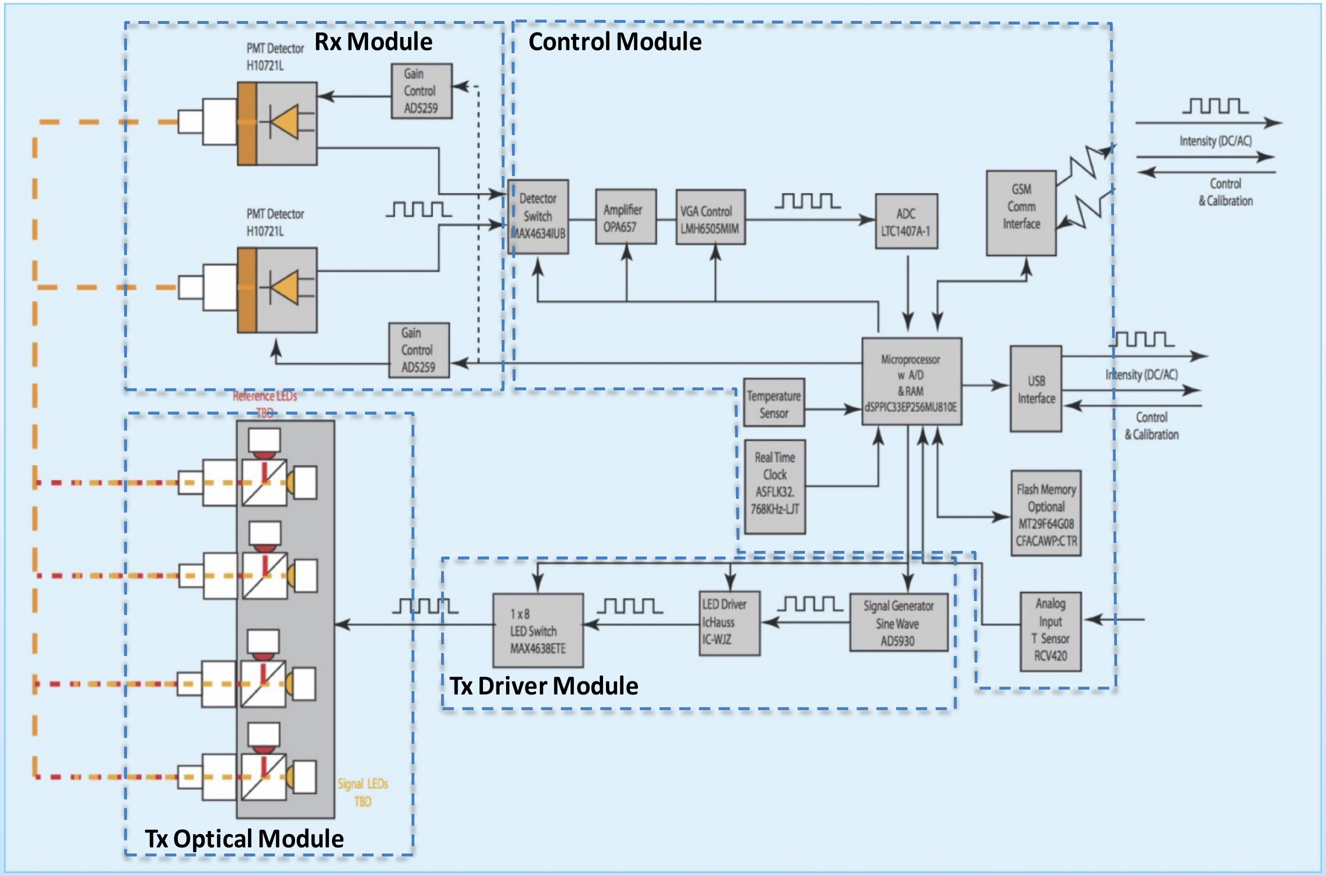




Technical Status

Progress: *Design Multi-parameter Monitor*



Technical Status

Progress: ***Integrate Multi-parameter Monitoring System***

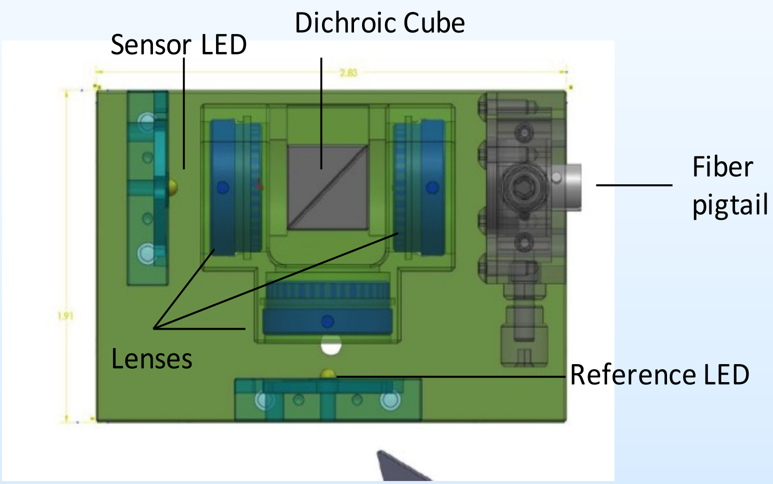
Control Module

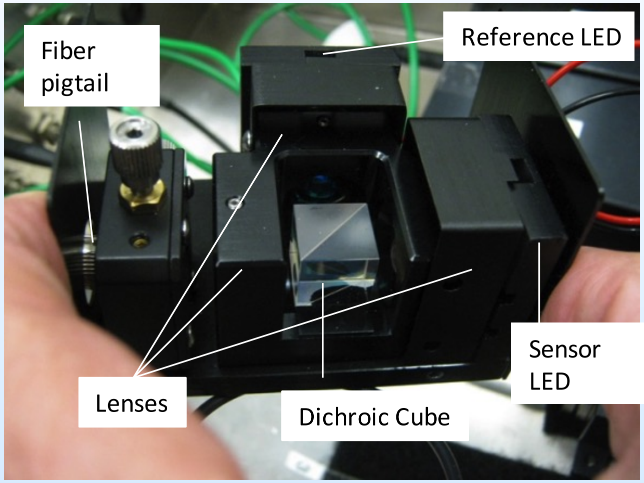
Rx Module

Technical Status

Progress: *Design Multi-parameter Monitor*

Tx Optical Module





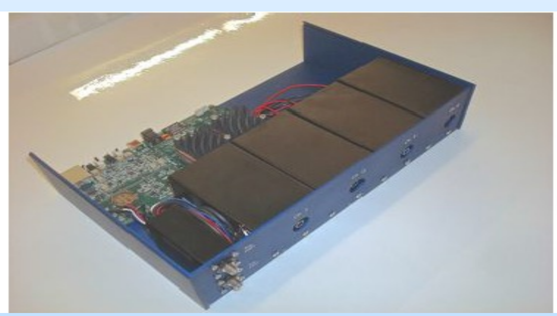
INTELLIGENT OPTICAL SYSTEMS, INC.

Technical Status

Progress: *Design Multi-parameter Monitor*

RICO_2M Multi-parameter Monitoring System

Simplified demonstrator assembled for first field evaluation

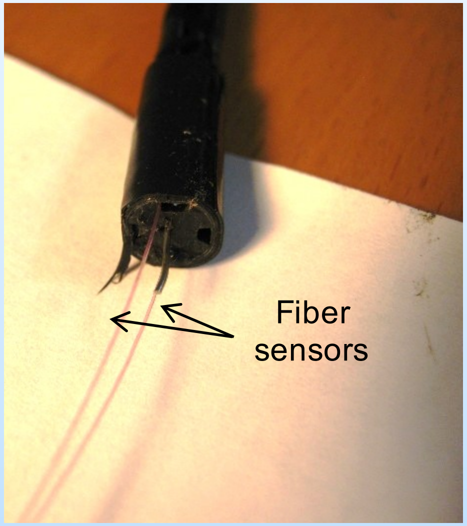


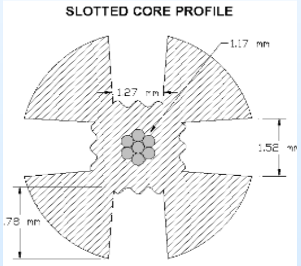
Technical Status

Progress: *Fabricate Multi-fiber Sensor Cables*
Sensor Cable Approach

Advantages: Possibility of fabricating long sensor segments, and narrow diameter of the cable.

Challenge: Assembling the fiber optic sensors, in particular the novel pH and salinity sensors.





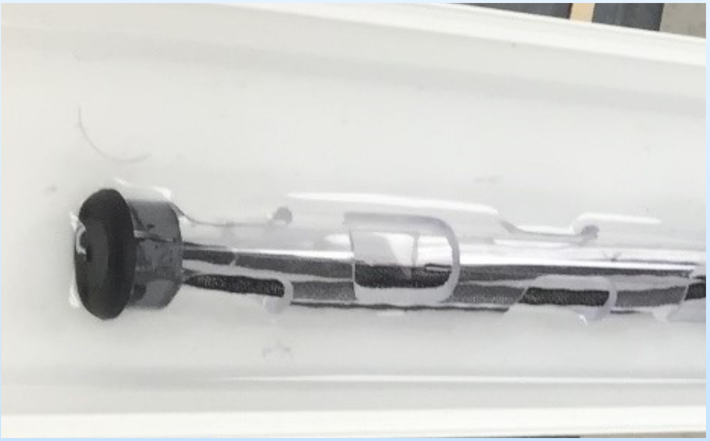
Technical Status

INTELLIGENT OPTICAL SYSTEMS, INC.

Progress: *Fabricate Multi-fiber Sensor Cables*
Sensor Probe Approach

Advantages: Makes fabrication easier, and simplifies storage and shipping.

Limitation: Applicable only where significant spatial coverage is not required.



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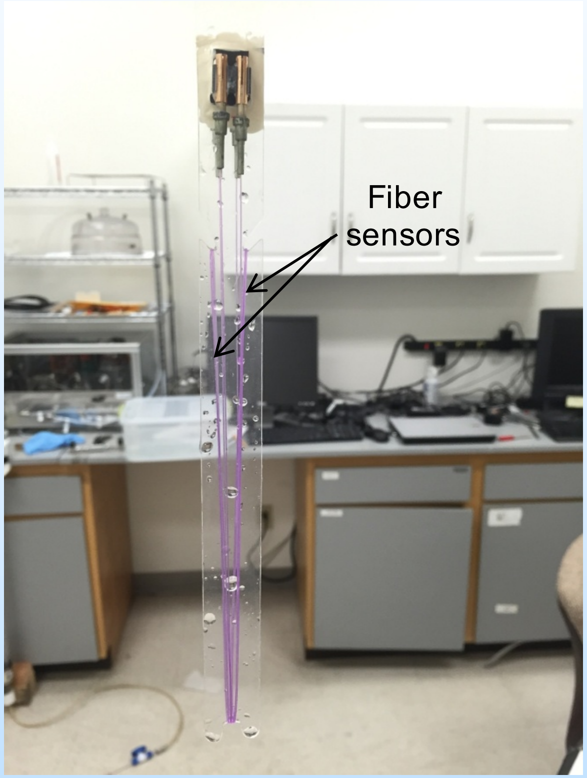
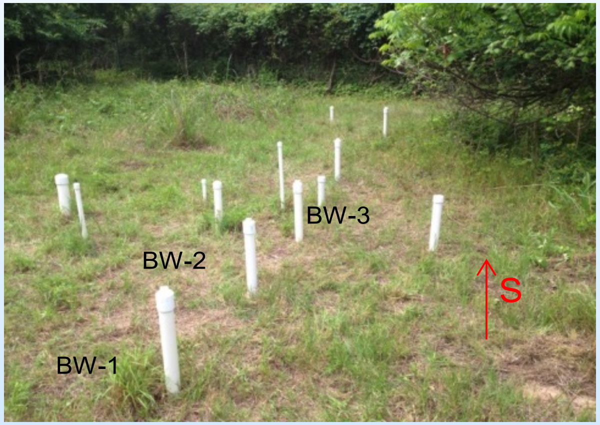
Sensor probe



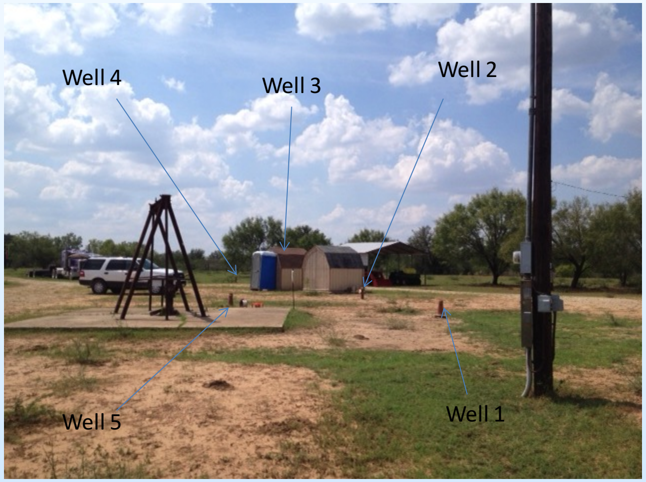
Technical Status

Progress: *Deploy Sensor System at Aquifers*

The Brackenridge Field Laboratory (BFL)
is an 82-acre research site with a siliclastic-dominated alluvial aquifer adjacent to the Colorado River in Austin, Texas.



The Devine Test Site (DTS)
is a 100-acre site less than 50 miles southwest of San Antonio in Medina County, Texas.



A Class V well authorization for the project at the Brackenridge Field Laboratory has been secured.

INTELLIGENT OPTICAL SYSTEMS, INC.

Technical Status

Progress: *Deploy Sensor System at Aquifers*

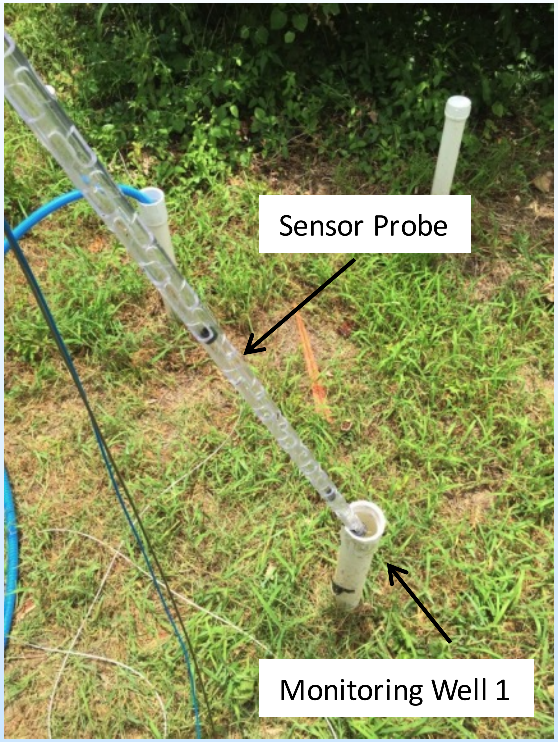
First system assembly for field test

Demonstrator units

Distribution cable

Technical Status

Progress: ***Deploy Sensor System at Aquifers***



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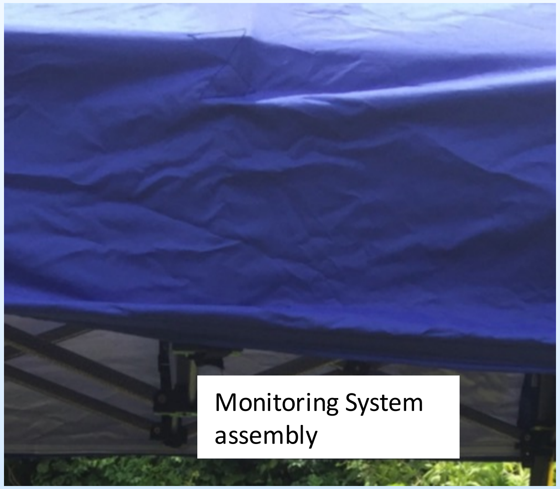
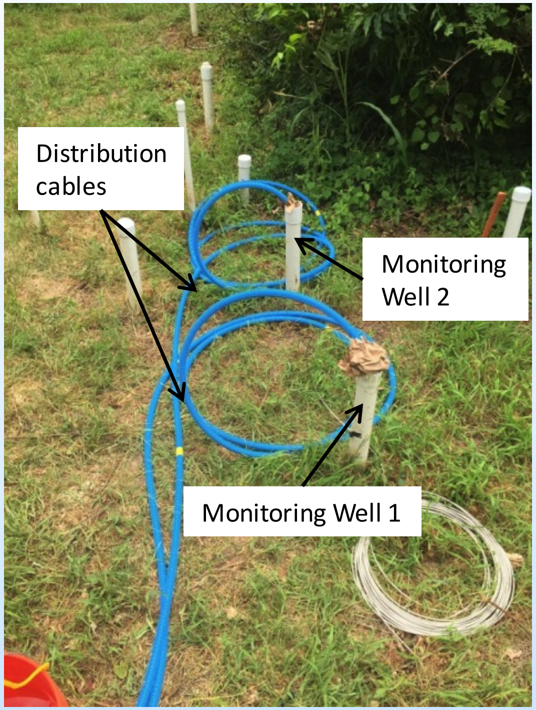


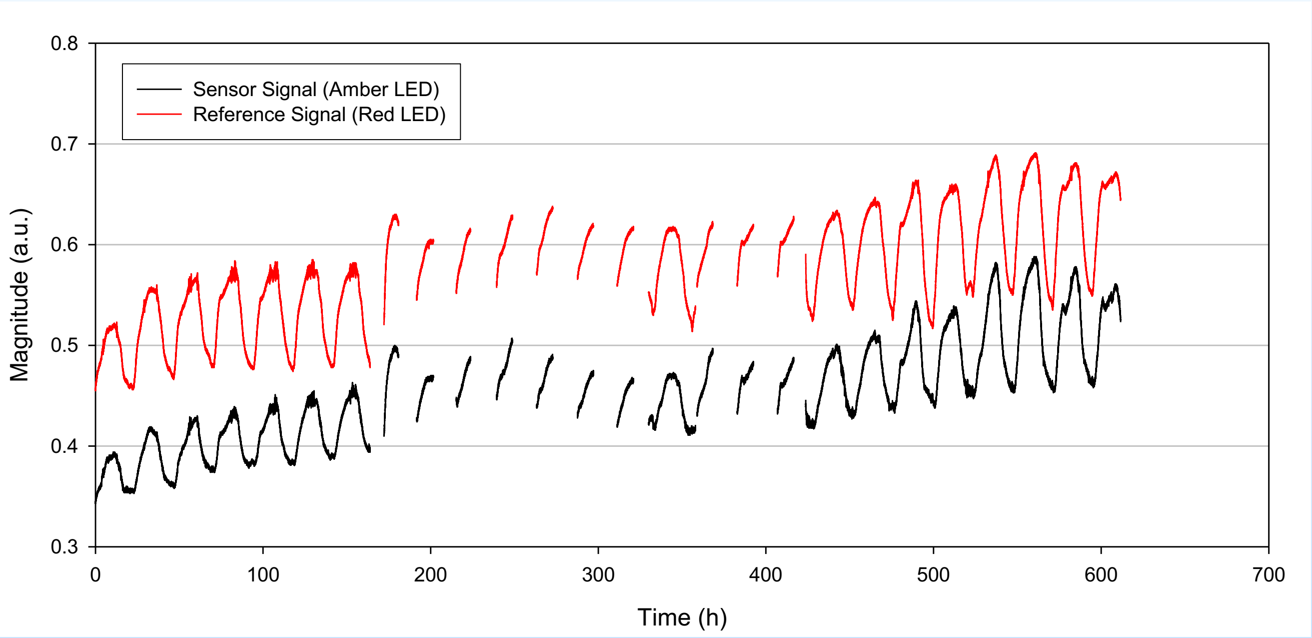


Technical Status

Progress: *Conduct Baseline Monitoring*

Field operation is always exciting!

Challenges: Interference from daylight in the measurements – error in the fabrication of the distribution segment. Calibration conducted in the laboratory has not yet been applied in the field.



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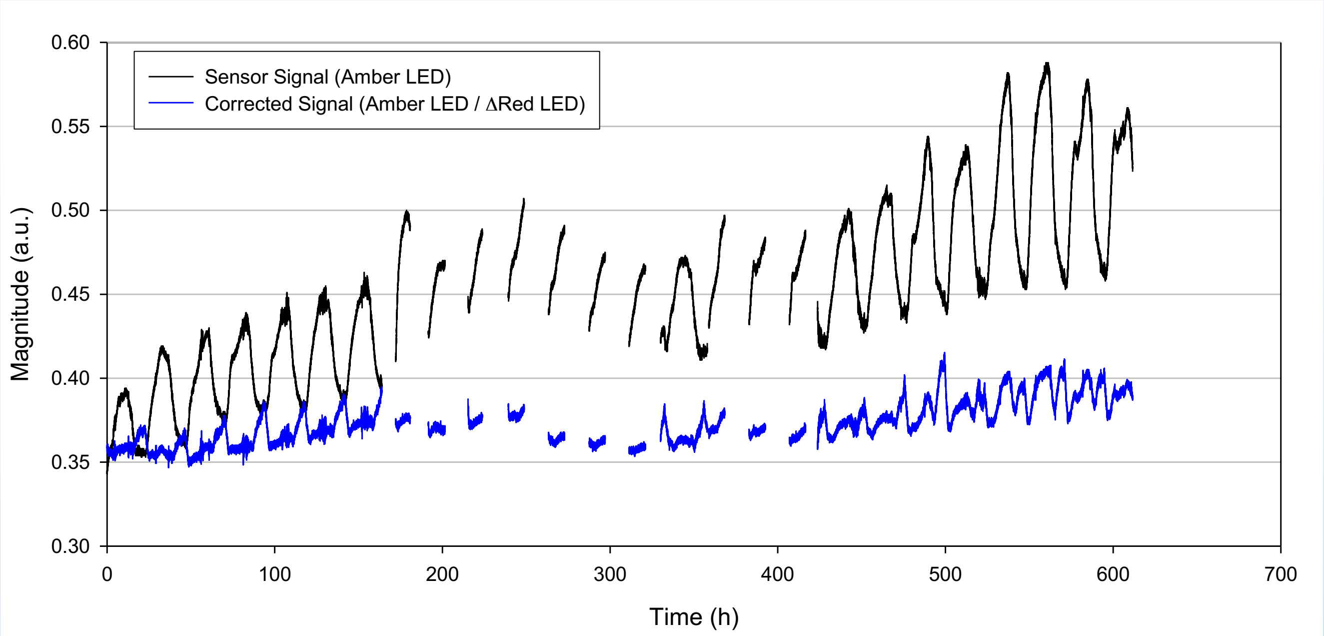

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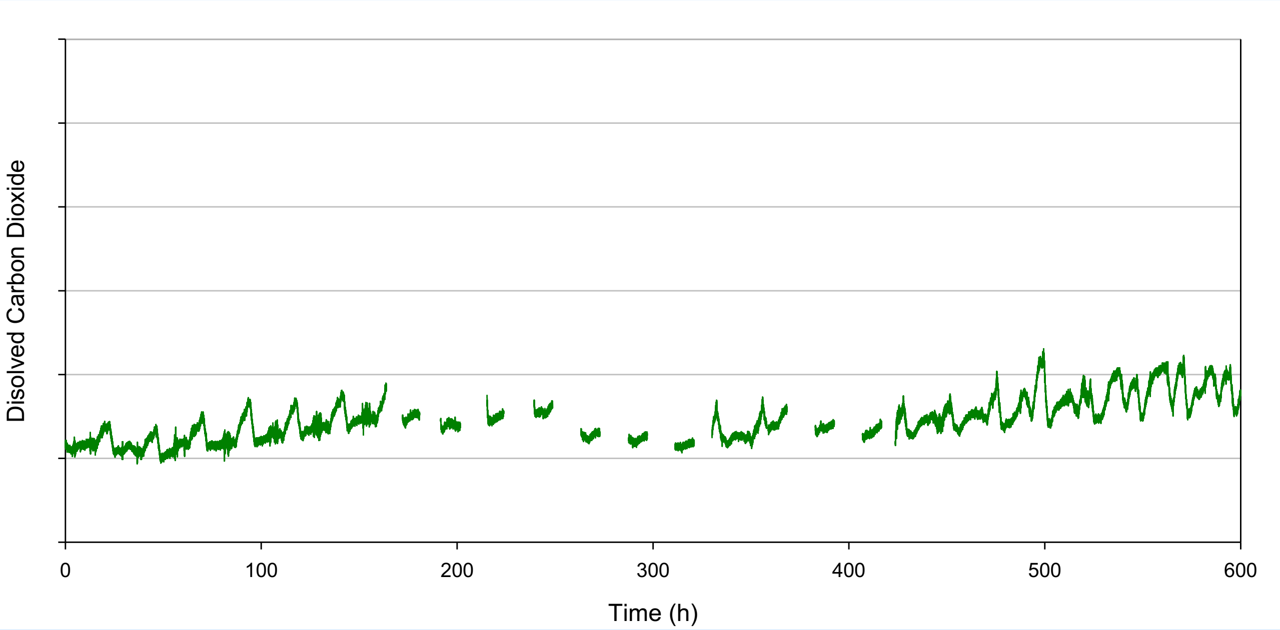
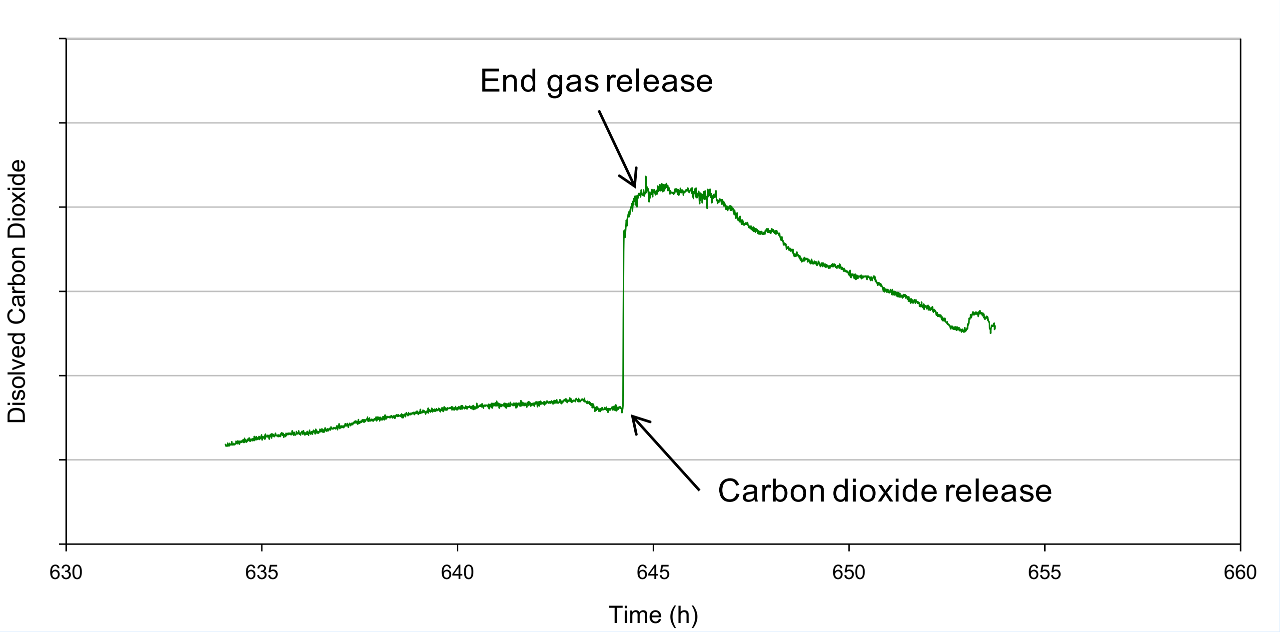
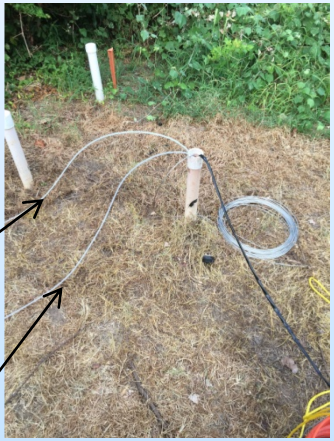


Technical Status

Progress: *Controlled Carbon Dioxide Release*



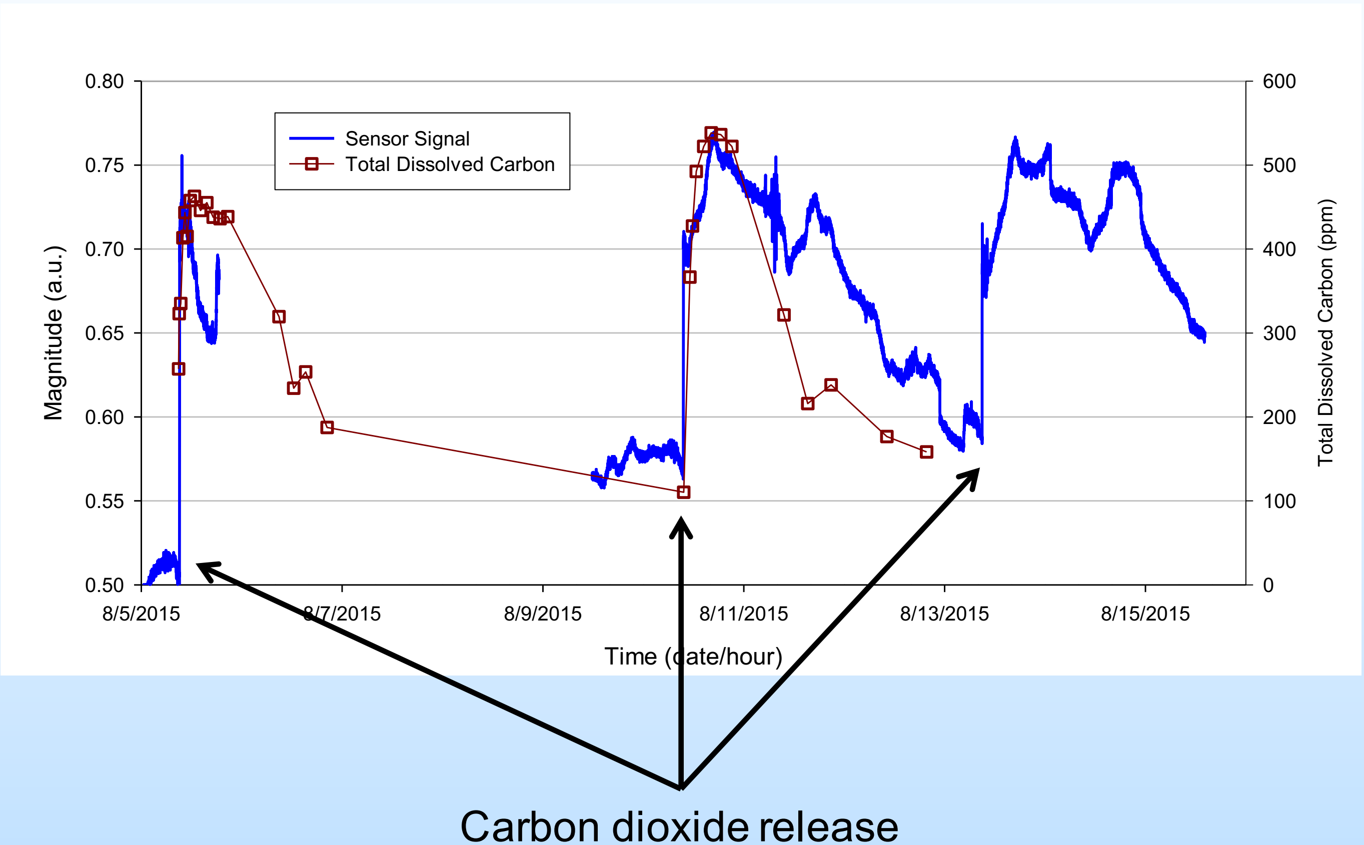


Water sampling pump

Carbon dioxide release tube

Technical Status

Progress: *Controlled Carbon Dioxide Release*



Summary

Accomplishments to Date

- Designed, fabricated, and integrated the first version of the optoelectronic unit for the fiber optic multi-parameter monitor.
- Assembled a simplified version of the optoelectronic unit to perform the first field studies.
- Designed and fabricated sensor cables and, as an alternative design, sensor probes.
- Assembled and deployed in the field the first multi-parameter monitor using the simplified demonstrators. Identified and implemented necessary system adaptation for field operation.
- Conducted a first CO_2 controlled-release test.

Summary
Planned Work

- Verify opto-electronic unit incorporating complete functionality (RICO_2M v1.0).
- Deploy first generation RICO_2M v1.0 system.
- Monitor performance of v1.0 systems in the field for several months.
- Assemble and deploy in the field the second generation RICO_2M system (v2.0).
- Compare results with established analytical techniques (determine accuracy).
- Demonstrate detection of CO_2 leaks by controlled-release tests (determine sensitivity).
- Advance and validate reactive transport modeling for CO_2 by comparison with continuous monitoring.

Acknowledgments

NETL Department of Energy

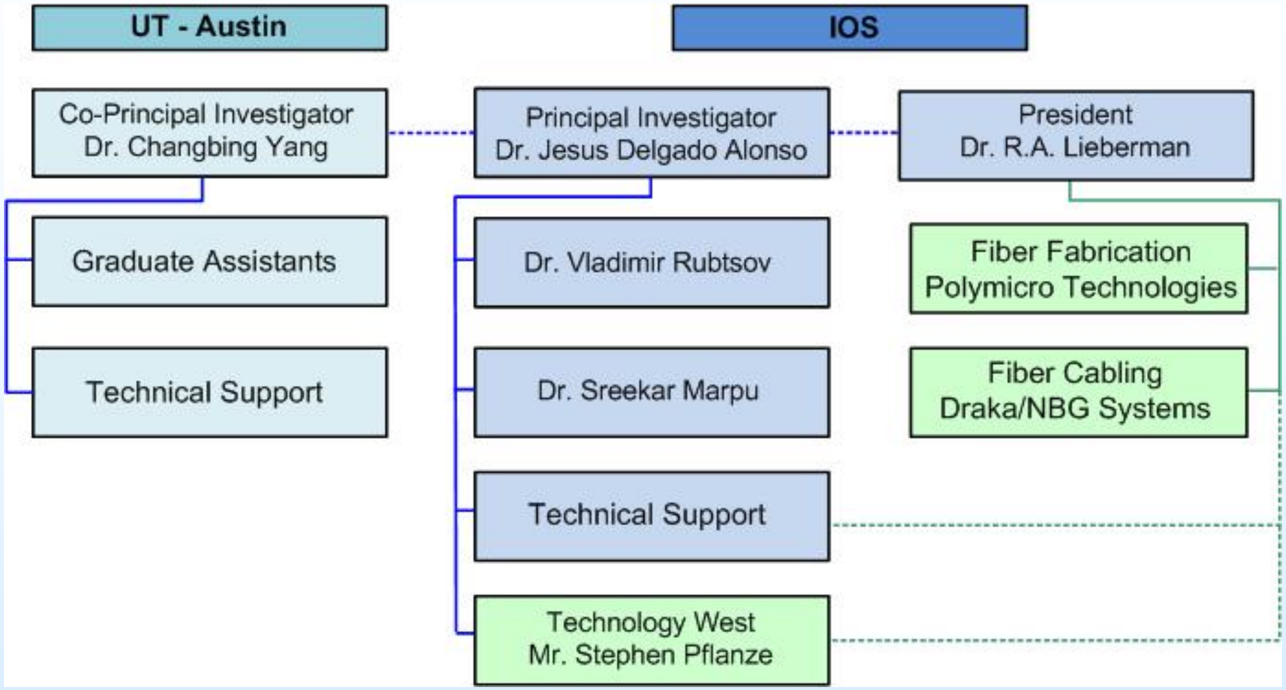
Joshua Hull

Robie Lewis, Robert Noll, Barbara Carney

Appendix

- Organization Chart
- Project Schedule
- Bibliography

Organization Chart

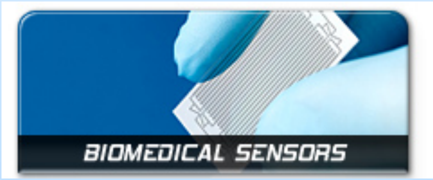


As the prime contractor for this project, IOS will carry out all activities related to the design, fabrication, and testing of the distributed CO_2 sensor network, and will provide field support to the University of Texas at Austin (UT-Austin) throughout the system Phase II field trials.

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



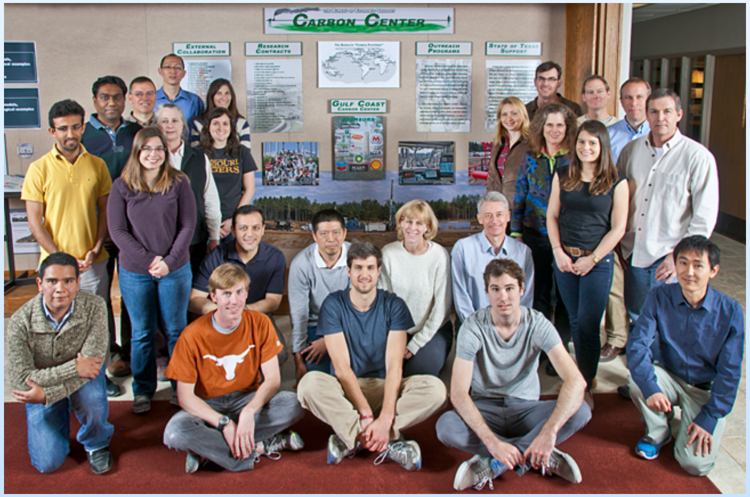
Organization Chart:
The University of Texas at Austin

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

Year 1

Tasks	1	2	3	4	5	6	7	8	9	10	11	12
1. Management	■	■	■	■	■	■	■	■	■	■	■	■
2. System requirements	■	■	■	■								
3. Sensor for pH	■	■	■	■	■	■	■	■	■	■		
4. Sensor for salinity			■	■	■	■	■	■	■	■	■	■
5. Multi-fiber sensor cables										■	■	■
6. Multi-parameter monitoring unit										■	■	■
7. Characterization in laboratory												
8. Fabrication of network												
9. Deployment and monitoring												
10. Controlled-release field tests												
11. Design review												
MILESTONES				1						2		3

Year 2

Tasks	13	14	15	16	17	18	19	20	21	22	23	24
1. Management	■	■	■	■	■							
2. System requirements												
3. Sensor for pH												
4. Sensor for salinity												
5. Multi-fiber sensor cables	■	■										
6. Multi-parameter monitoring unit	■	■	■									
7. Characterization in laboratory		■	■	■	■							
8. Fabrication of network						■	■	■	■	■	■	■
9. Deployment and monitoring						■	■	■	■	■	■	■
10. Controlled-release field tests												
11. Design review												
MILESTONES			4		5	6	7		8			

Year 3

Tasks	25	26	27	28	29	30	31	32	33	34	35	36
1. Management												
2. System requirements												
3. Sensor for pH												
4. Sensor for salinity												
5. Multi-fiber sensor cables												
6. Multi-parameter monitoring unit												
7. Characterization in laboratory												
8. Fabrication of network	■	■	■	■								
9. Deployment and monitoring	■	■	■	■	■	■	■	■				
10. Controlled-release field tests							■	■	■	■	■	■
11. Design review										■	■	■
MILESTONES				9						10		11

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.