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

Project Number DE-FE0012706

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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

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

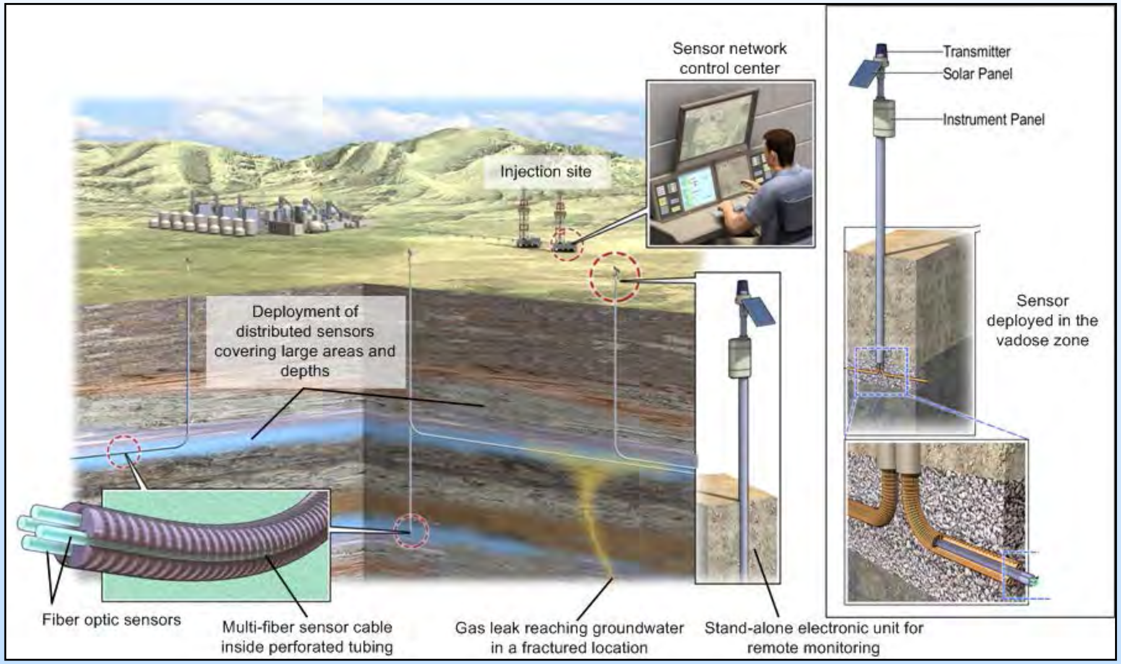
  Validation in the field, and commercial demonstration.

Technology

Distributed Intrinsic Fiber Optic Chemical Sensors

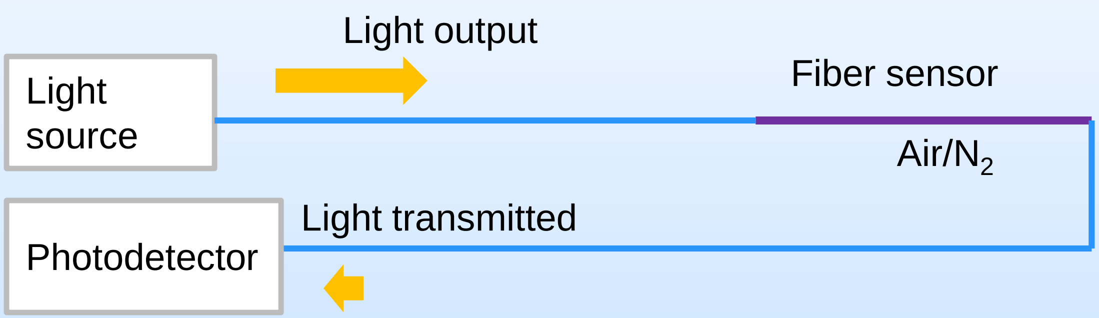
Unique Characteristics

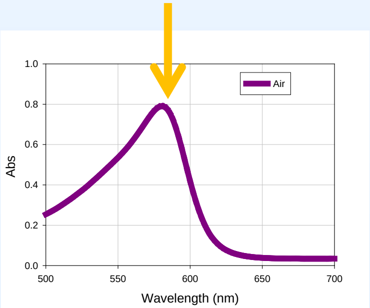
- The entire length of the fiber is a sensor
- Direct detection of dissolved CO_2
- A single cable may include CO_2, pH, salinity, and temperature sensors.



Technology

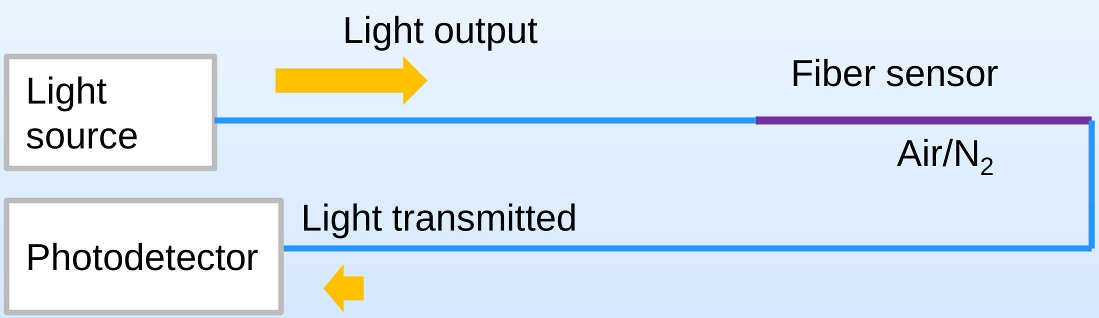
- An optical fiber coated with a polymer cladding containing a colorimetric indicator, which absorbs light at a particular wavelength.
- A light source is placed at one end of the fiber and a photodetector at the other end, and light transmission is measured.

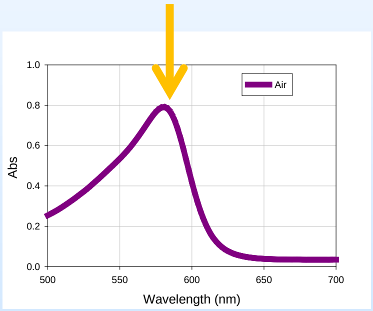


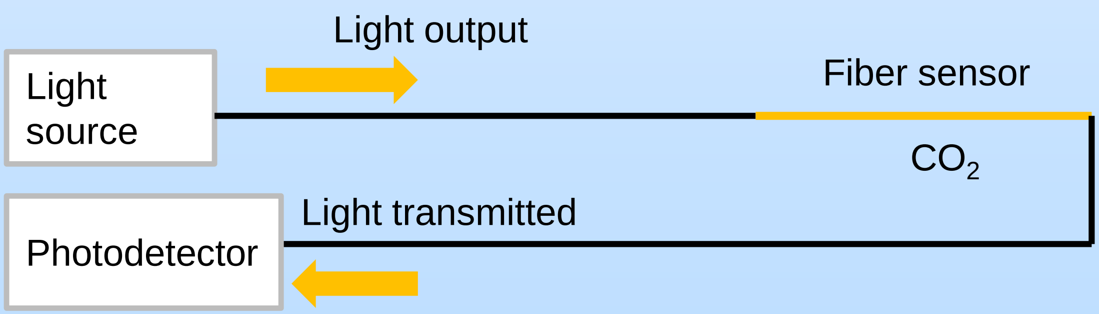


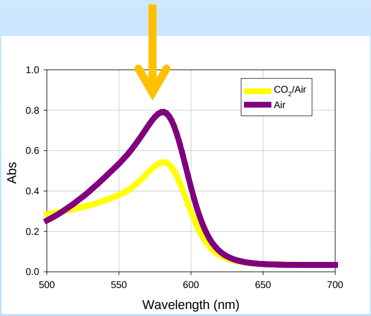
Technology

- The coating color varies with the analyte (pH, CO_2…)
- The light transmitted through the fiber at wavelengths absorbed by the indicator varies with the concentration of analyte (pH, CO_2…).









Technology

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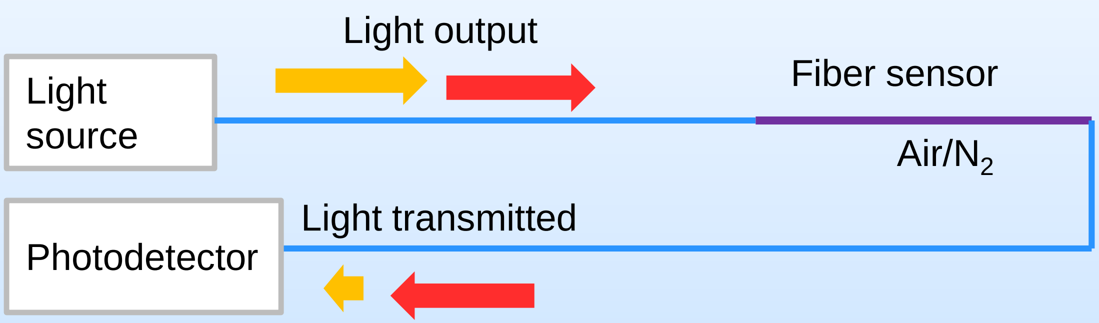

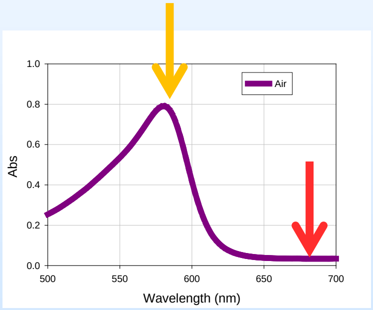

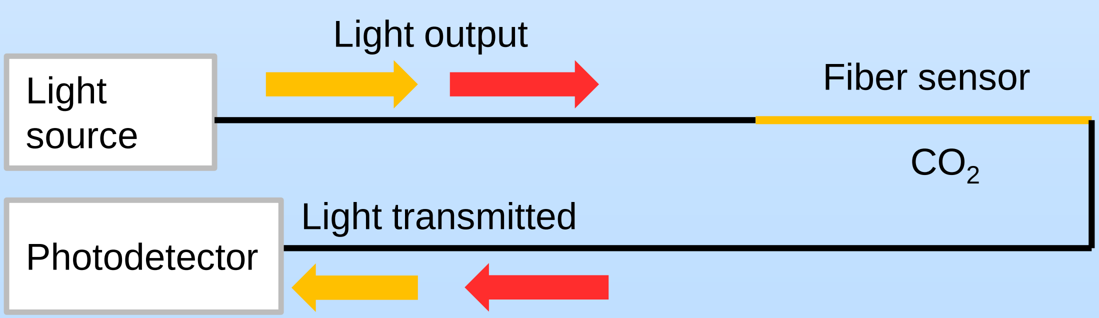

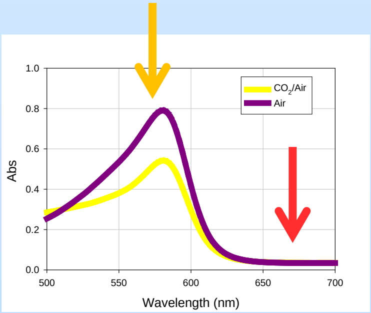

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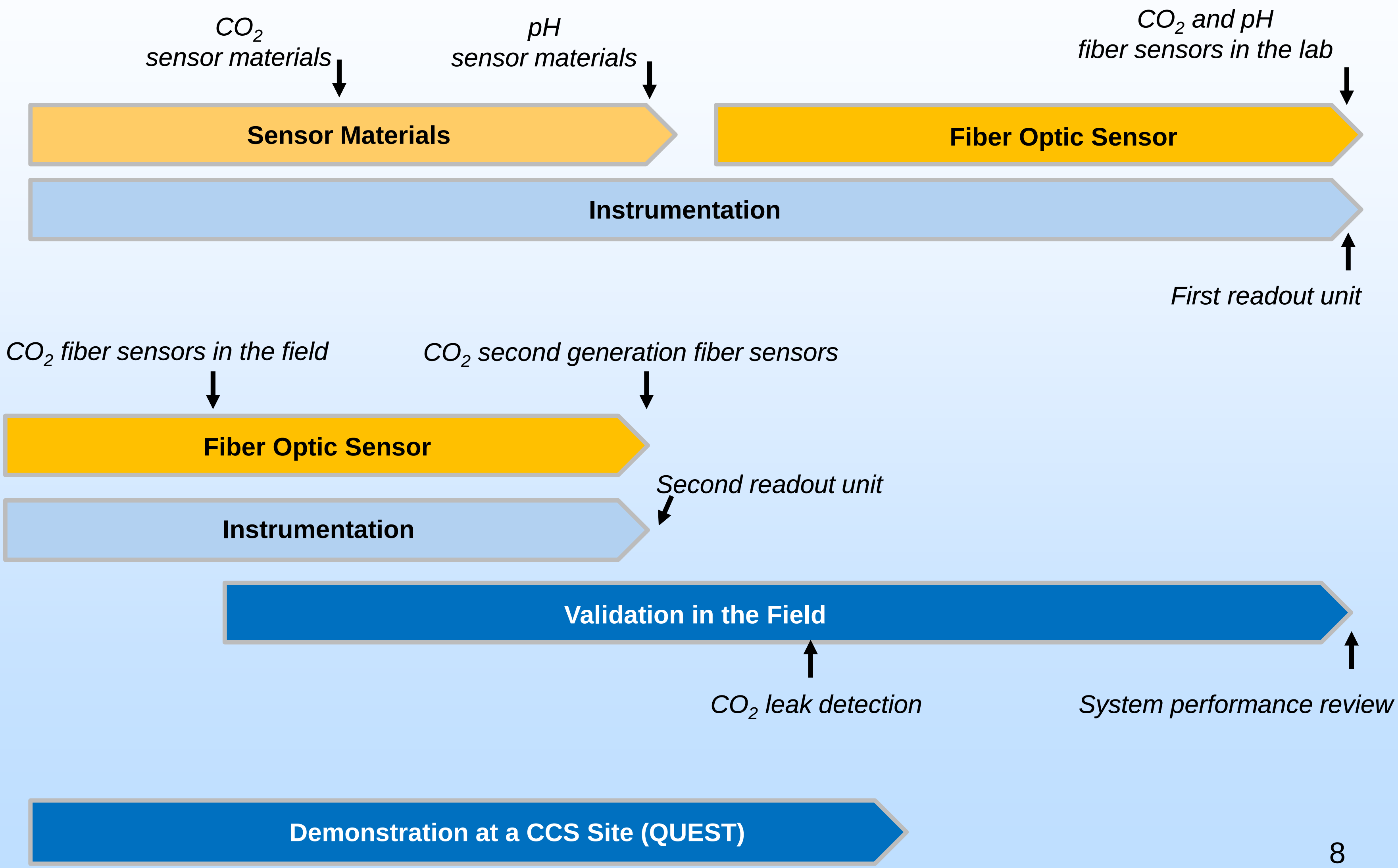
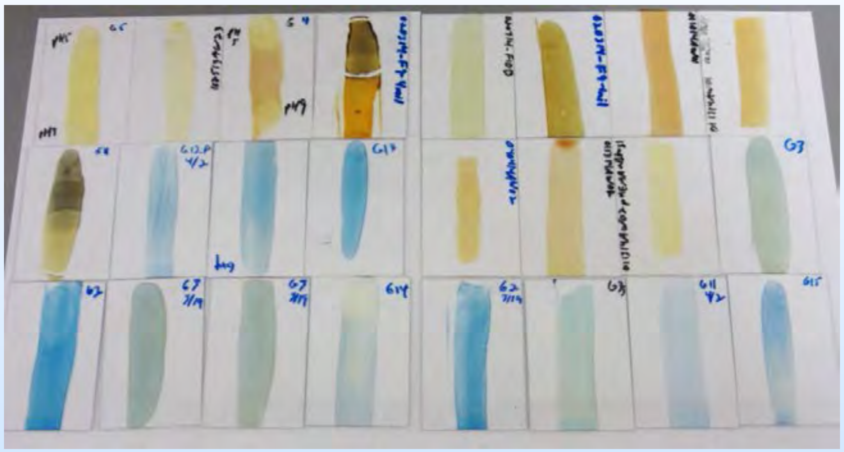
Four Years of Sensor Development

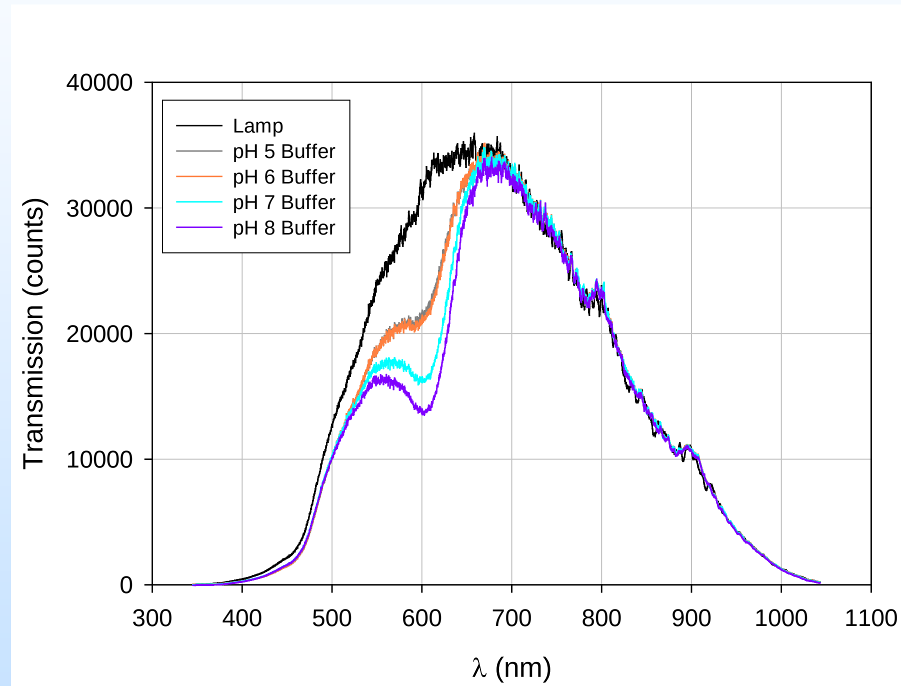


Four Years of Sensor Development

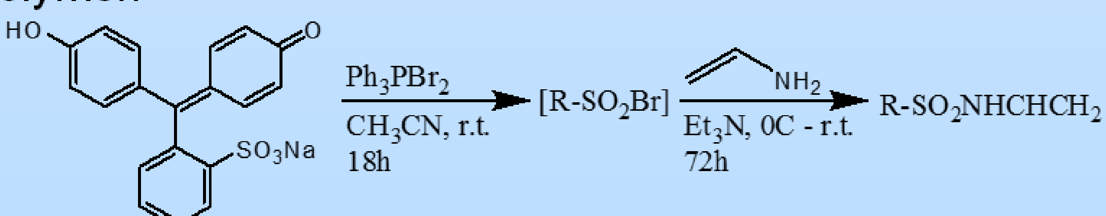
Demonstration in the lab

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.

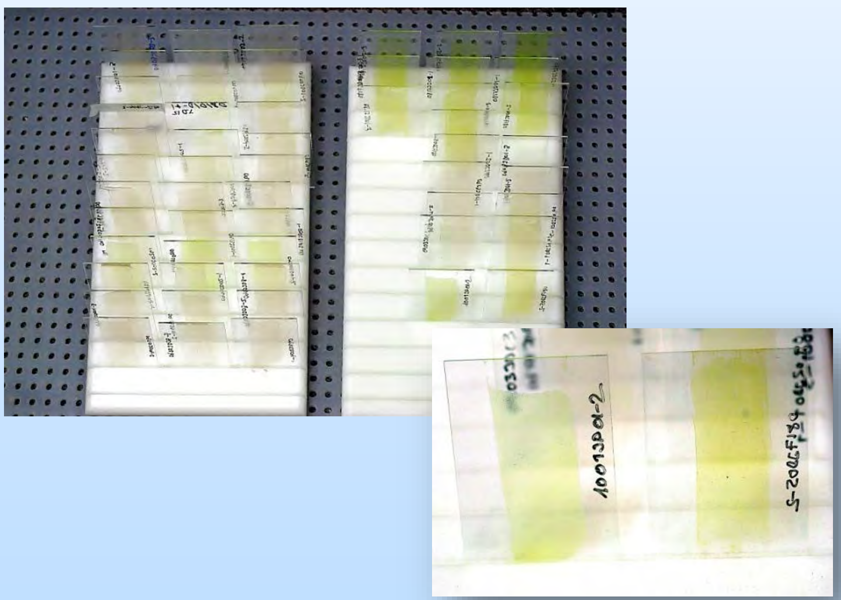


Four Years of Sensor Development

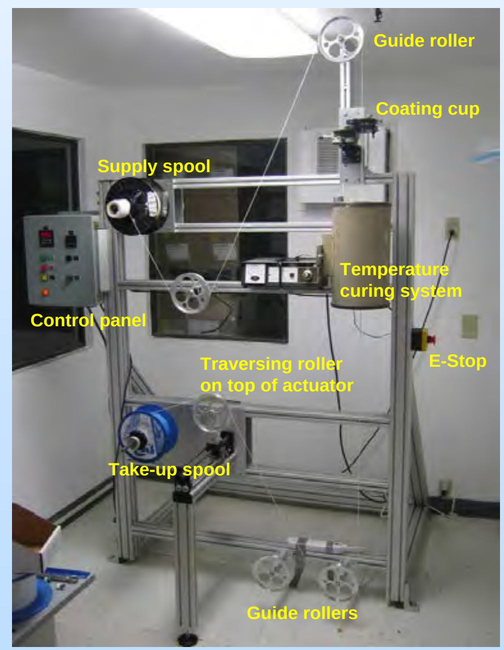
Demonstration in the lab

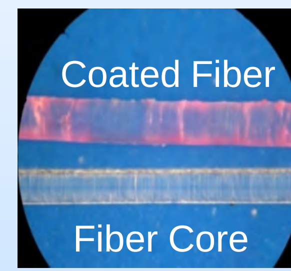
Fiber Optic Sensor: Glass-core fiber coated with sensitive materials

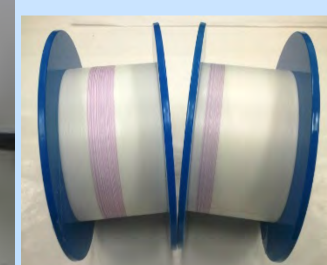
Cladding material coated onto glass slides



Prototypes of optical fibers fabricated at IOS





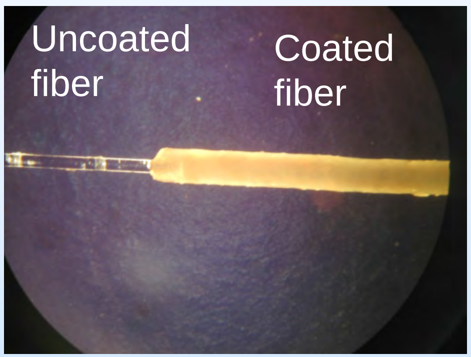


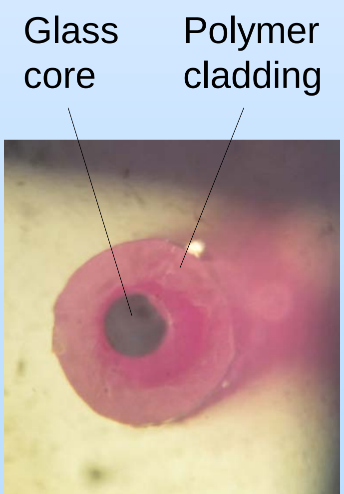
Four Years of Sensor Development

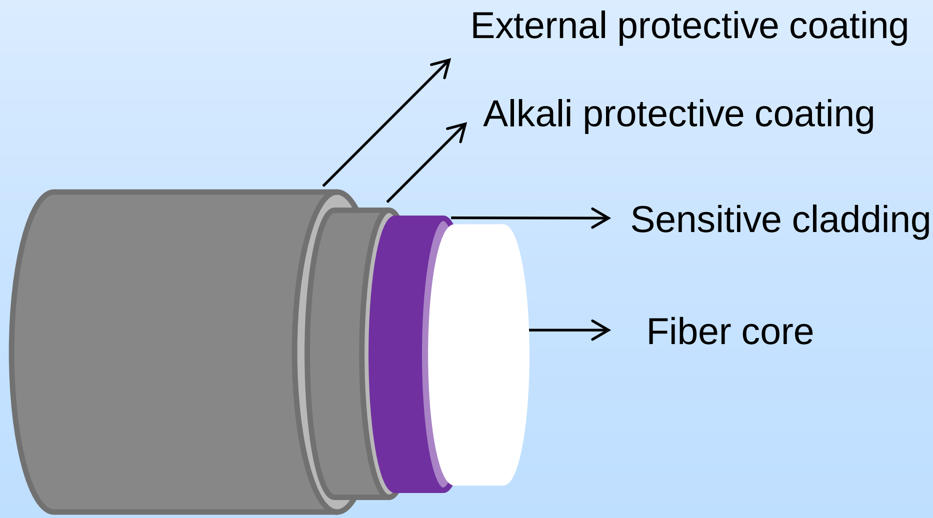
Demonstration in the lab

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



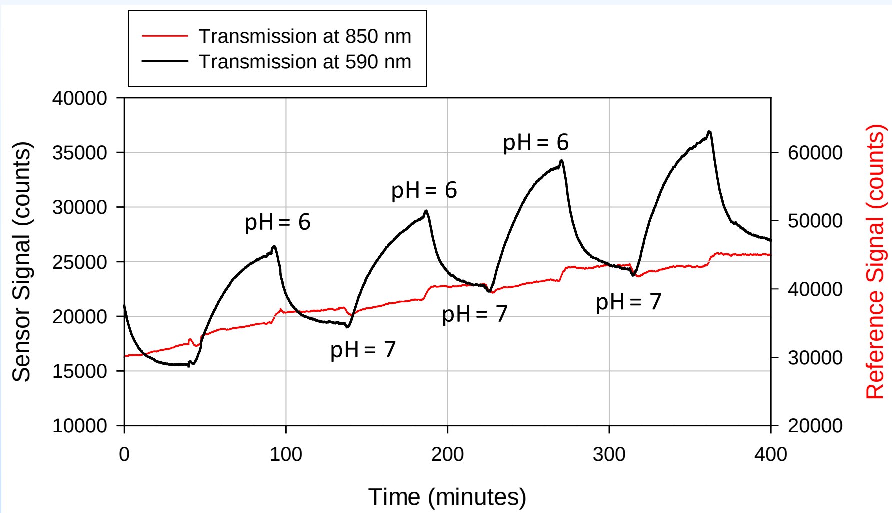


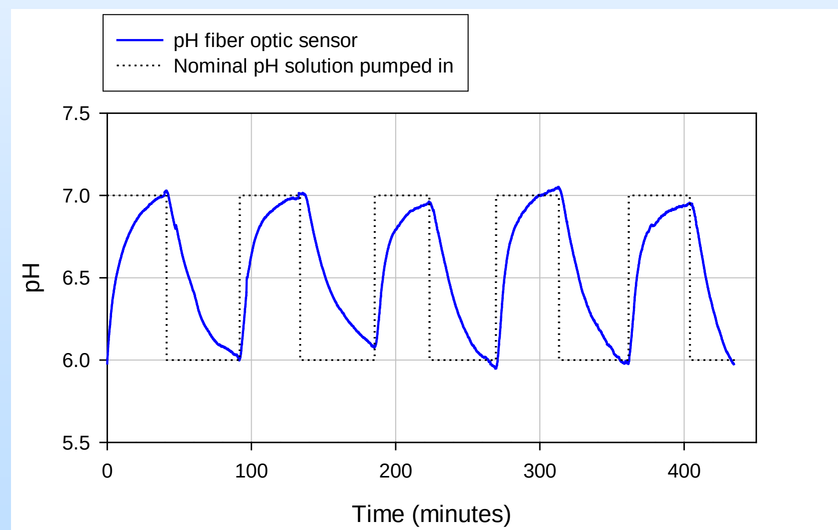


Four Years of Sensor Development

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

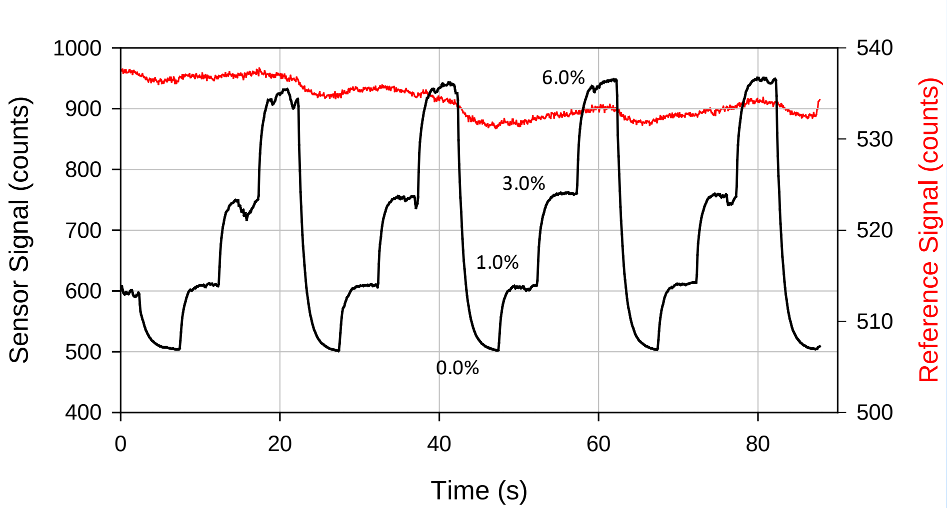
Temperature range: 5°C to 30°C

Temperature compensation: 1.4% / °C

Four Years of Sensor Development

Demonstration in the lab

Fiber Optic Sensor for CO_2: Analytical characterization



- Testing
- Cladding material reformulation
- Fiber fabrication protocol review

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

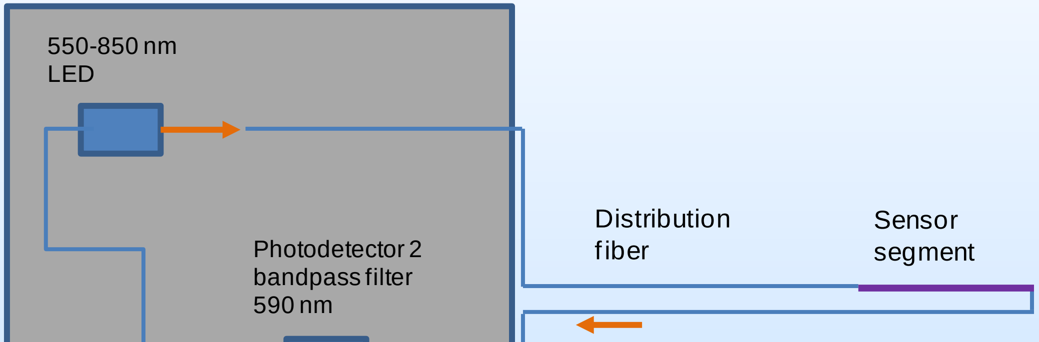
Four Years of Sensor Development

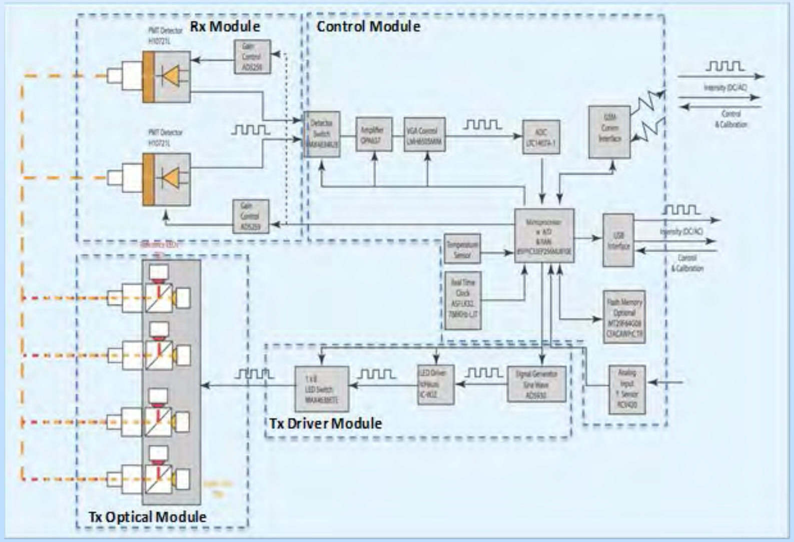
Demonstration in the lab

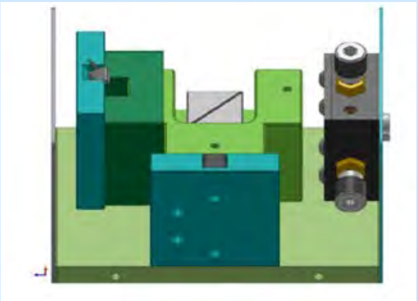
Instrument Development

- High level design
- Detailed hardware and software design

Dual Photodetector System





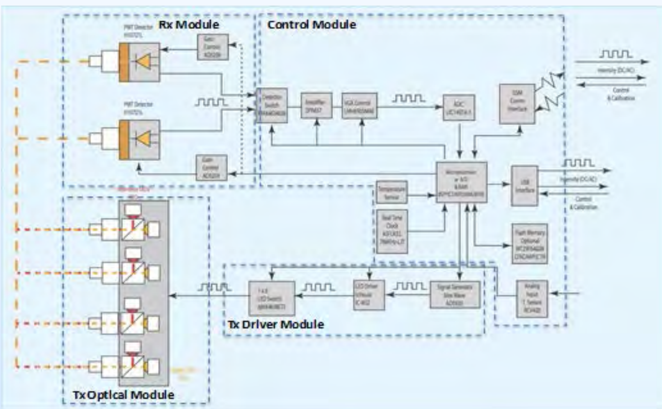


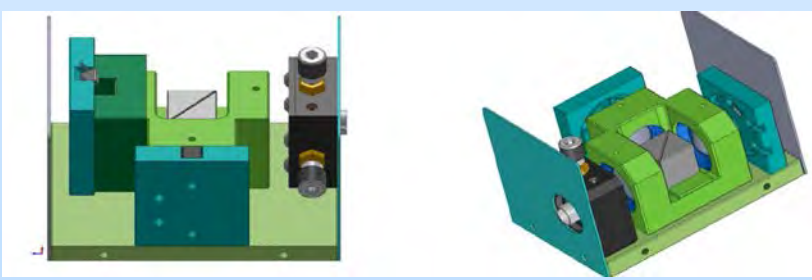
Four Years of Sensor Development

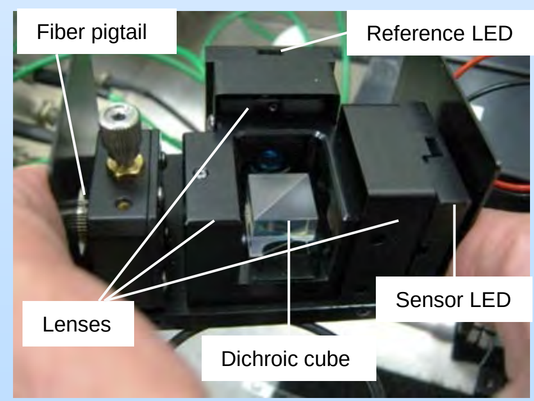
Demonstration in the lab

Instrument Development

- PCB design, fabrication, and assembly
- Optical module design and fabrication







Four Years of Sensor Development

Demonstration in the lab

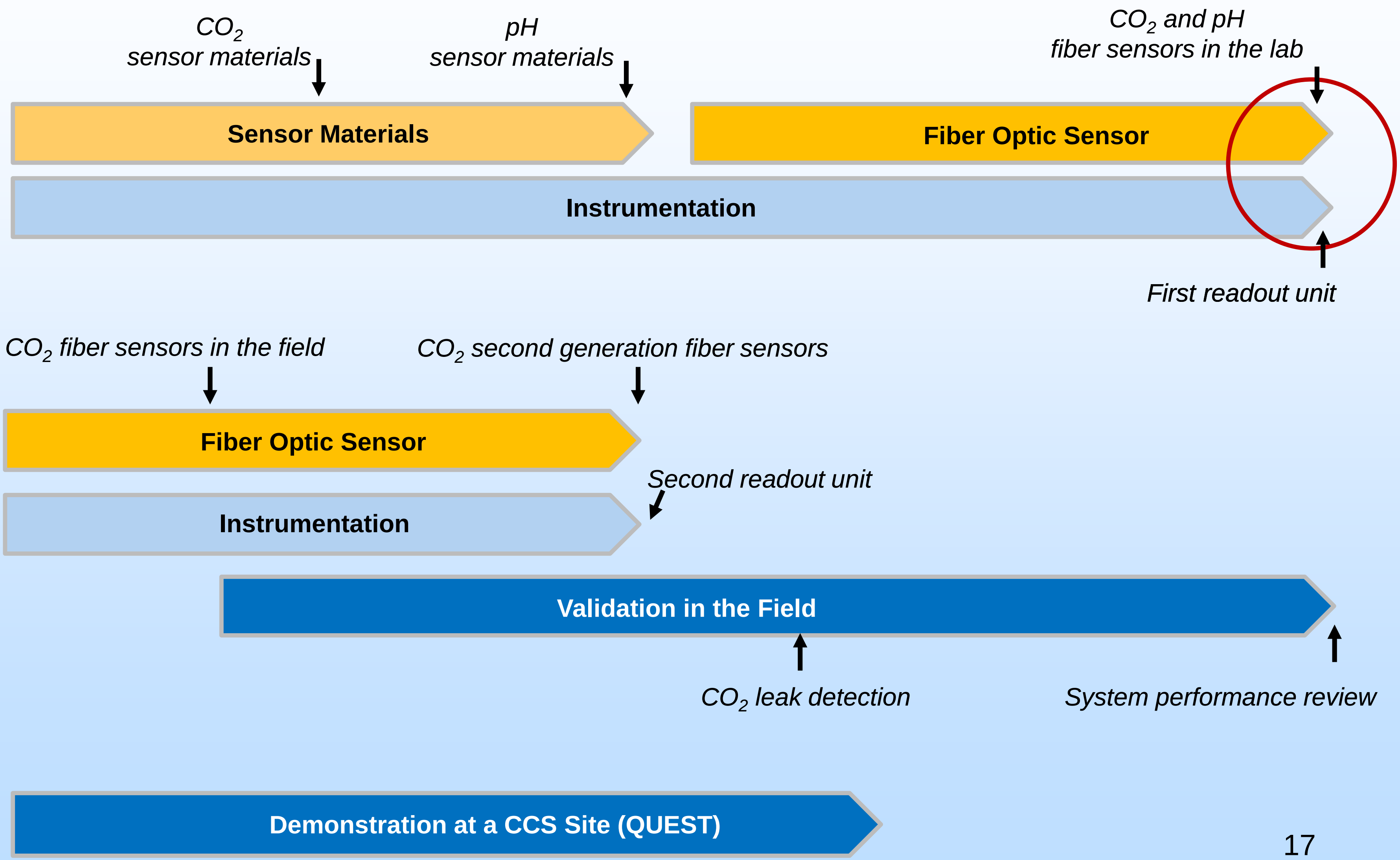
Demonstrator

- System integration
- Testing
- Design review

First Generation

Second Generation
Series fabrication

Four Years of Sensor Development



Four Years of Sensor Development

Validation in the field

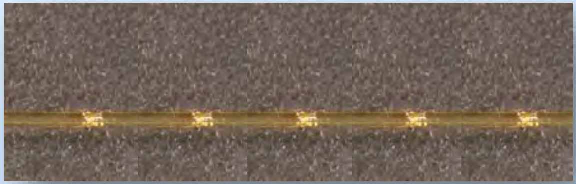
Sensor Probe Fabrication: Protection for fiber sensor

- 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

Multi-well optical fiber



Wells filled with dye-doped polymer

- 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

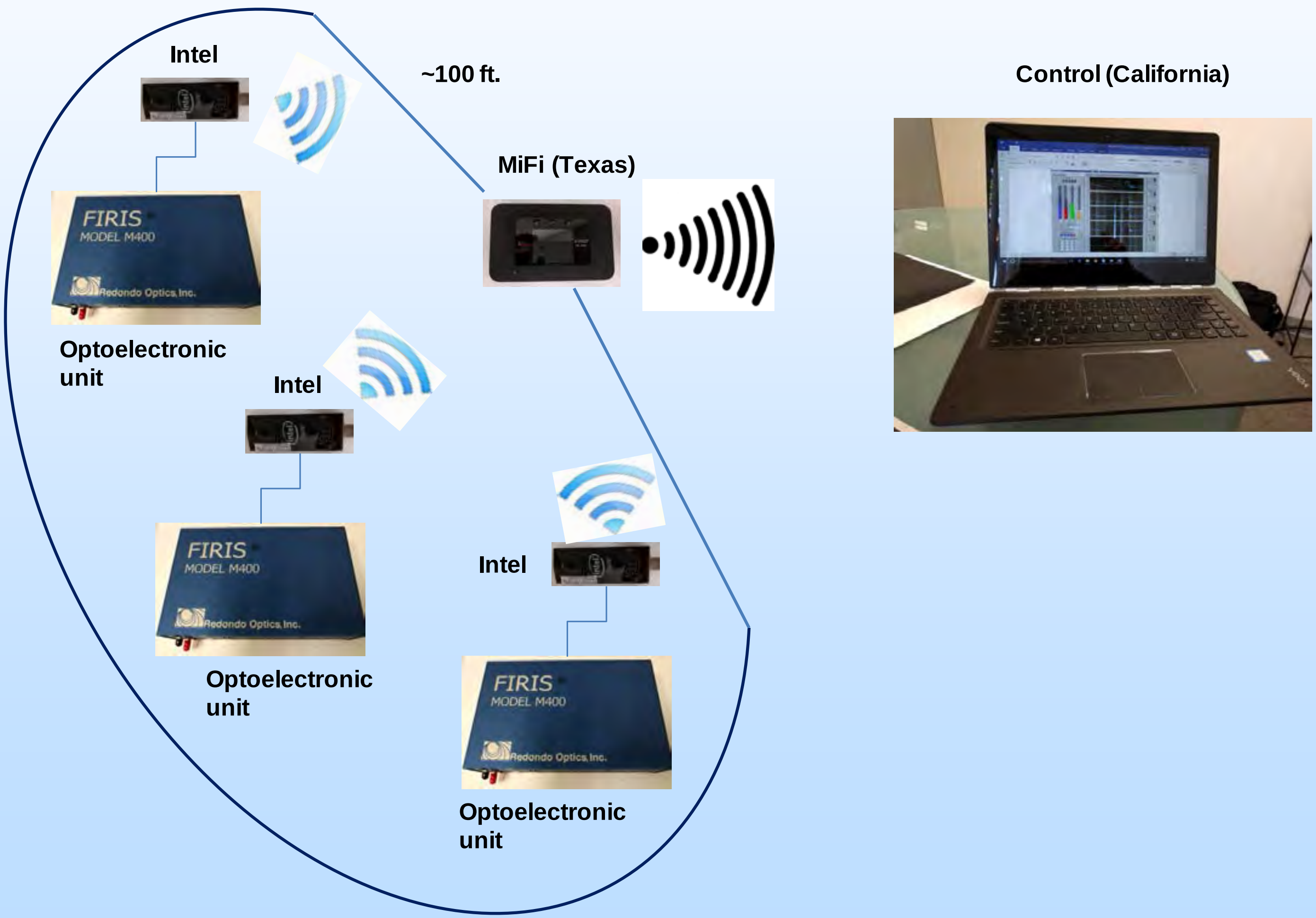
RICO2M v3.0 PN005

Chassis integrates temperature control module.

Four Years of Sensor Development

Validation in the field

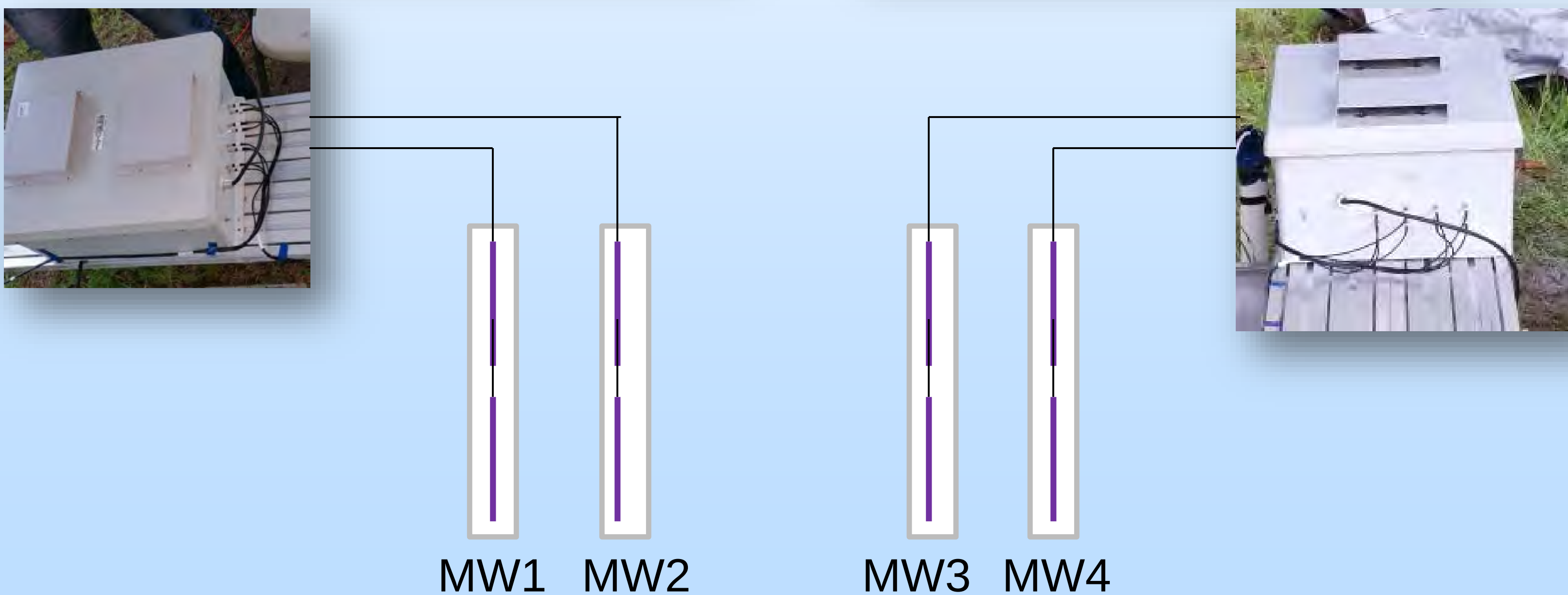
Data Storage and Remote Communication



Four Years of Sensor Development

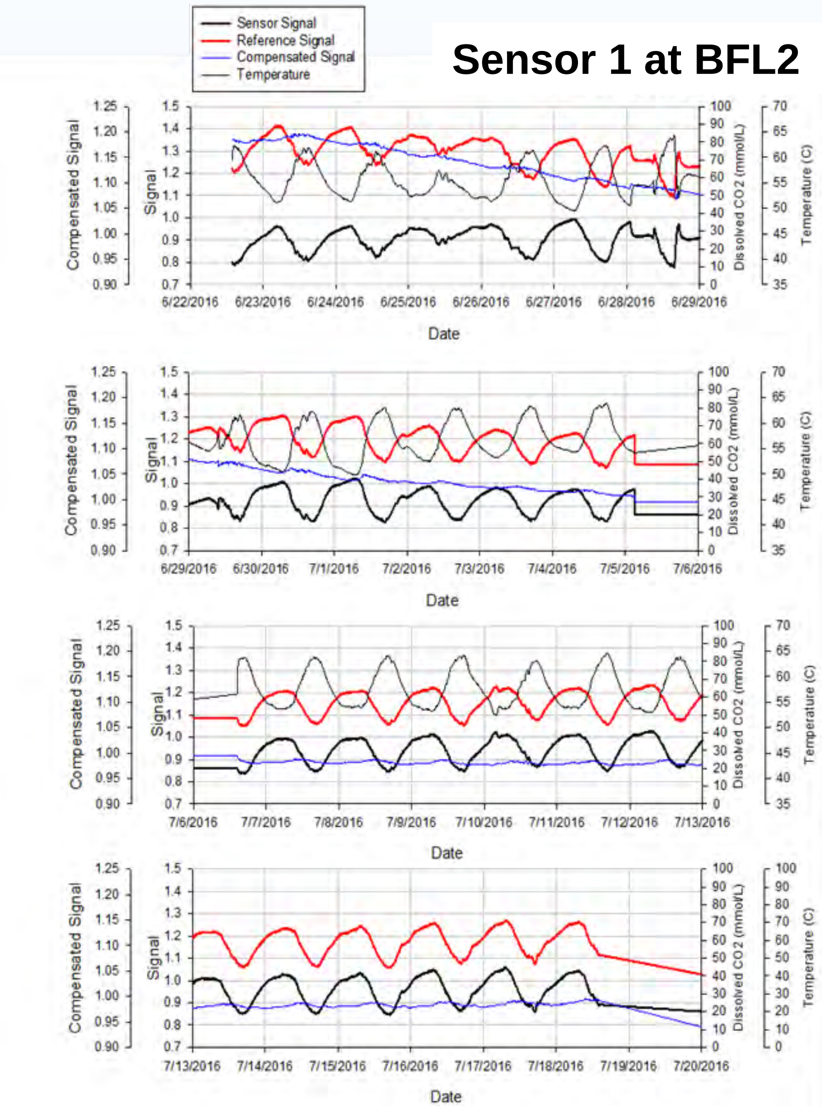
Validation in the field

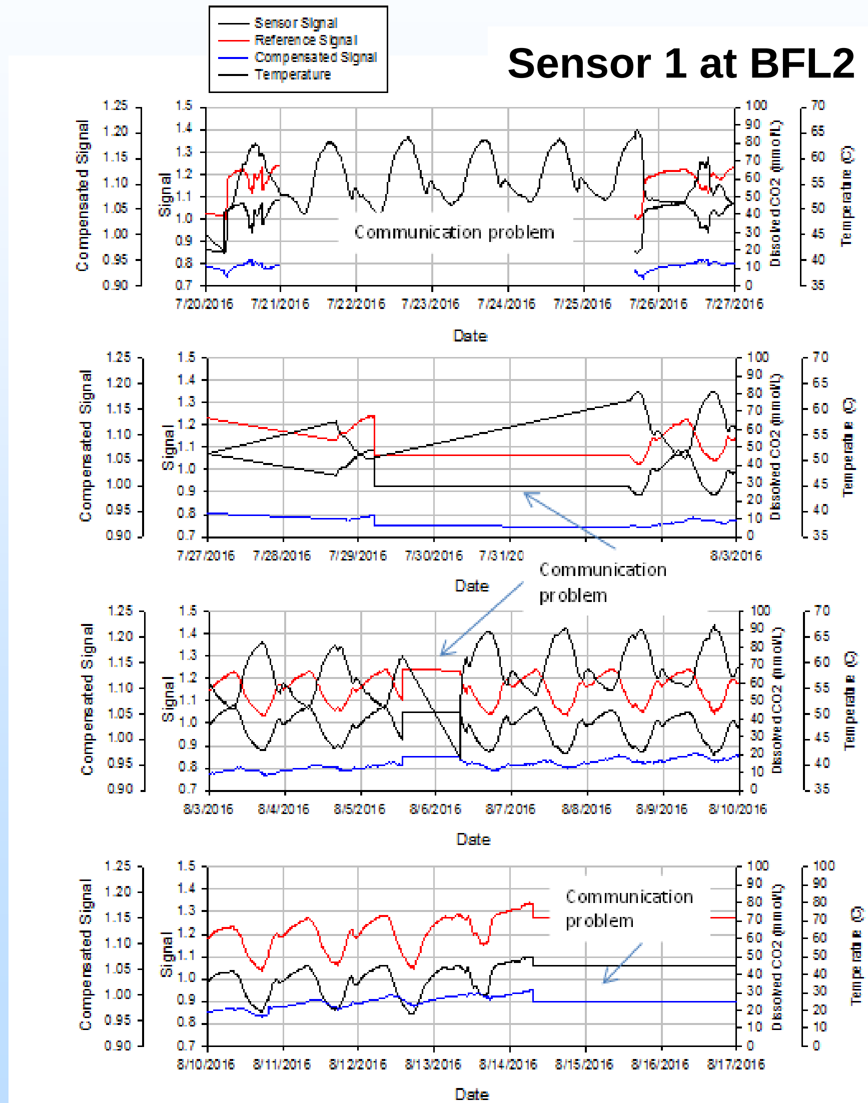
System Deployment and Data Collection



Four Years of Sensor Development

Validation in the field

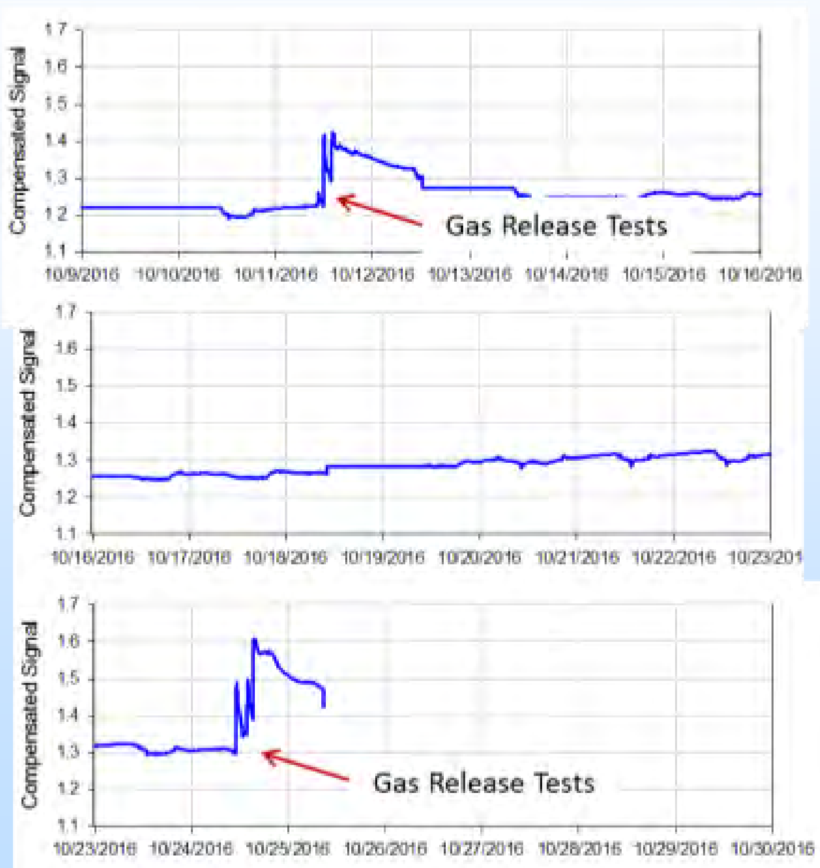




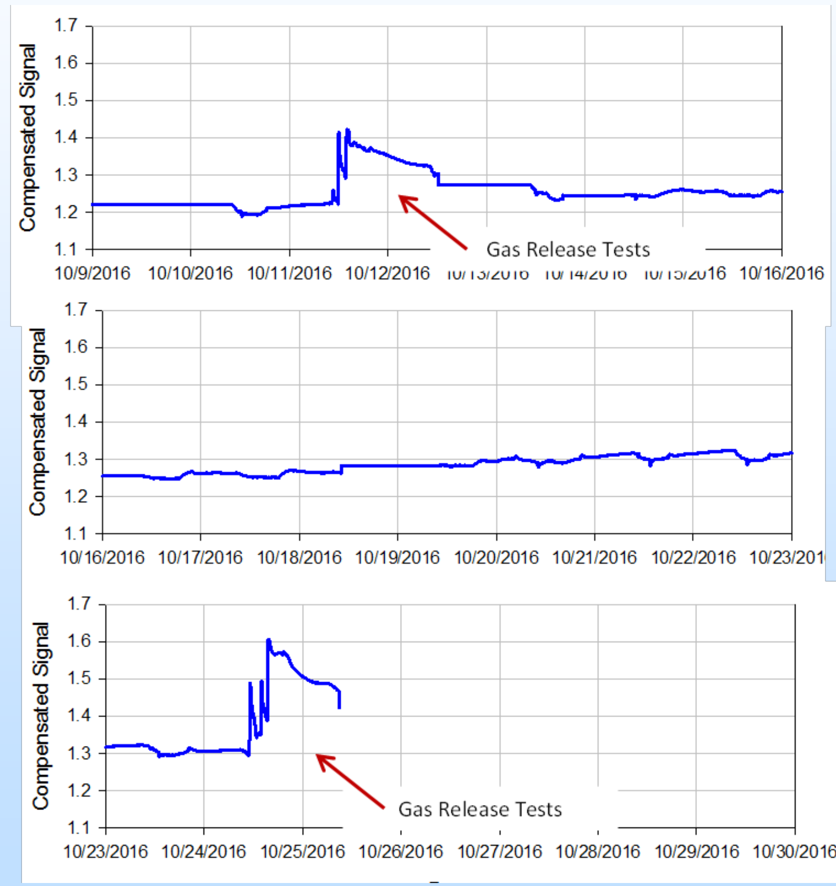
Four Years of Sensor Development

Validation in the field

Sensor 1 at BFL2

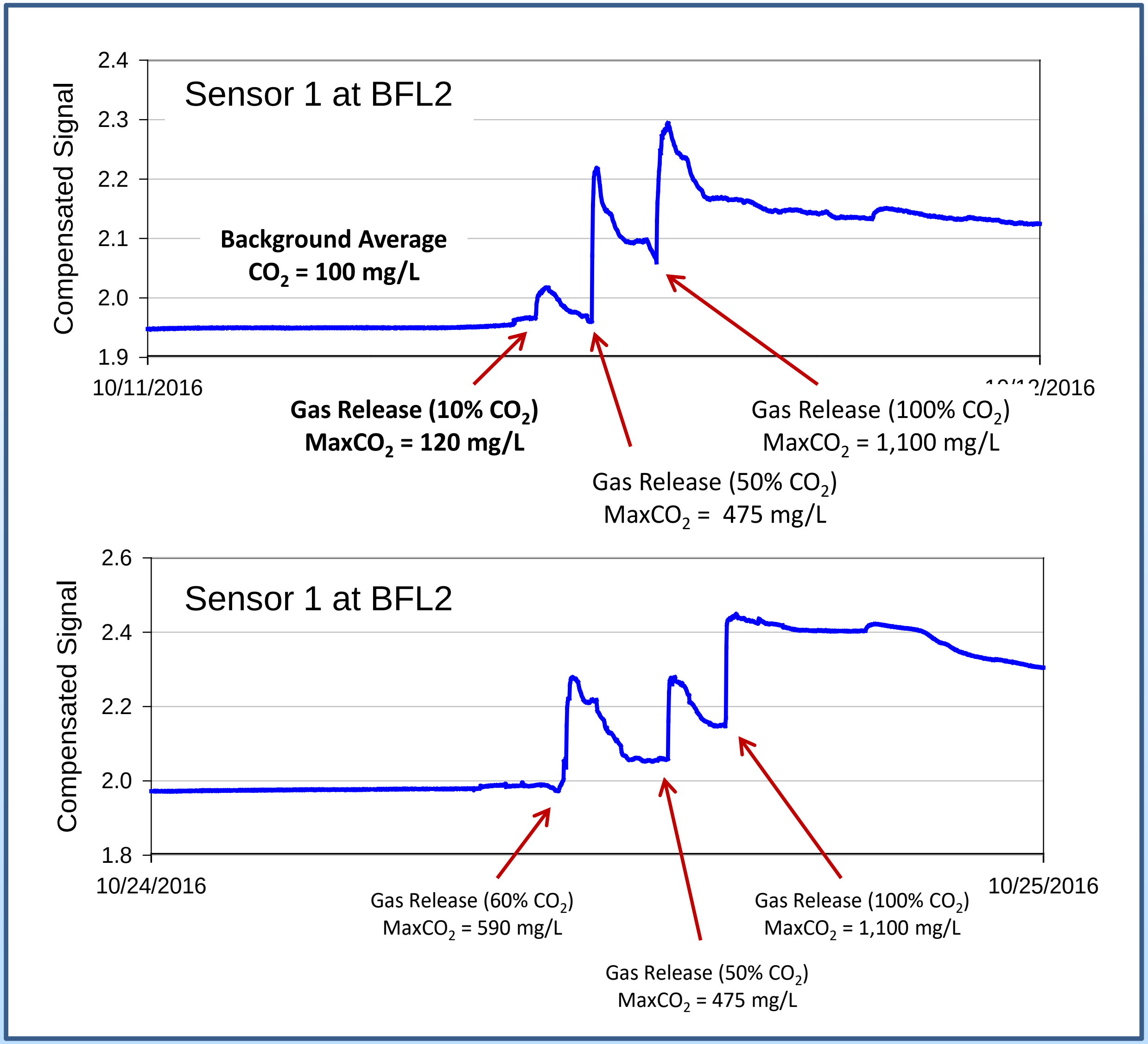


Sensor 2 at BFL2



Four Years of Sensor Development

Validation in the field



Four Years of Sensor Development

Validation in the field

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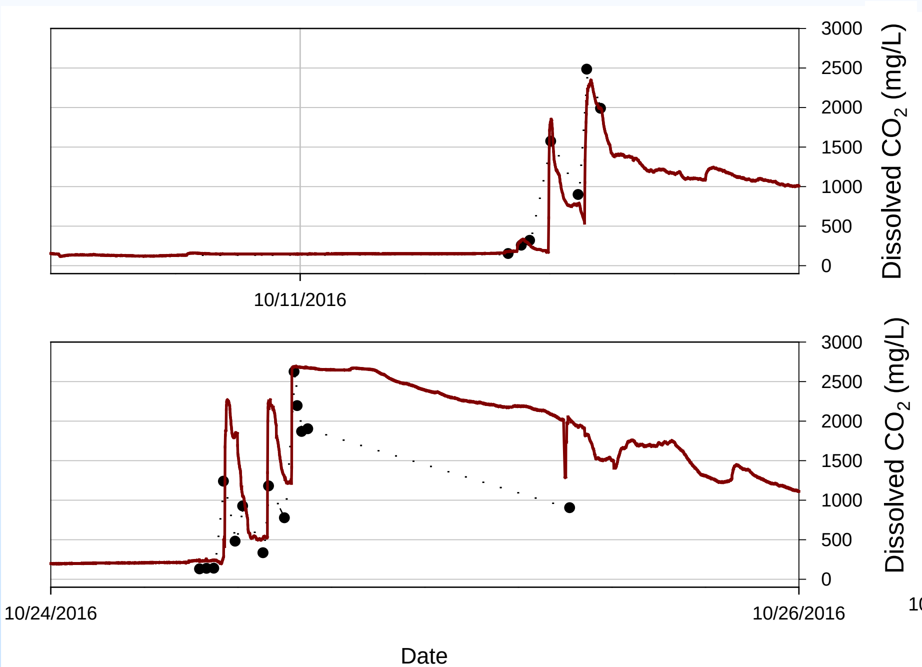
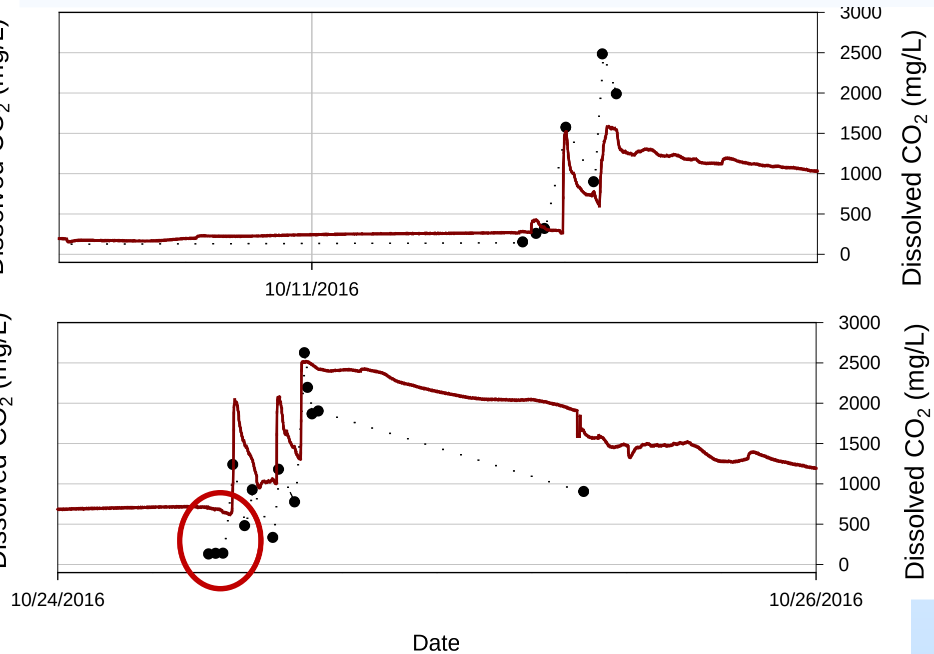
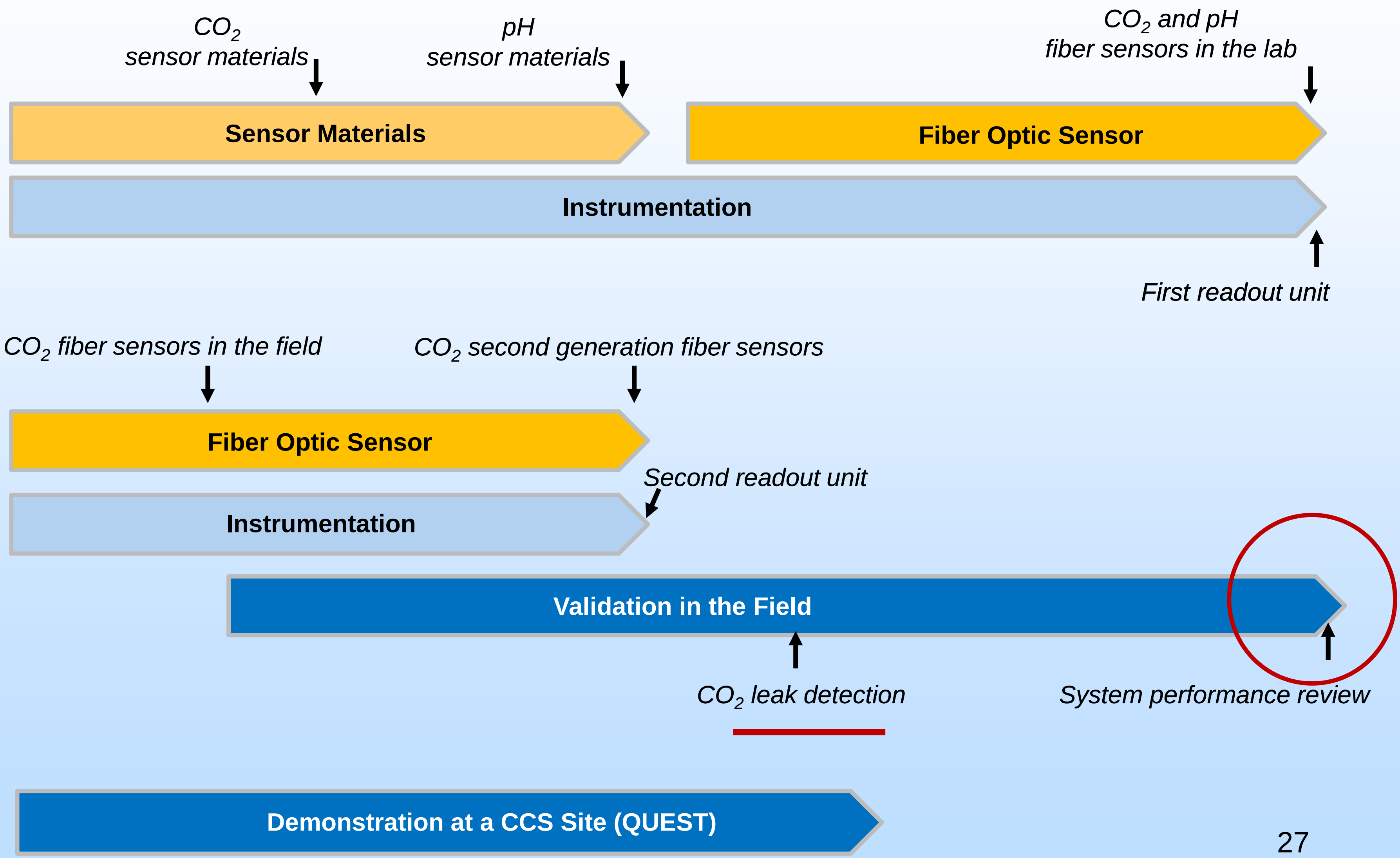


Sensor 2 at BFL2



- Excellent performance detecting small and large gas leaks reaching the aquifer
- Limited accuracy in monitoring CO_2 concentration over time.

Four Years of Sensor Development



Four Years of Sensor Development

Demonstration at QUEST

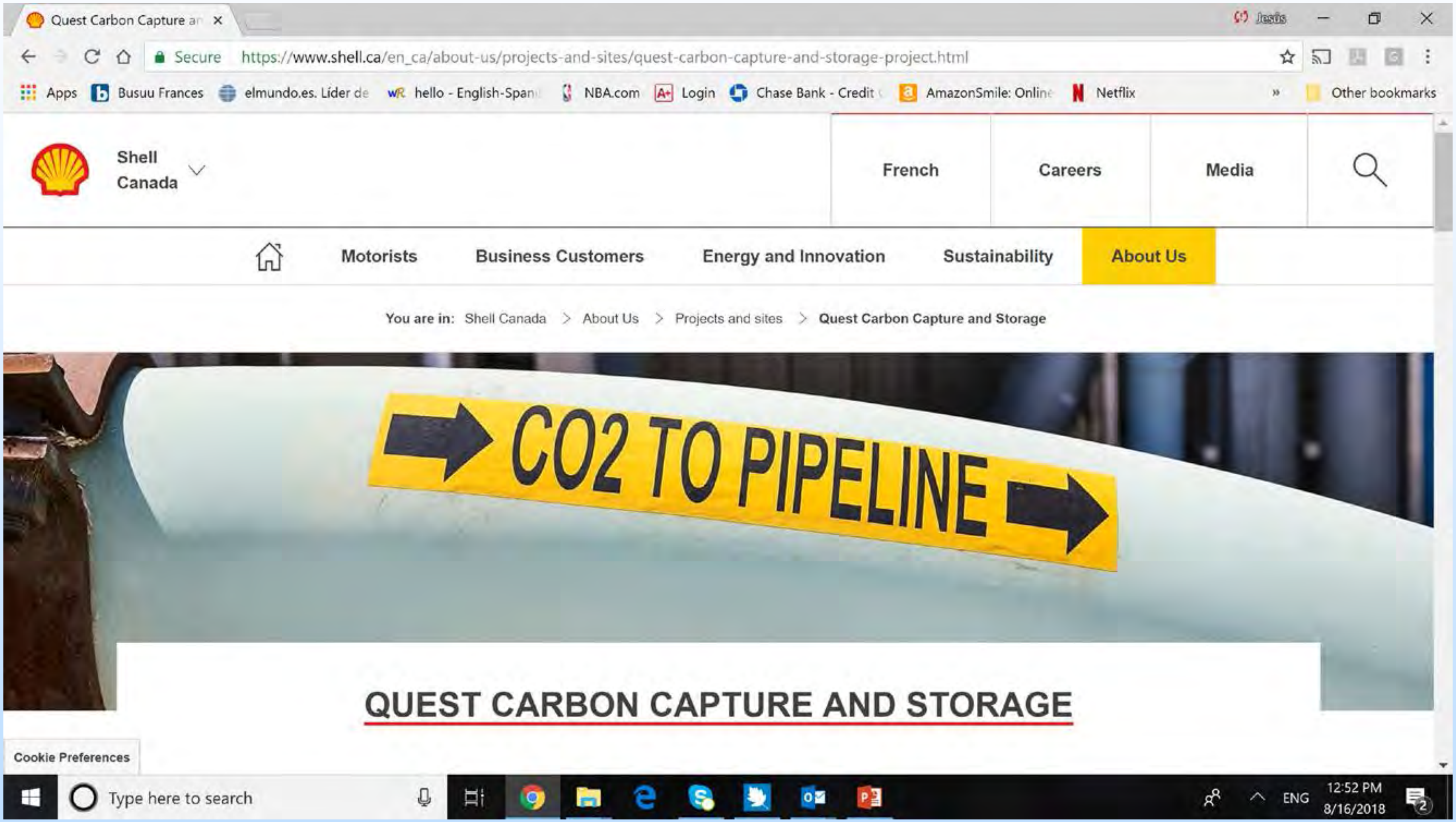
RICO2M System

- The RICO2M system must be **capable of detecting CO_2 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.

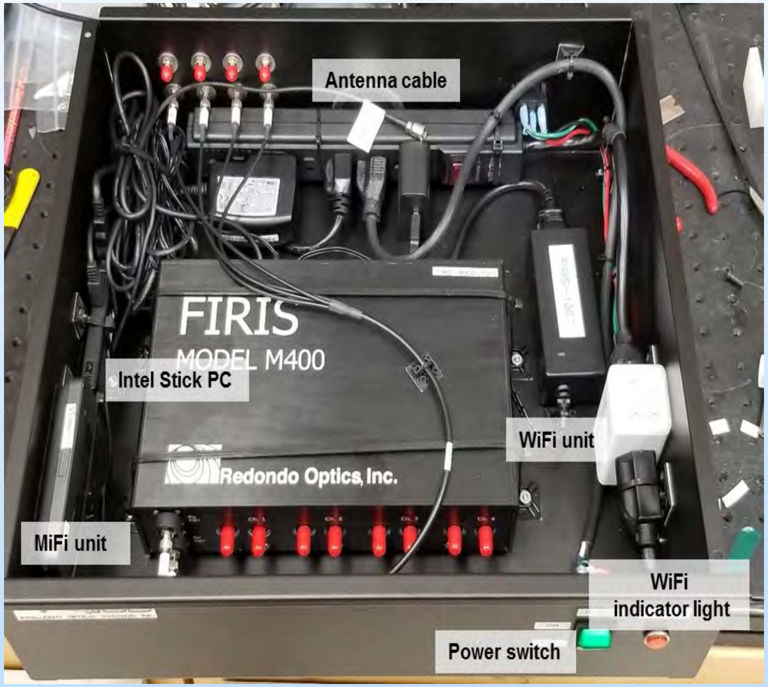
Four Years of Sensor Development

Demonstration at QUEST



Four Years of Sensor Development
Demonstration at QUEST

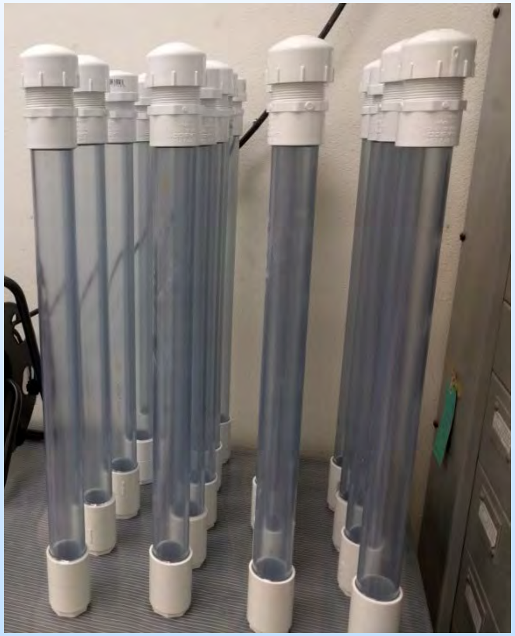
Adapt instrumentation for installation at QUEST facilities



Four Years of Sensor Development

Demonstration at QUEST

Fabricate series of distribution cables and probes



Input Connector	Channel In	Output Connector	Channel Out	Power (µW) λ = 850 nm	Power (µW) λ = 1300 nm
SMA	A01	LC	B01	78.3	93.6
SMA	A02	LC	B02	91.5	112.0
SMA	A03	LC	B03	105.2	121.5
SMA	A04	LC	B04	100.2	120.9
SMA	A05	LC	B05	78.0	96.1
SMA	A06	LC	B06	93.1	112.7
SMA	A07	LC	B07	89.7	104.8
SMA	A08	LC	B08	109.8	128.0

Input Connector	Channel In	Output Connector	Channel Out	Power (µW) λ = 850 nm	Power (µW) λ = 1300 nm
SMA	A01	LC	B01	158	181
SMA	A02	LC	B02	165	185
SMA	A03	LC	B03	163	182
SMA	A04	LC	B04	158	184
SMA	A05	LC	B05	159	180
SMA	A06	LC	B06	145	164
SMA	A07	LC	B07	154	173
SMA	A08	LC	B08	157	176

Input Connector	Channel In	Output Connector	Channel Out	Power (µW) λ = 850 nm	Power (µW) λ = 1300 nm
SMA	A01	LC	B01	147.2	165.1
SMA	A02	LC	B02	153.9	172.0
SMA	A03	LC	B03	144.8	158.5
SMA	A04	LC	B04	146.3	172.7
SMA	A05	LC	B05	152.3	173.8
SMA	A06	LC	B06	144.7	163.9
SMA	A07	LC	B07	149.2	167.8
SMA	A08	LC	B08	150.1	171.9

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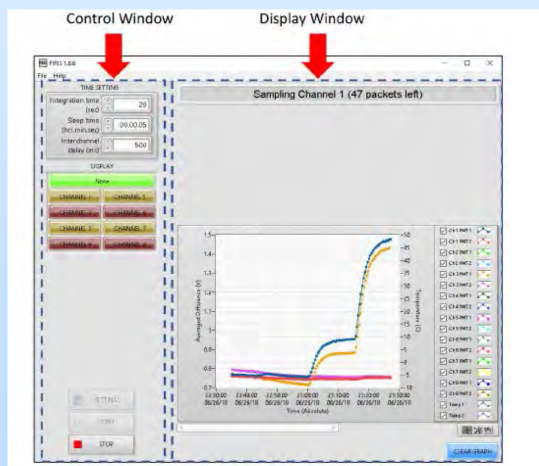
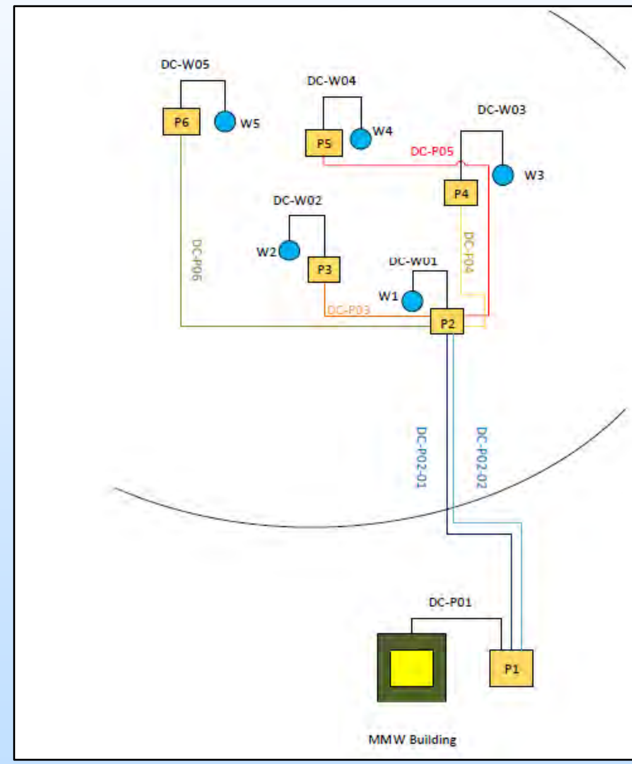
Four Years of Sensor Development

Demonstration at QUEST

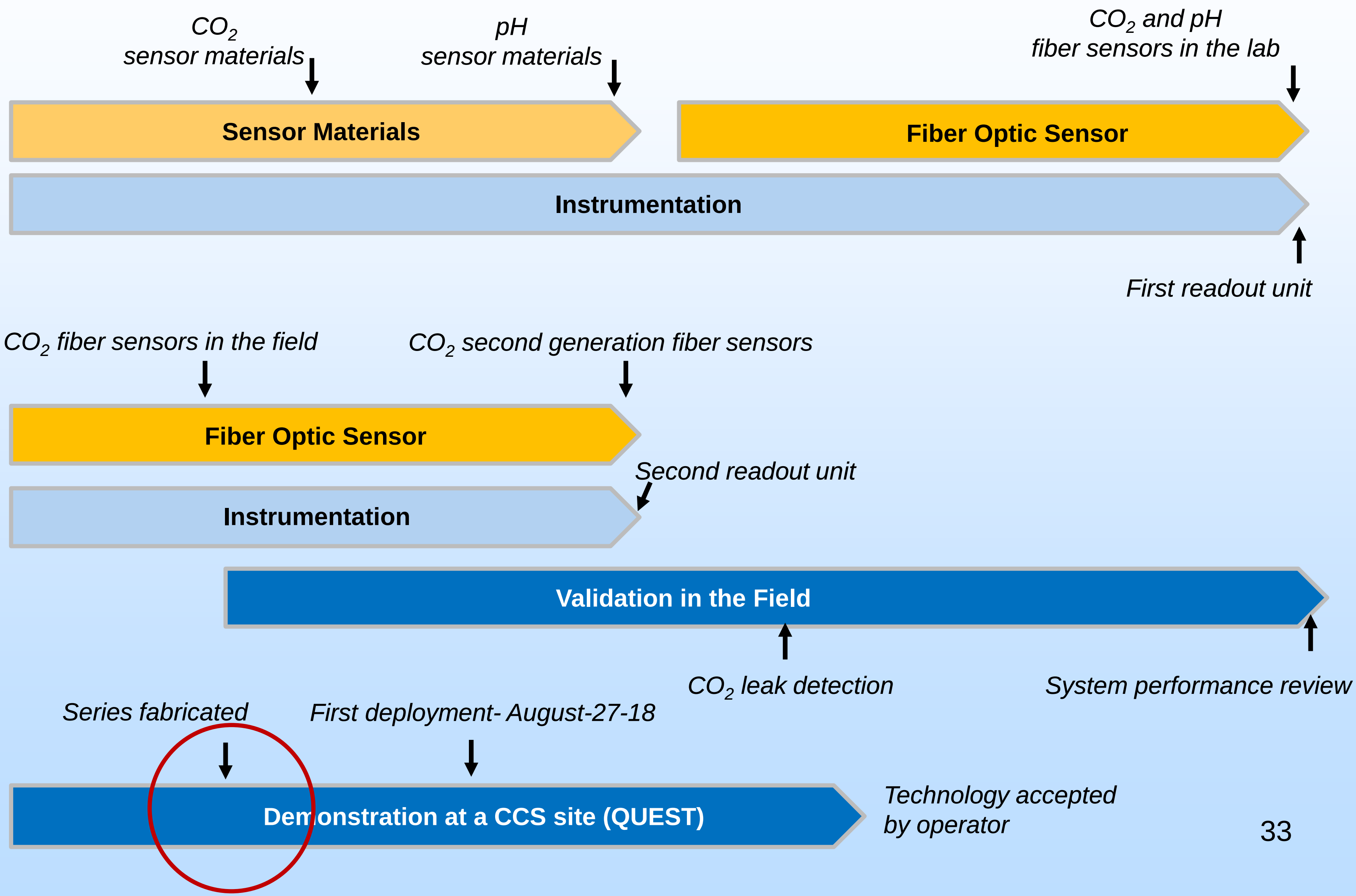
Generate documentation and obtain approval

- Subcontract agreements
- User manual
- Installation plan and protocol: onsite quality control
- Maintenance plan and protocol





Four Years of Sensor Development



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 CO_2 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.

Project Summary – Future Work

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 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

- 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.
  - 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

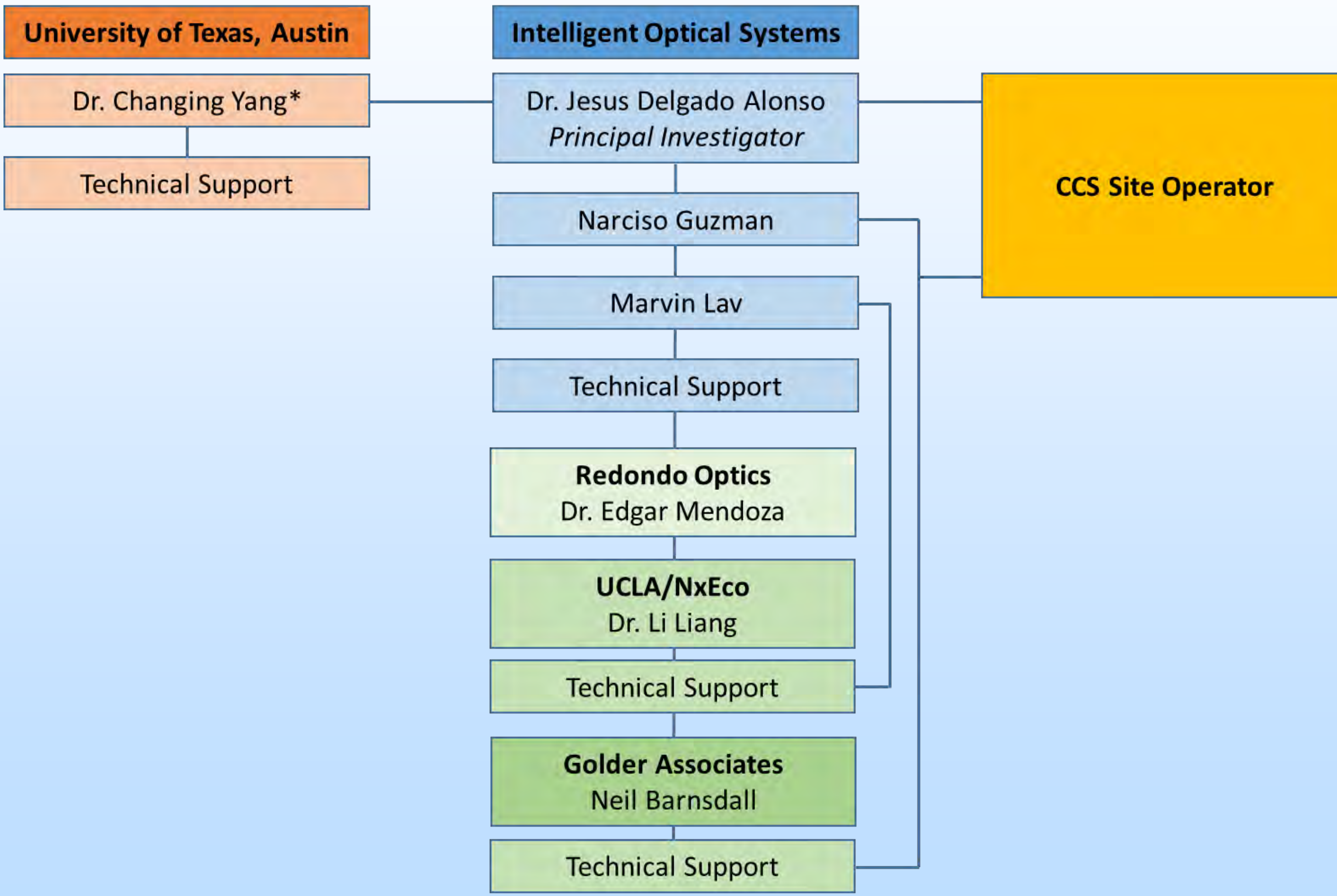
- **Phase I Objective:** Develop a multi-parameter system for highly sensitive and accurate detection of CO_2 in groundwater

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



Project Schedule

Gantt Chart related to technology demonstration at a CCS site