Real-time In-situ CO_2 Monitoring (RICO2M) Network for Leakage Detection in Groundwater

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&

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U.S. Department of Energy

National Energy Technology Laboratory

Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration:
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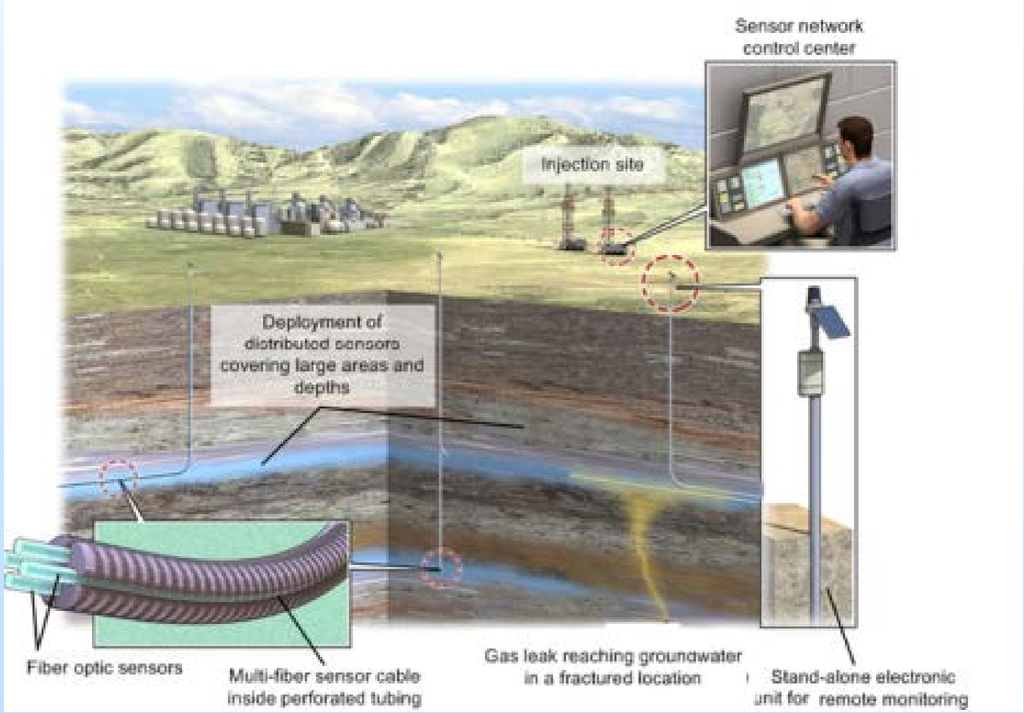
Background

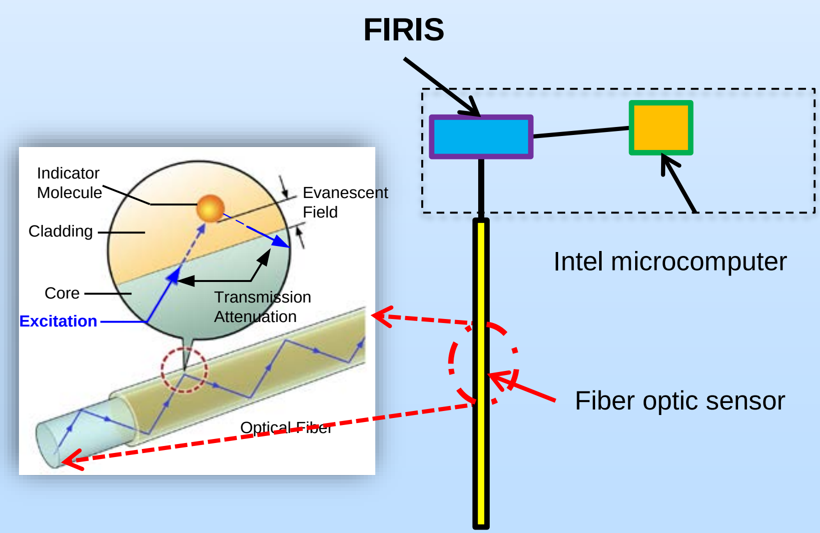
- Current geochemical monitoring requires water samples to be collected periodically, and analyzed either onsite or in a chemical laboratory.
- This is a labor- and cost-intensive process.

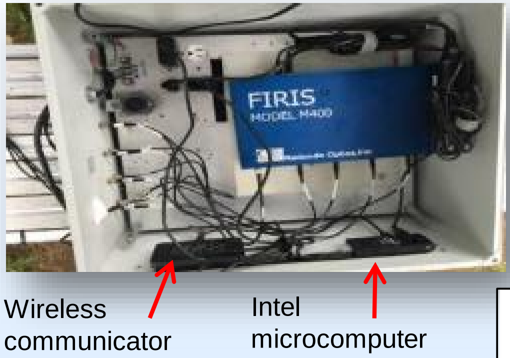
Can we use sensors for real-time, in-situ monitoring of geochemical parameters in groundwater, to make geochemical monitoring as simple as pressure monitoring?

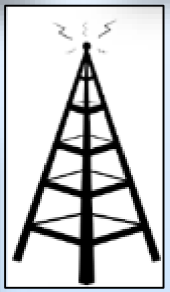


RICO2M Development

- Major components:
  - Fiber optic chemical sensor
  - FIRIS (opto-electronic unit)
  - Intel microcomputer (data acquisition)
  - Wireless communicator

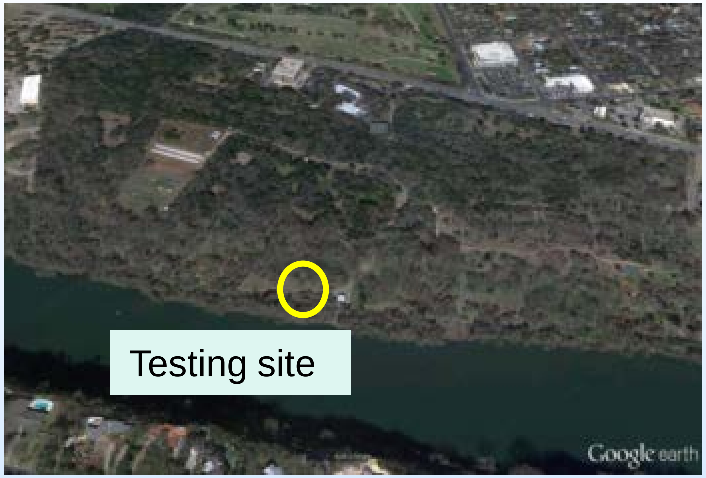


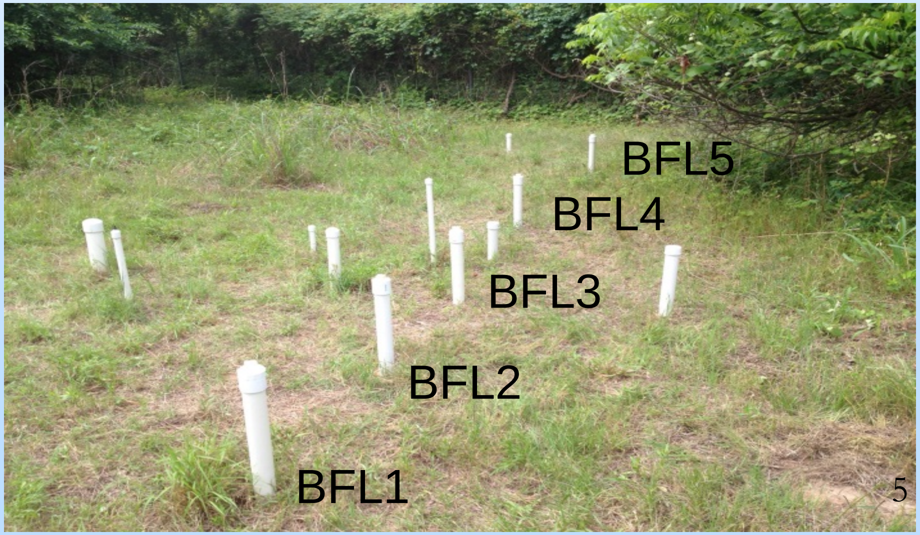




Field Site

- **Brackenridge Field Laboratory** (BFL) is located in Austin, TX, and is managed by the University of Texas at Austin (UTA).
- There are ~five water wells in a shallow and unconfined aquifer drilled to depths of 20 ft., and screened from 10 ft. to 20 ft. below the surface.
- Groundwater table is ~8 ft. below the surface.
- The bottom of the aquifer is limestone.
- Aquifer sediments contain >20% carbonates.



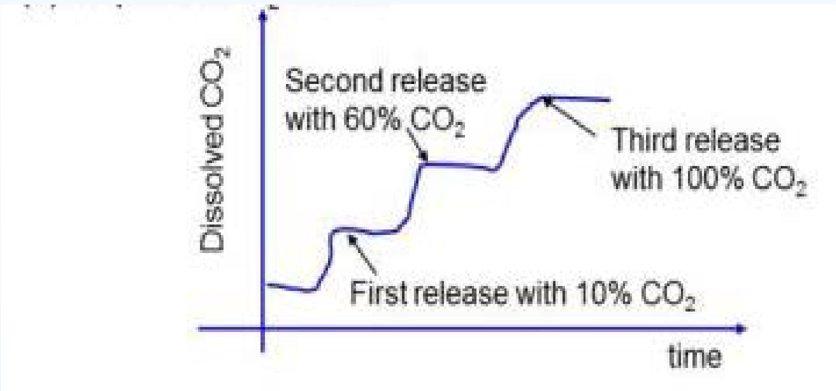


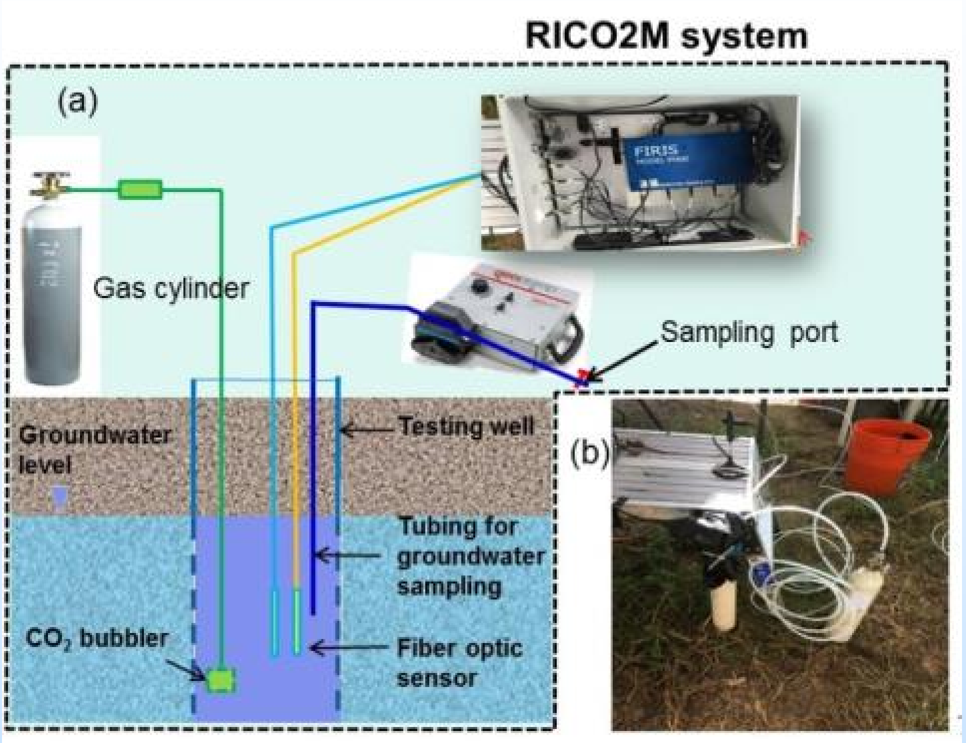
$RICO_2M$ Installation

- 8 Sensors
- 4 Monitoring wells
- 2 Systems
- Over 12 months

Controlled release tests

Step-wise CO2 release tests





- Onsite measurements of pH and alkalinity.
- Onsite measurements of dissolved CO_2 with a CarbonQC.

Controlled release tests

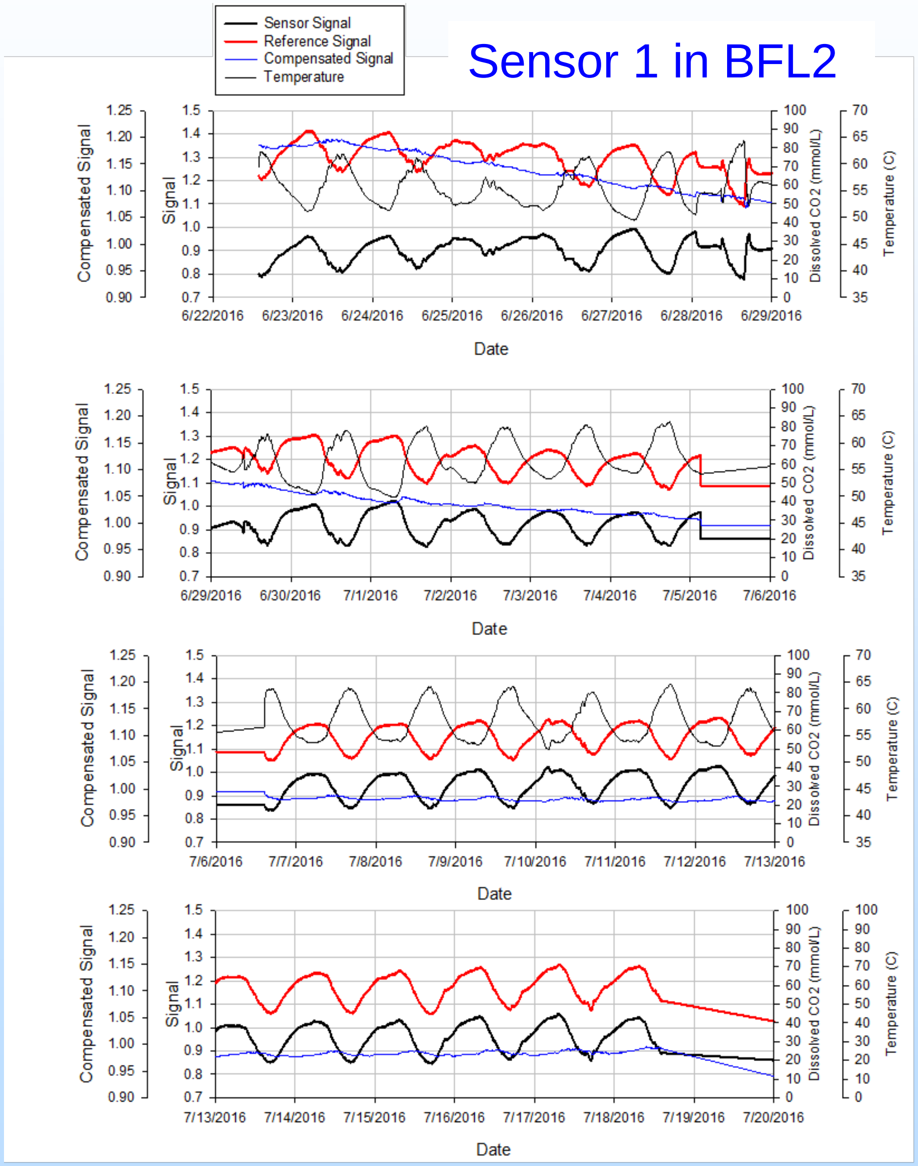





Field Results

- **Background with the sensor signals since June 22, 2016**

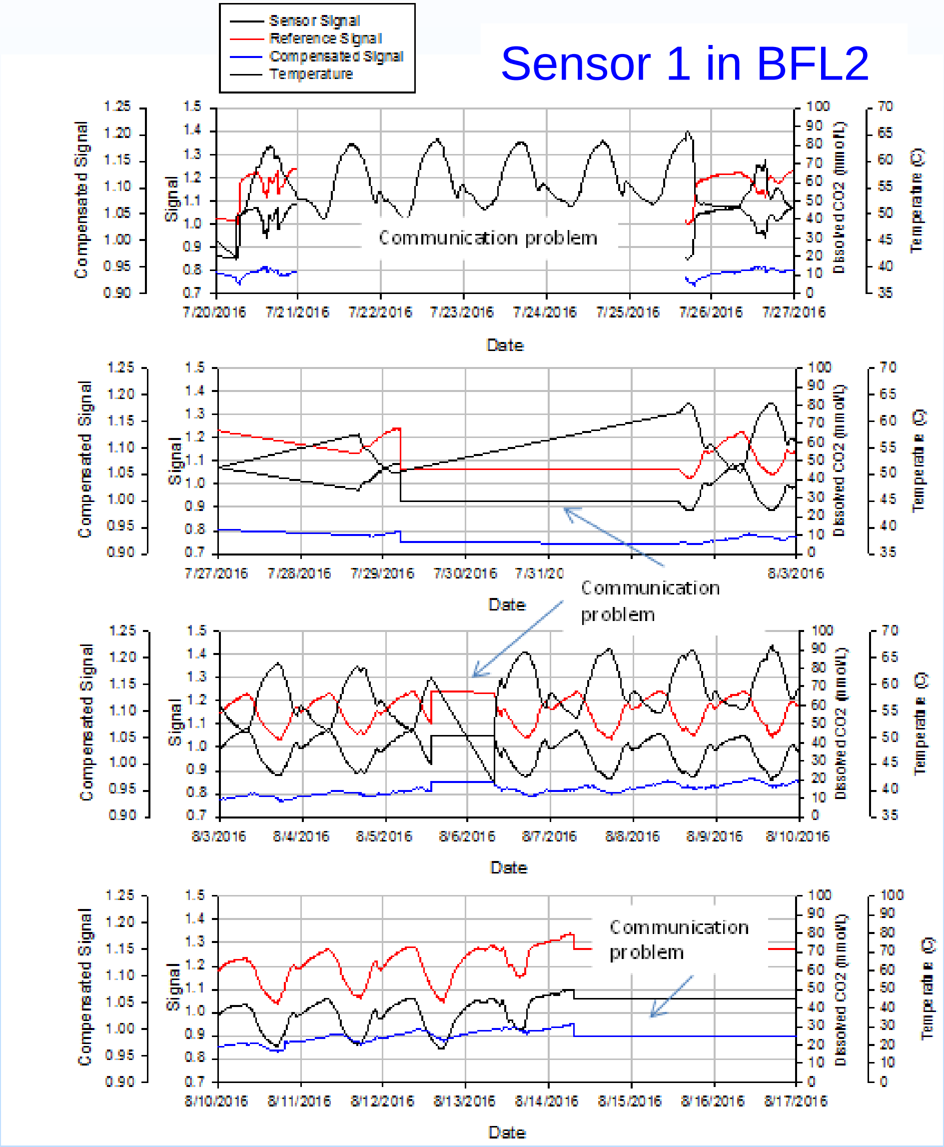
From June 22 through July 20, 2016



Field Results

- **Background with the sensor signals since June 22, 2016**

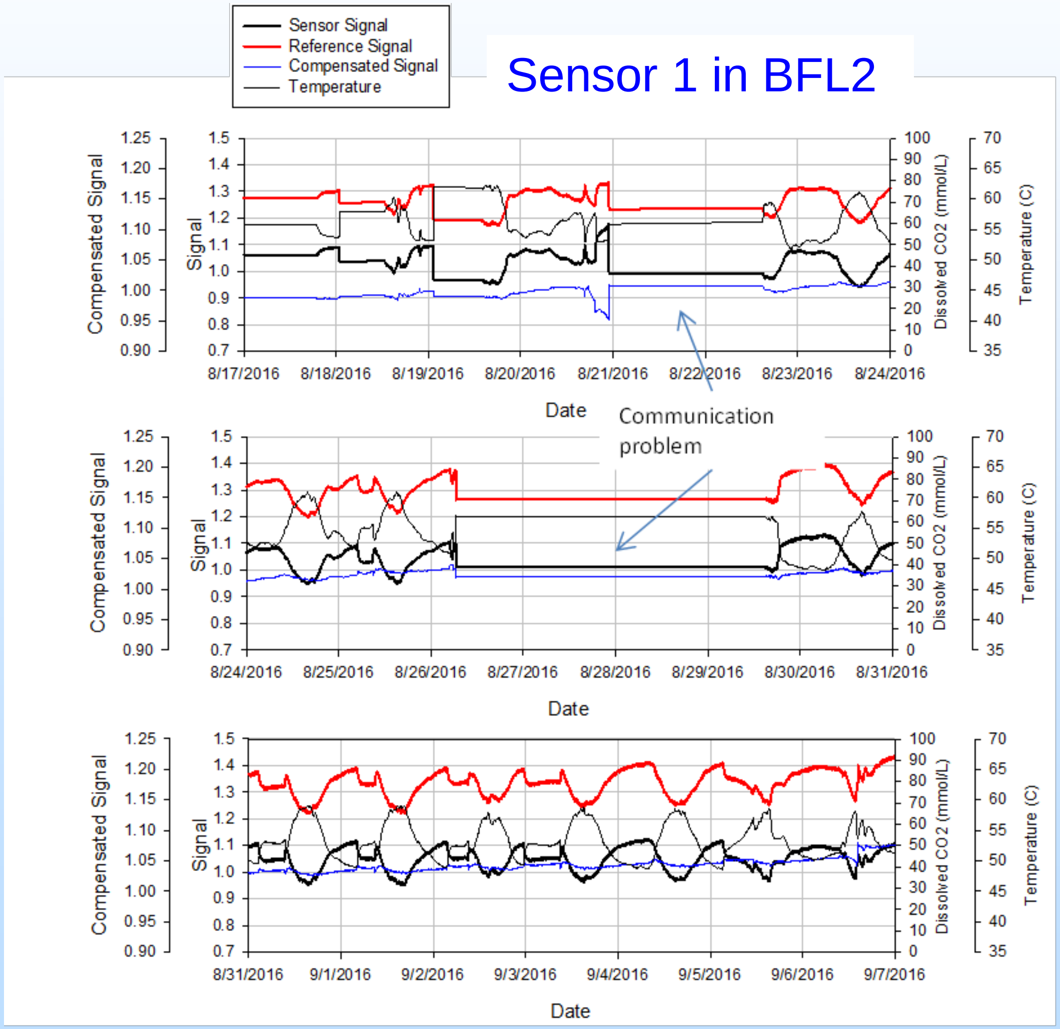
From July 20 through August 17, 2016



Field Results

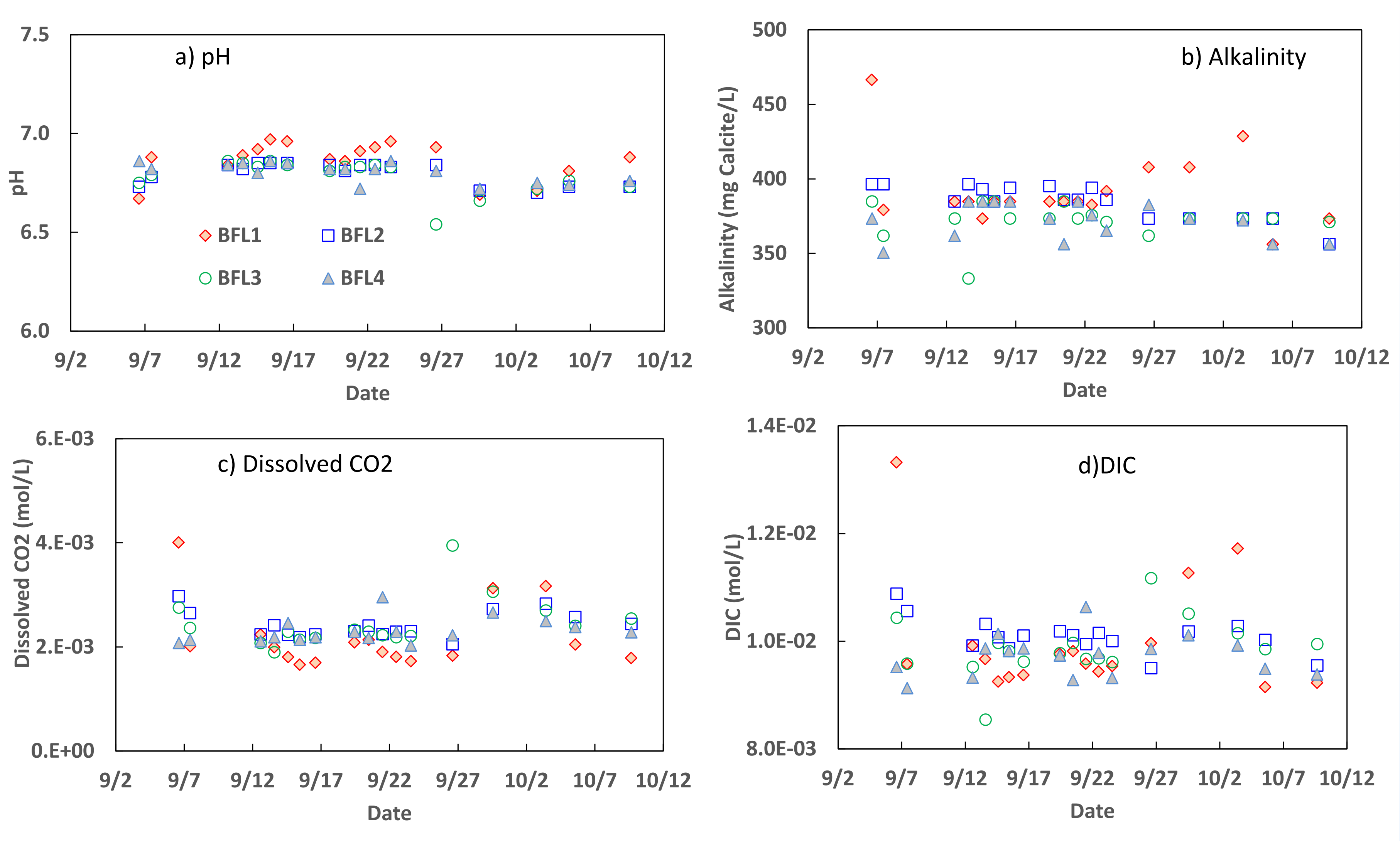
- **Background with the sensor signals since June 22, 2016**

From August 17 through September 7, 2016



Field Results

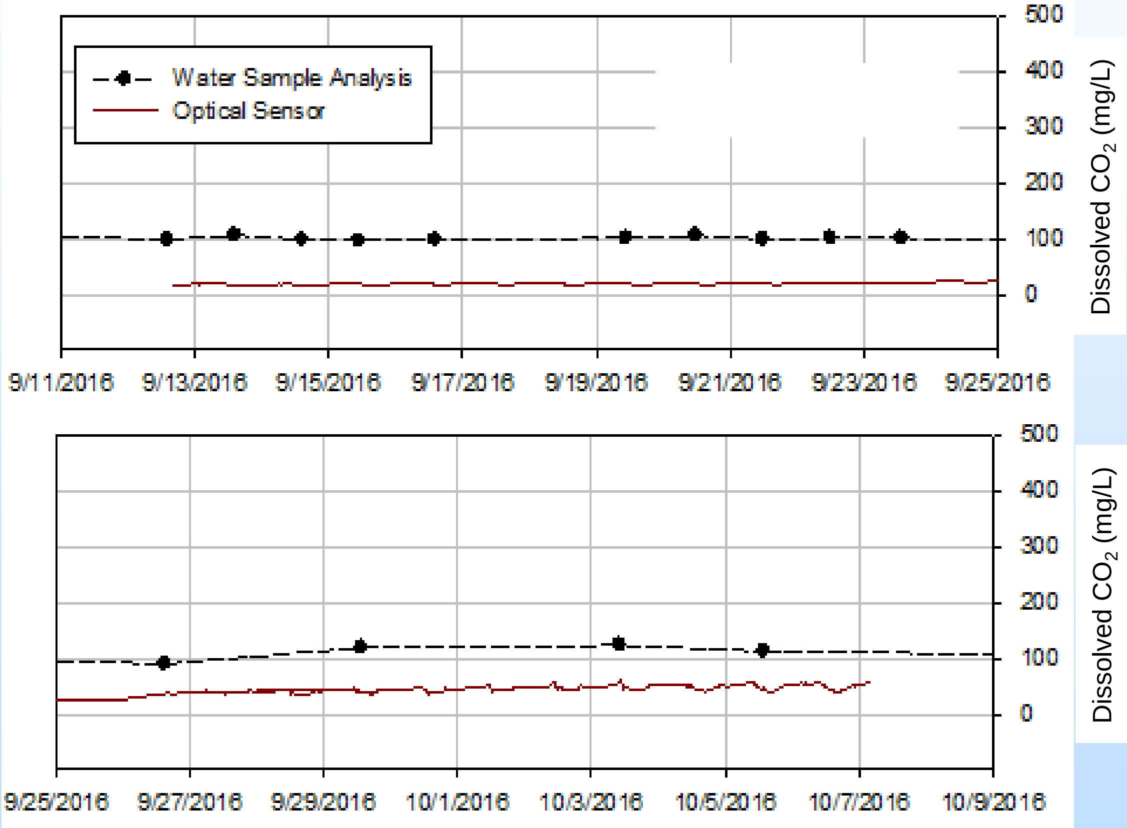
- **Background characterization with the sampling method from Sept. 7 through Oc. 10, 2016**



Field Results

- Comparison of sensor measurements with the results of the sampling approach

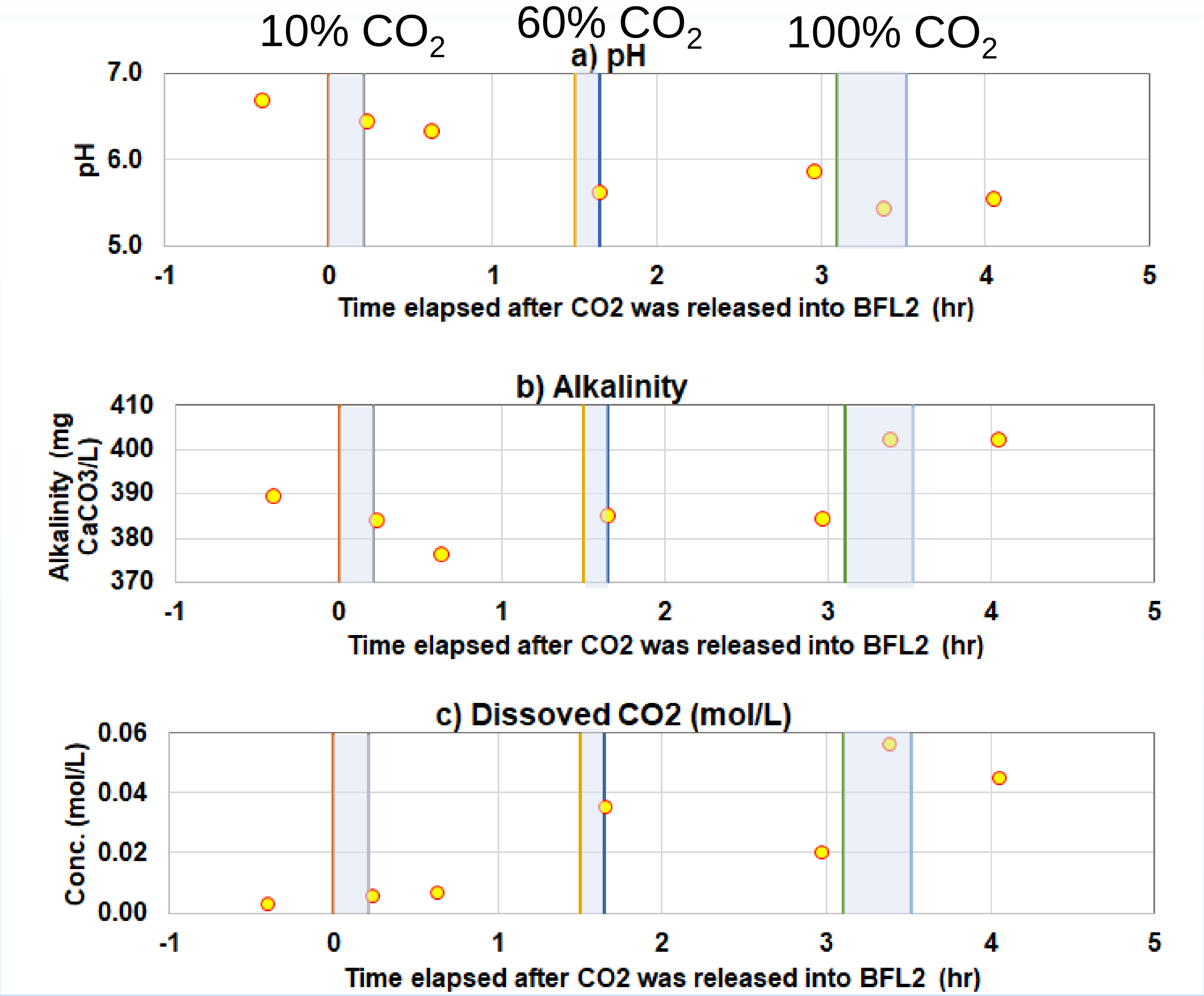
Sensor 1 in BFL2



➢ Lack of accuracy in long-term background CO_2 concentration monitoring

Field Results

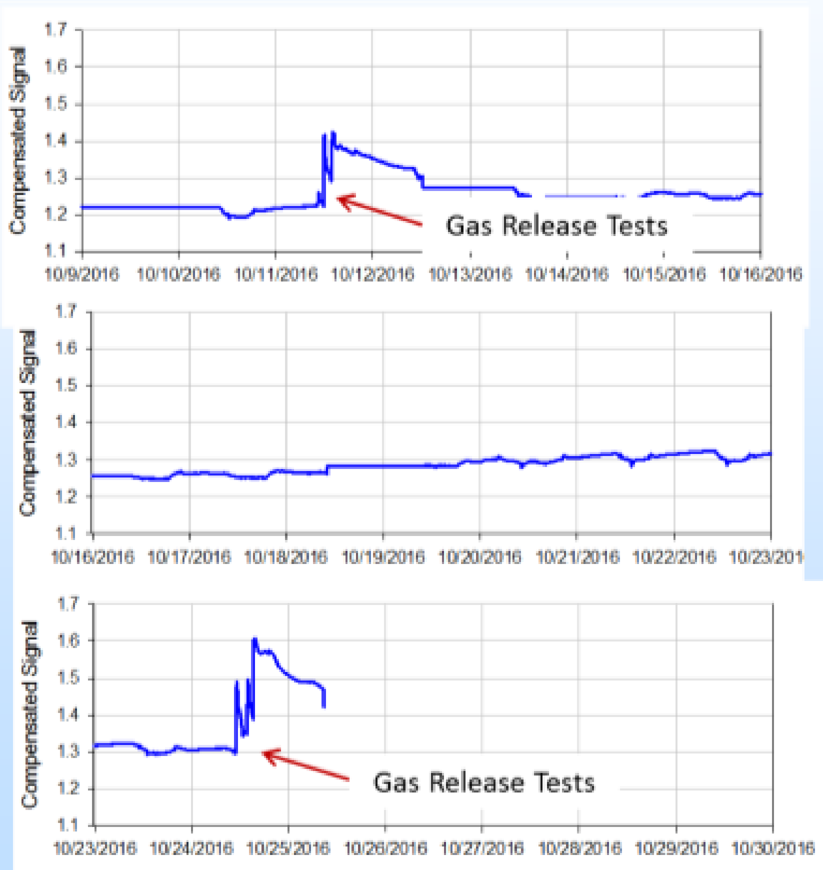
- Stepwise CO_2 release tests at the week of Oct. 10, 2016 in BFL2



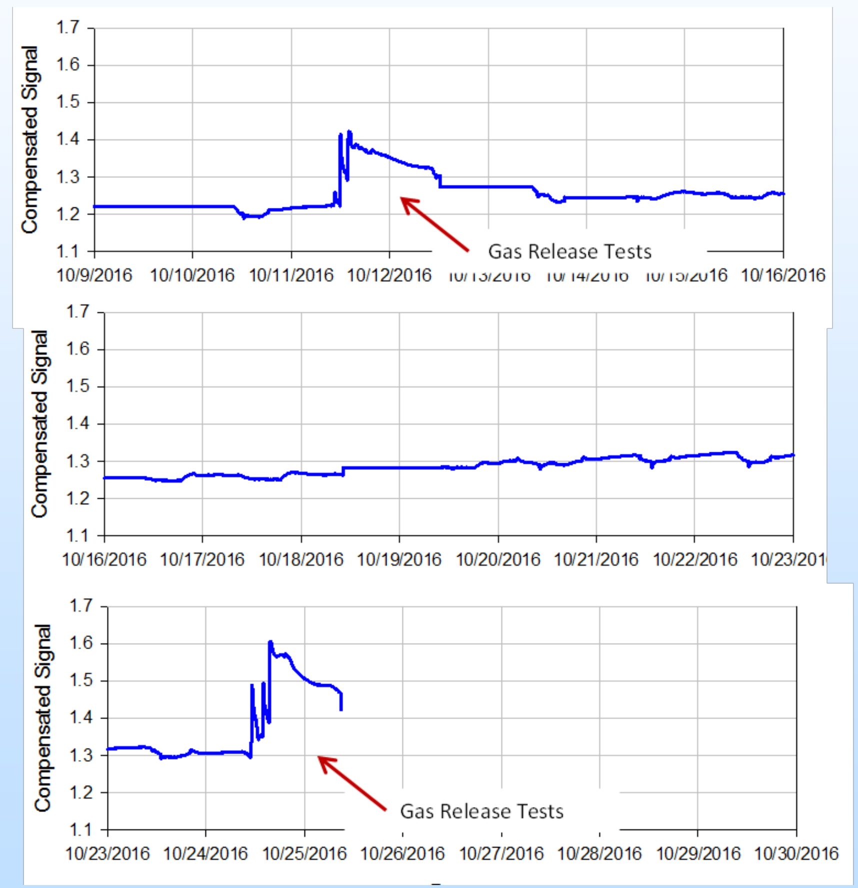
Field Results

- **Sensor responses during the stepwise release tests**

Sensor 1 in BFL2

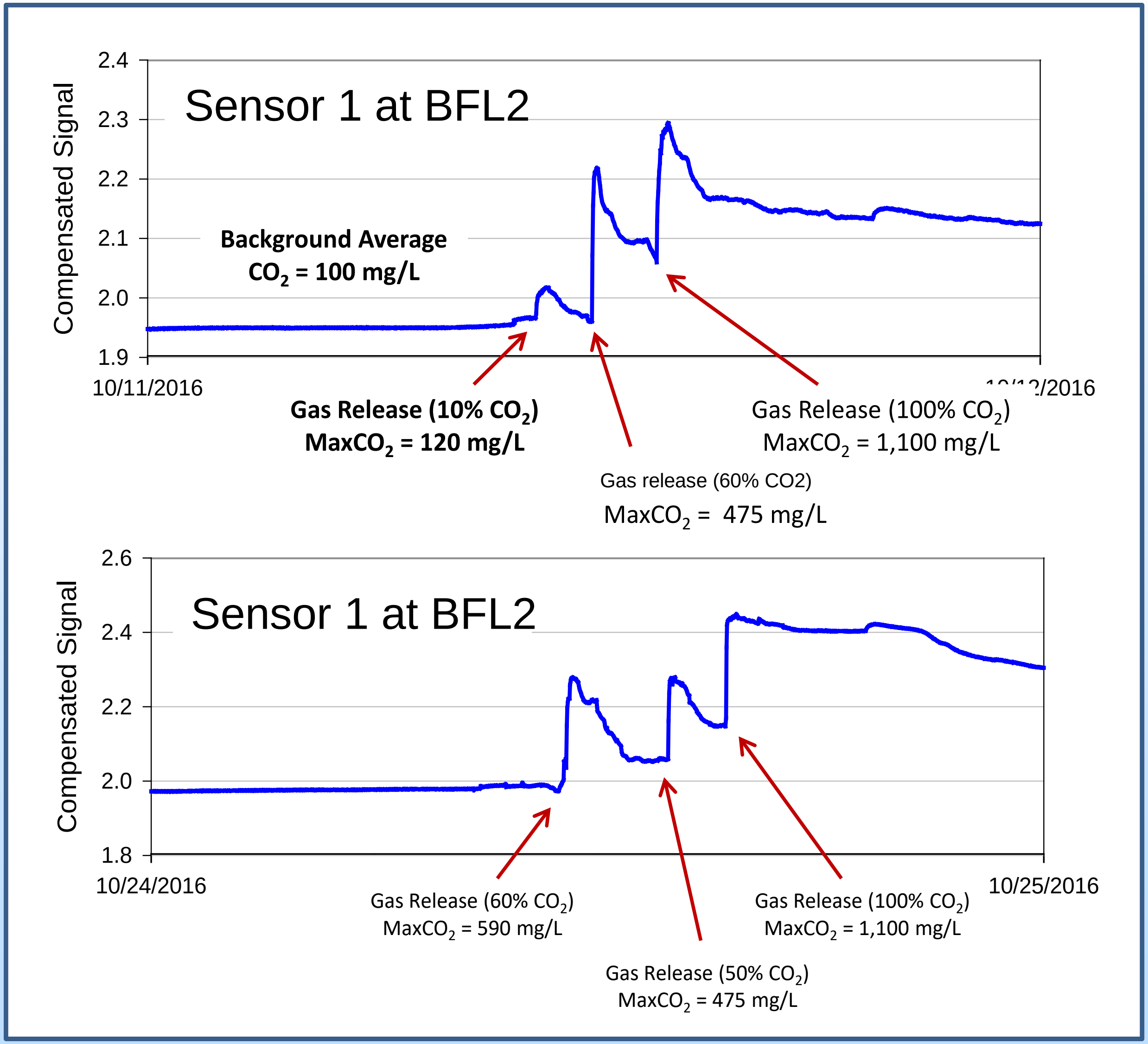


Sensor 2 in BFL2



Field Results

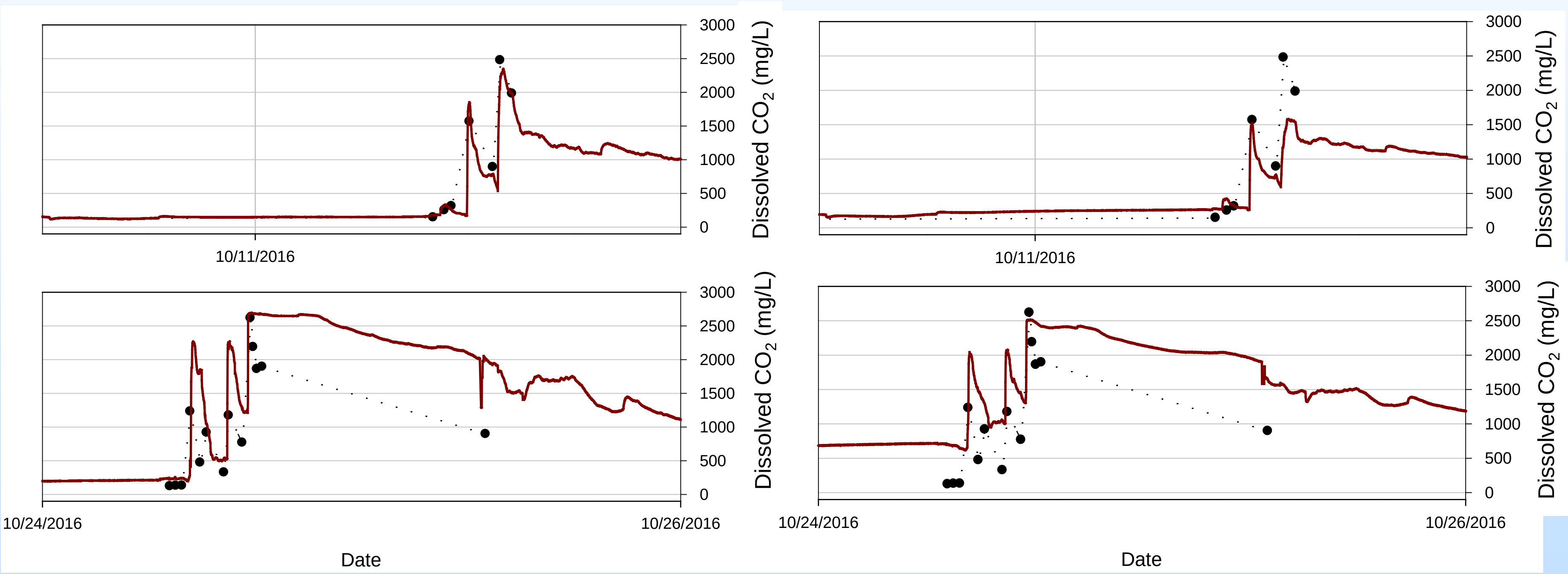
- **Sensor responses during the stepwise release tests**



Field Results

- **Comparison of sensor measurements with the results of the sampling method during the stepwise release tests**

Sensor 1 at BFL2 Sensor 2 at BFL2

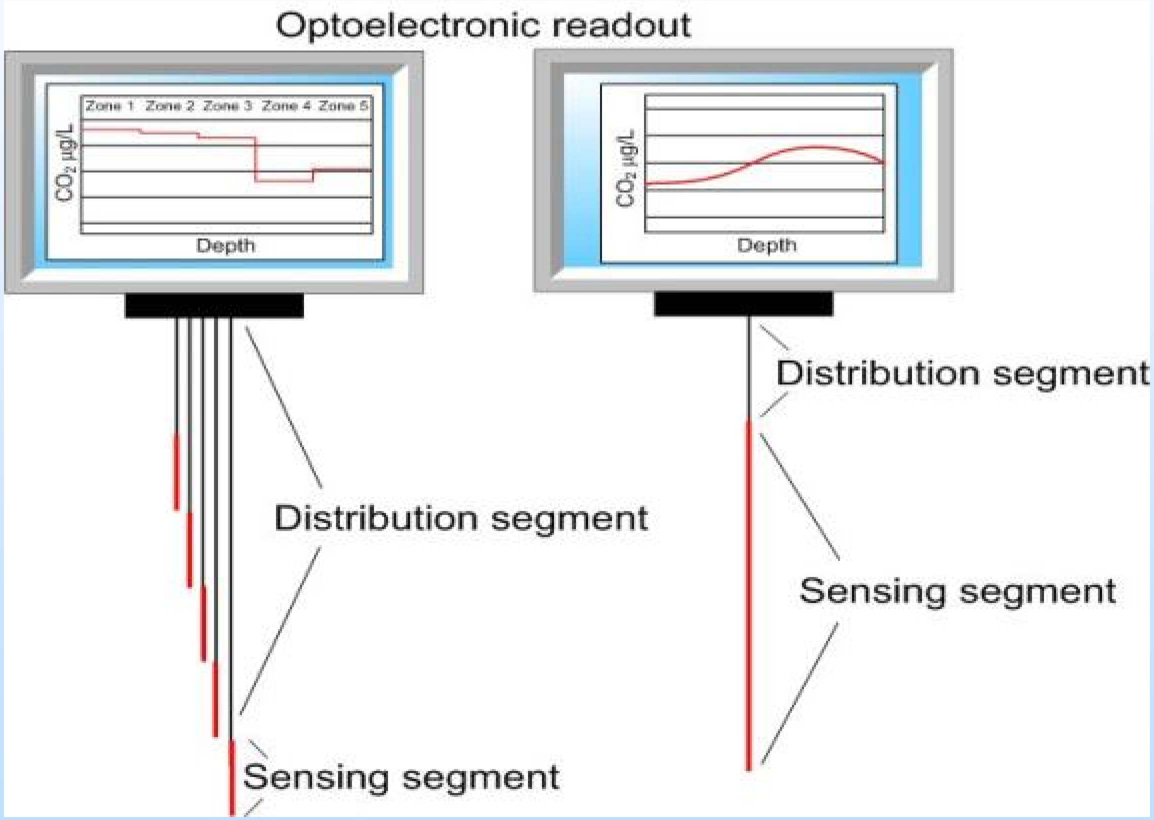


- ➢ Excellent performance detecting small and large gas leaks reaching the aquifer

Assessment of distributed measurements in the context of spatial leakage detection

- **Optical time domain reflectometry (OTDR)**
  - **Zone-by-zone**

Distributed chemical sensor readout: (left) Zone-by-zone integration; (right) OTDR (concentration vs. length)



- **Spatial resolution**
- **Sensitivity**
- **Cable range**
- **System cost**

Assessment of distributed measurements in the context of spatial leakage detection

Spatial resolution

Capability of providing CO_2 readings at different depths

- The OTDR system could provide CO_2 measurement over a depth of 100 m, with a measurement every 5 meters (thus, CO_2 measurements at 20 depths);
- The zone-by-zone would only provide CO_2 readings at four depths.

The OTDR approach provides better spatial resolution of CO_2 concentration than the zone-by-zone approach

Assessment of distributed measurements in the context of spatial leakage detection

Sensitivity

The minimum variation in the CO_2 concentration that can be detected by the instrument.

- The sensitivity of the zone-by-zone sensor can be from 10 to 100 times better than that of the OTDR instruments.
- The signal-to-noise ratio is more favorable in the zone-by-zone approach, which results in much better sensitivity.

Assessment of distributed measurements in the context of spatial leakage detection

Cable range

The length of the distribution segment plus the length of the sensing segment, which determines the maximum depth the sensor cable can reach;

- We consider a sensor range of 1,000 m for the OTDR and 3,000 m for the zone-by-zone approach feasible;
- The cable range is longer for the zone-by-zone approach than for the OTDR approach.

Assessment of distributed measurements in the context of spatial leakage detection

System cost

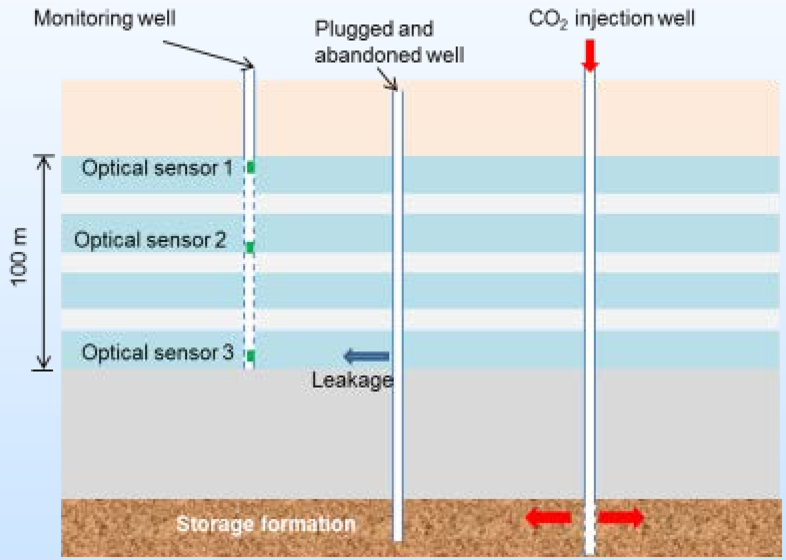
The total cost of the instrumentation, including the optoelectronic instruments and the sensor cable

- The fabrication cost of the RICO2M for the zone-by-zone units is about 55% to 65% for the OTDR operation.

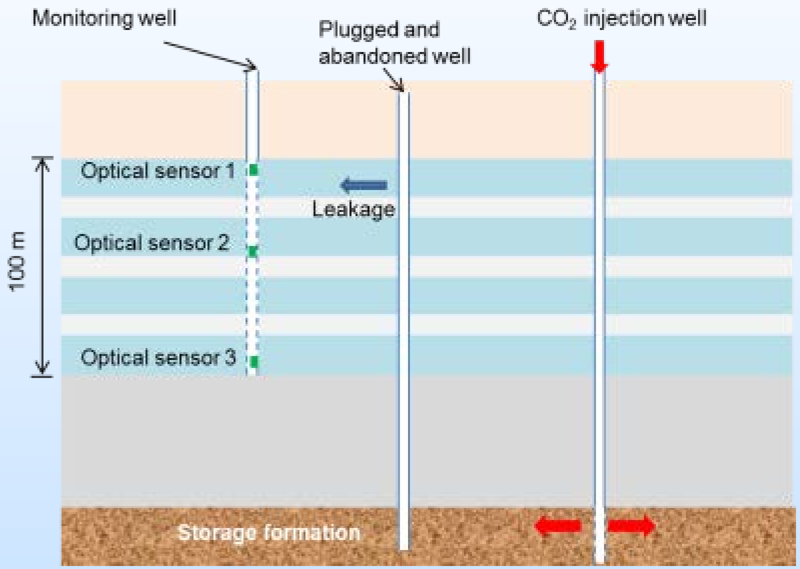
- The OTDR method is significantly more costly because quality lasers and faster electronics (operating in the MHz) are needed, in comparison to the LEDs and low frequency of operation (in the kHz) for the zone-by-zone method.

Assessment of distributed measurements in the context of spatial leakage detection

Numerical assessment of the zone-by-zone approach for leakage detection in a monitoring well



Leakage scenario 1



Leakage scenario 3

As long as CO_2 is leaked into the monitoring well, the leakage signals can be captured by at least one of the three sensing segements.

Accomplishments to Date

- Assembled and deployed in the field the second and third generation of the RICO2M system.

- Sensors for dissolved CO_2 have been tested in the field for over a year and progressively improved. The capability of the CO_2 sensors to detect leaks of CO_2 reaching groundwater has been clearly demonstrated. However, continuous quantification of CO_2 has not been achieved.

- An assessment of the pros and cons of distributed measurements (OTDR) compared with average measurements (Zone-by-zone) in the context of spatial leakage detection has been conducted.

- Evaluation of deployment strategies in different scenarios, with associated costs for RICOM sensor technology and for classic water analysis campaigns has been conducted.

Acknowledgments

NETL Department of Energy

Joshua Hull

- The following are the supplementary slides

Project Overview

Goals and Objectives

- **General Objective:**

  To design, build and validate a cost-effective Intelligent Real-time In-situ CO_2 Network (RICO_2M Net) for Monitoring Geochemical Parameters with Highly Sensitive and Accurate Detection of CO_2 in Sensitive Groundwater in Carbon Capture, Utilization, and Storage (CCUS).

  Unlike other surface- or subsurface-deployed sensors, the optical cable sensor elements of RICO_2M Net are capable of covering large areas and detecting small changes from background concentrations in the subsurface.

Project Overview

Goals and Objectives

The following phases and specific objectives have been established.

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

Objective 1. Manufacture long (hundreds of meters) fiber optic sensors for monitoring pH in groundwater (measurement range from pH 4 to pH 10, with 0.1 pH precision).

Objective 2. Demonstrate and fabricate fiber optic sensor prototypes for salinity monitoring (measurement range from 0 to 10,000 mg/L NaCl).

Objective 3. Assemble a monitoring system incorporating fiber optic distributed or quasi-distributed sensors for dissolved CO_2, pH, total inorganic carbon (TIC), salinity, and temperature.

Objective 4. Demonstrate CO_2 measurements in the laboratory in drinking water and complex aqueous matrices, with high accuracy at low CO_2 concentrations (limit of detection of 0.1 mg/L of dissolved CO_2 or better, precision of 0.1 mg/L or better and accuracy of 0.3. mg/L or better).

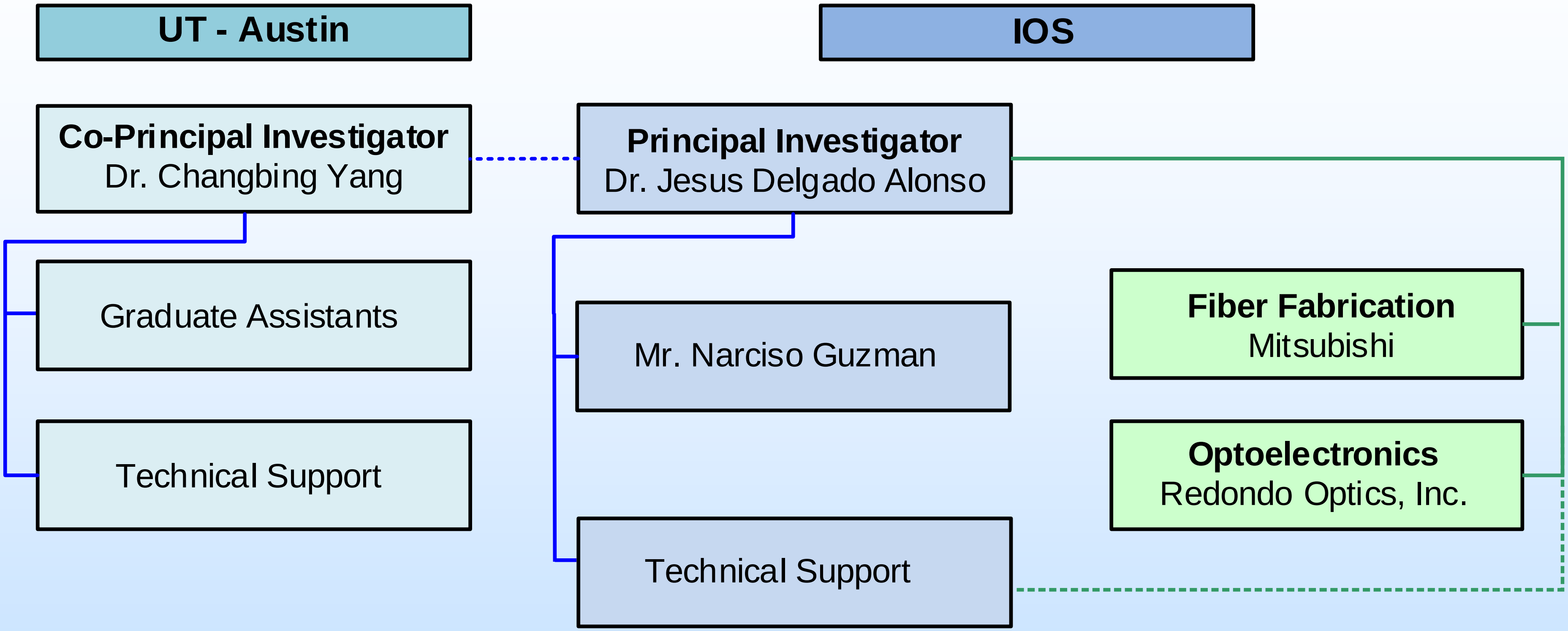
- ***PHASE II*: Deploy and validate Intelligent Real-time In-situ Network (RICO_2M Net) for highly sensitive and accurate detection of CO_2 in groundwater.**

Objective 5. Design and fabricate monitoring network.

Objective 6. Deploy the multi-parameter system, and perform continuous monitoring of geochemical parameters.

Objective 7. Demonstrate results from the novel multi-parameter system comparable with those of established monitoring techniques.

Organization Chart



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

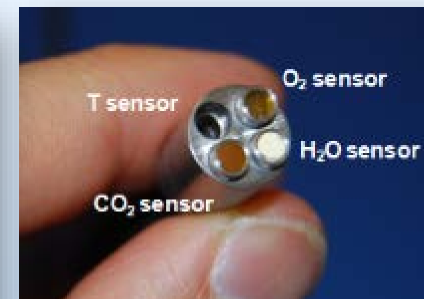
Intelligent Optical Systems, Inc.

Maven Biotechnologies Polaron Reader™


Laser Ultrasonic Noncontact Structural Inspection

- Founded in 1998
  - Spun-off from Physical Optics Corporation
- Focus areas:
  - Chemical optical-based sensors
  - Rapid diagnostic assays (LFAs)
- Several million dollars invested in equipment
- 11,500 square foot facility in Torrance, CA
- Several spin-off companies with >$22M in private funding
- Commercial technology developed or acquired
  - Laser ultrasound for non-destructive examination
  - Light-emitting diode incapacitator for law enforcement
  - Biochip reader

Cell Phone-based LFA Reader



Multi Sensor Probe


LFA Multi-Panel Reader

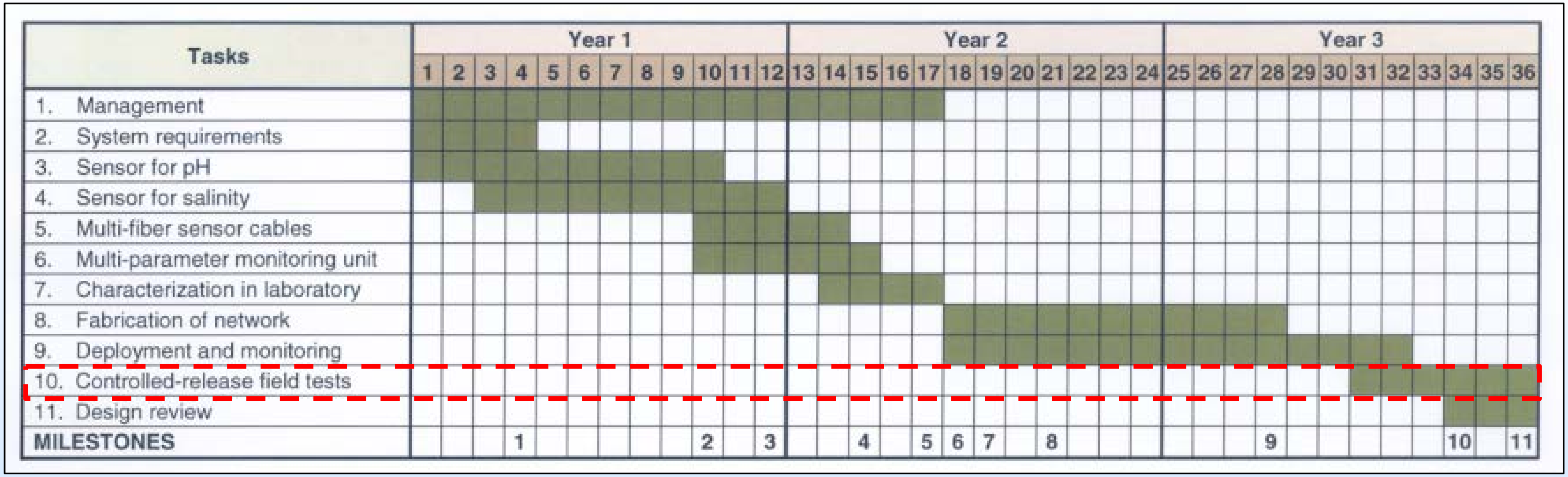

DICAST® Chemical Sensor Cables

Benefit to the Program

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

- Benefits Statement:
  - Develop a **sensor network based on distributed fiber optic sensors for in-situ, real-time monitoring of geochemical parameters in groundwater.**
  - Capable of covering large areas and measuring 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).

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.

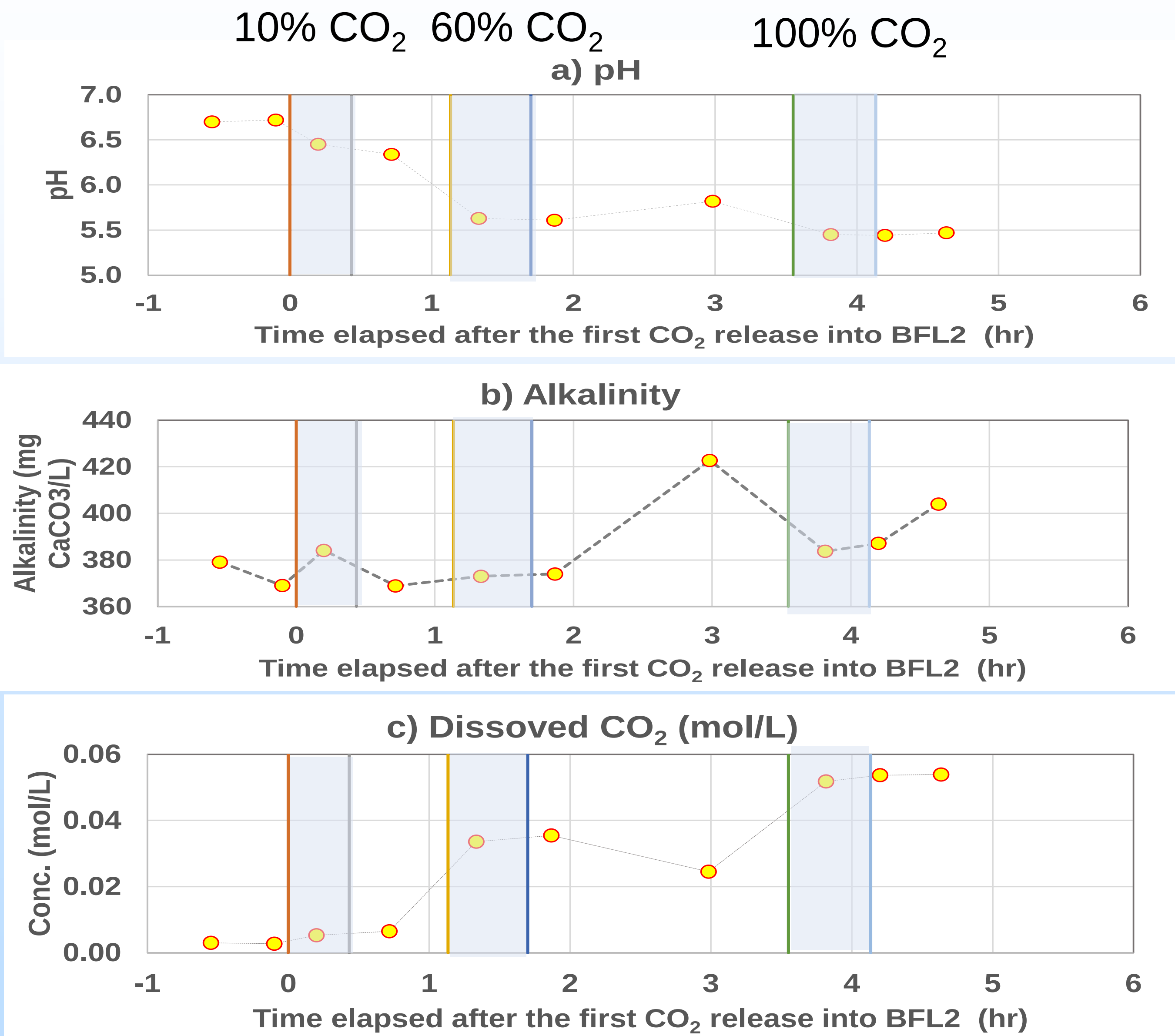
Milestone 9. Revised multi-parameter monitoring systems fabricated and deployed.

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

Milestone 11. System design reviewed.

Testing results (3)

Stepwise CO_2 release tests at the week of Oct. 10, 2016 in BFL1



Bibliography

– List peer reviewed publications generated from the project per the format of the examples below.

- Journal, one author:
  - Gaus, I., 2010, Role and impact of CO2-rock interactions during CO2 storage in sedimentary rocks: International Journal of Greenhouse Gas Control, v. 4, p. 73-89, available at: XXXXXXX.com.
- Journal, multiple authors:
  - MacQuarrie, K., and Mayer, K.U., 2005, Reactive transport modeling in fractured rock: A state-of-the-science review. Earth Science Reviews, v. 72, p. 189-227, available at: XXXXXXX.com.
- Publication:
  - Bethke, C.M., 1996, Geochemical reaction modeling, concepts and applications: New York, Oxford University Press, 397 p.