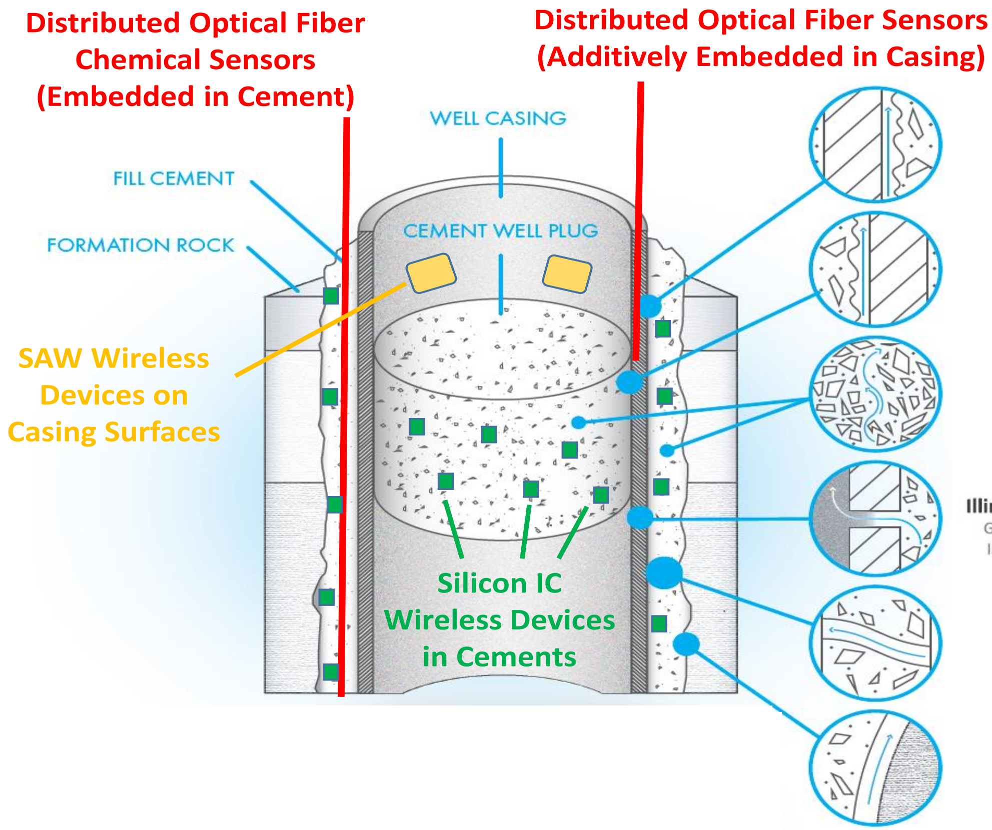
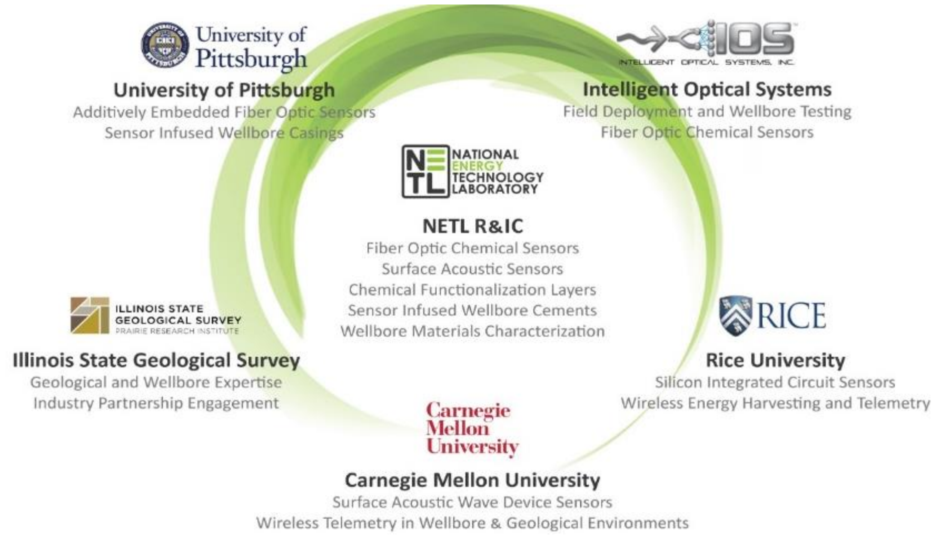




Embedded Sensor Technology Suite for Wellbore Integrity Monitoring

Project Officer: Erik Albenze

Total Project Funding: $4,496,319

November 14, 2017

Principal Investigator
Dr. Paul R. Ohodnicki, Jr.
National Energy Technology Laboratory

Track 2

Relevance to Industry Needs and GTO Objectives

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Problem Statement:

A need exists for embedded sensor technologies capable of ubiquitous, real-time monitoring of wellbore integrity.

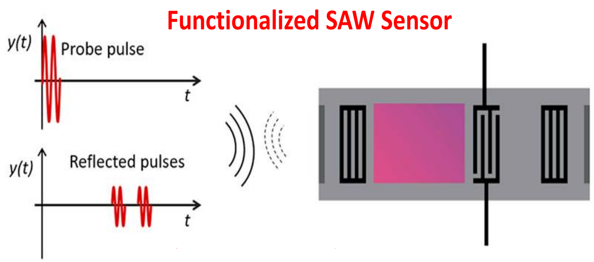
Primary Challenges:

- Sensor technologies must be robust and capable of operation in geothermal wellbore conditions.
- Electrical wires, contacts, and batteries are the most common point of failure for sensors.
- Embedded sensor technologies should not create additional potential sources of wellbore failures.

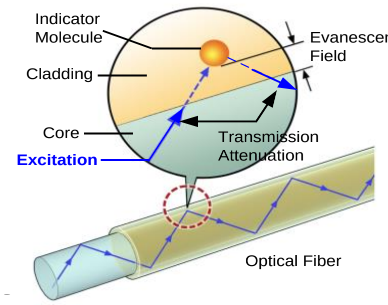
Proposed Solution:

A complementary set of technologies based on optical and microwave platforms that eliminate the need for electrical wires or active power at the sensing location.

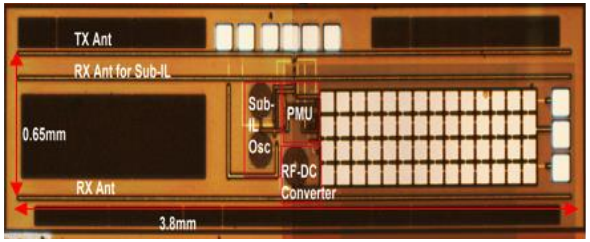
Functionalized SAW Sensor



Fiber Optic Chemical Sensor



Silicon Integrated Circuit Sensor



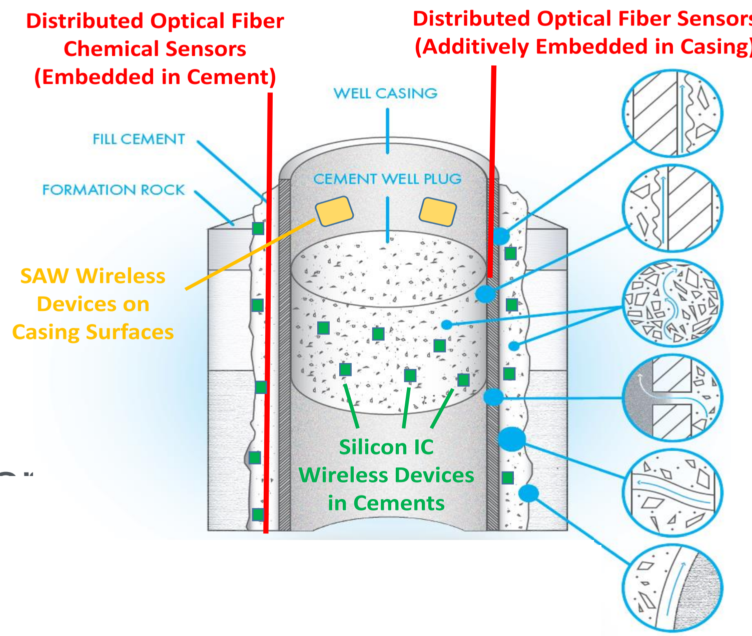
Relevance to Industry Needs and GTO Objectives

Knowledge Gaps to Be Addressed and Industry / GTO Relevance:

- Chemical sensing is a key gap in industry, yet monitoring of pH and early corrosion on-set yields insights into early signs of failure.
- Embedding sensors present technical challenges, including telemetry, but enables condition based maintenance rather than periodic inspections.
- Promotes environmentally responsible, economic geothermal energy.

Innovative Aspects of the Project:

- Functionalization of optical and microwave sensors with a focus on pH and corrosion
- Sensor embedding in wellbore materials
- Successful telemetry with embedded senso



Methods/Approach

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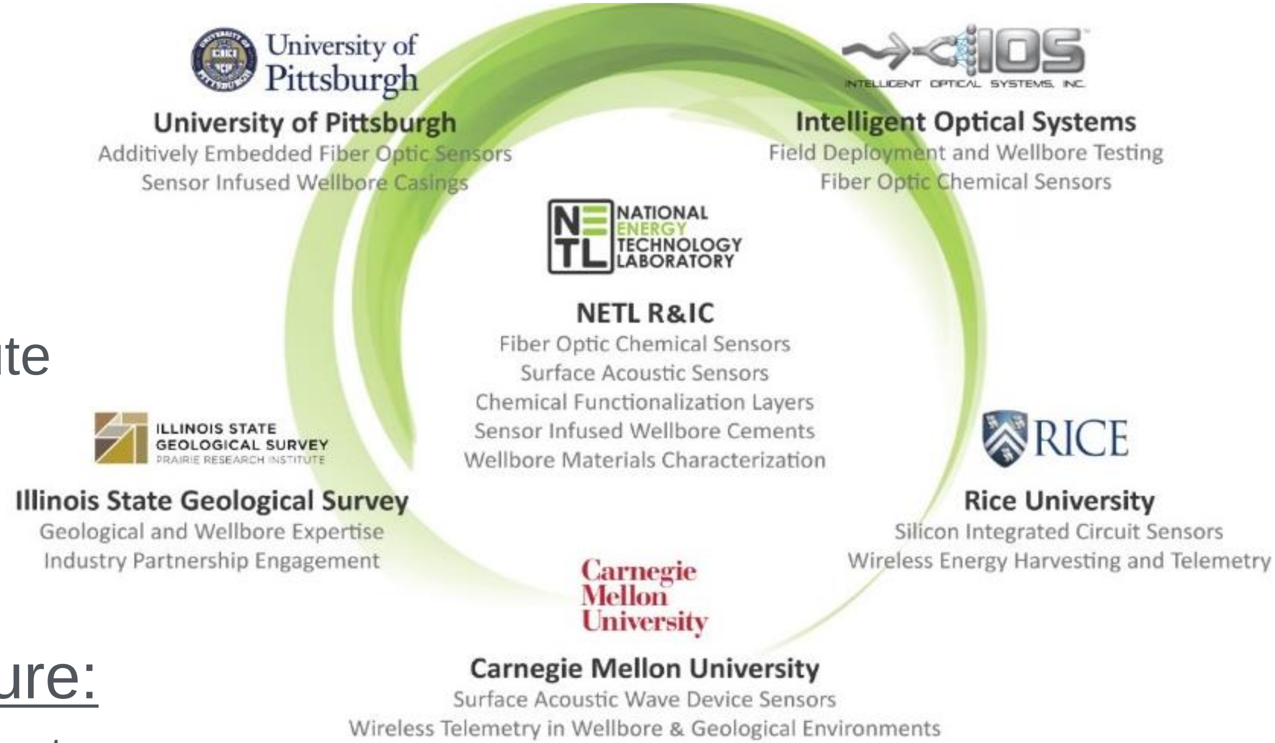
The Team:

DOE Laboratory

Industry

Academia

State Research Institute



Project Task Structure:

Task 1: Project Management

Task 2: Technology Maturation Plan & Industry Engagement

Task 3: Chemical Sensing Layer Research & Development

Task 4: Multi-Functional Optical Fiber Sensor Development & Deployment

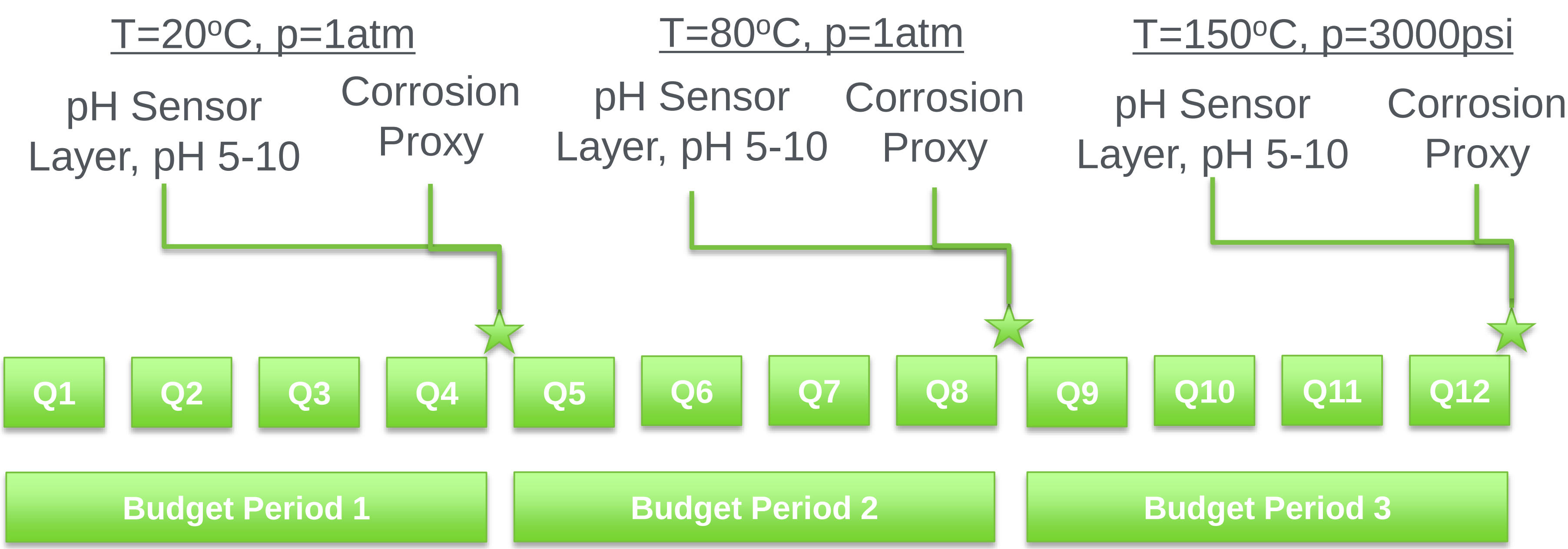
Task 5: Multi-Functional Wireless Based Sensor Device Development

Task 6: Sensor-Infused Wellbore Material Performance Characterization

Approach:

High temperature stable pH sensitive layers and corrosion proxy materials will be developed and integrated with the various device platforms.

Other parameters may also be explored (CO_2, hydrocarbons, water/humidity, etc.) based on inputs from the industry partnership group.



Task 3: Chemical Sensing Layer Research & Development

Methods/Approach

Embedded Chemical Sensing Requires Advances in Sensing Materials

System Properties: pH, Corrosion (Input Variables)

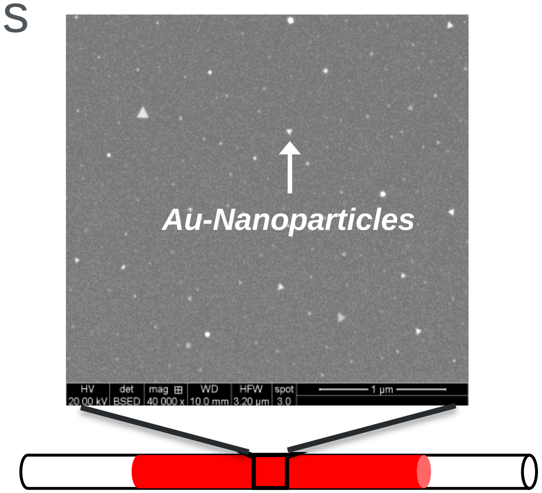
Key Challenge: Functional Sensor Materials

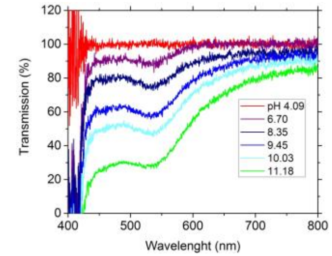
Functional Thin Film: Optical, Electrical, Electrochemical (Sensing Element)

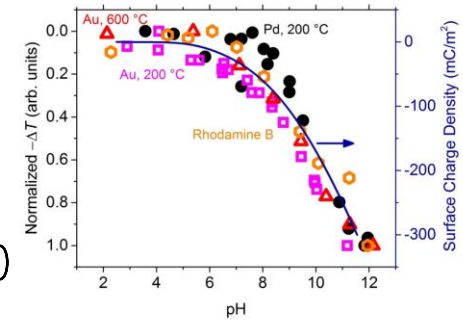
Sensor Technology: Optical, RF (Transducer)

Sensor Response (Sensitivity, Selectivity, Stability)

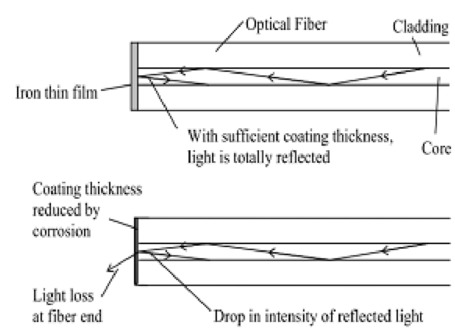
High Temperature pH Sensing

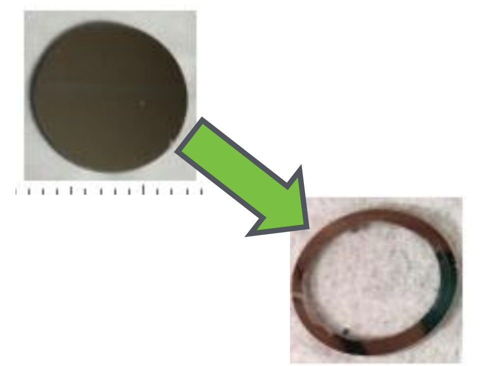






Engineered Corrosion Proxies Materials





Task 3: Chemical Sensing Layer Research & Development

Methods/Approach

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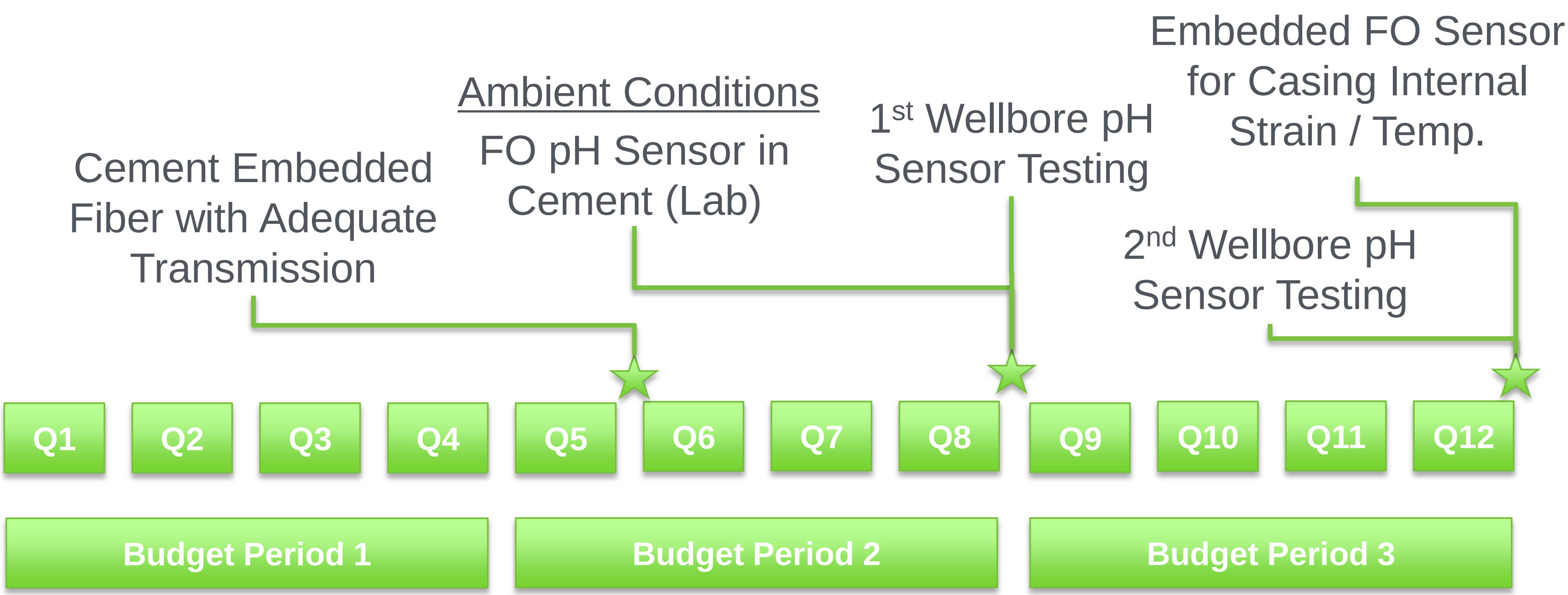
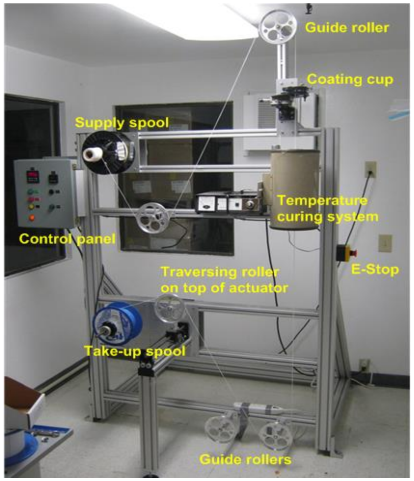
Approach:

Embedding of optical fiber sensors within cements and casings for monitoring evidence of corrosion on-set or incipient structural failures.

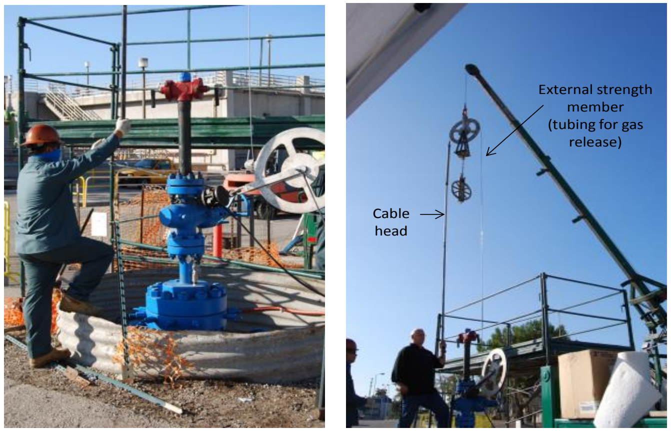
Two stage wellbore field deployment of fiber optic pH sensor technology.



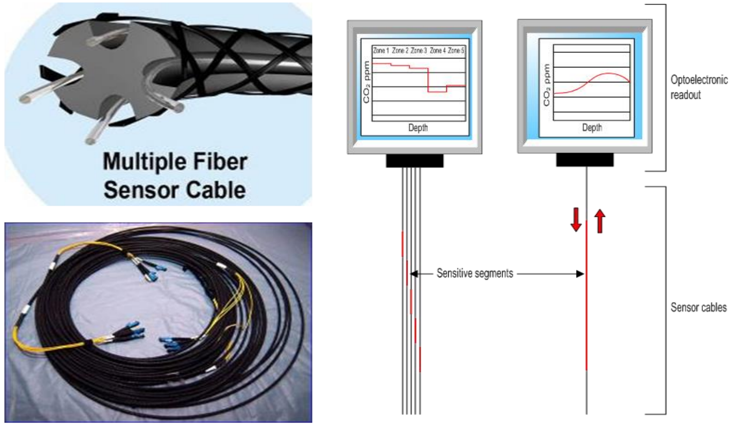
Task 4: Multi-Functional Optical Fiber Sensor Development



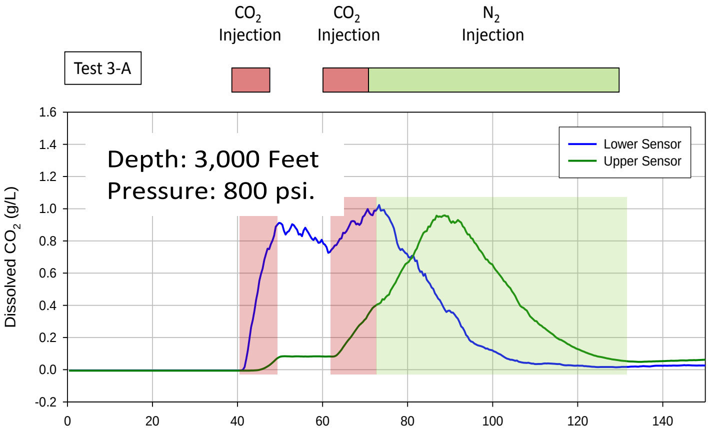
Reel-to-Reel Optical Fiber Coating System



Previous Wellbore Deployments



Multi-Fiber Bundles and Interrogators



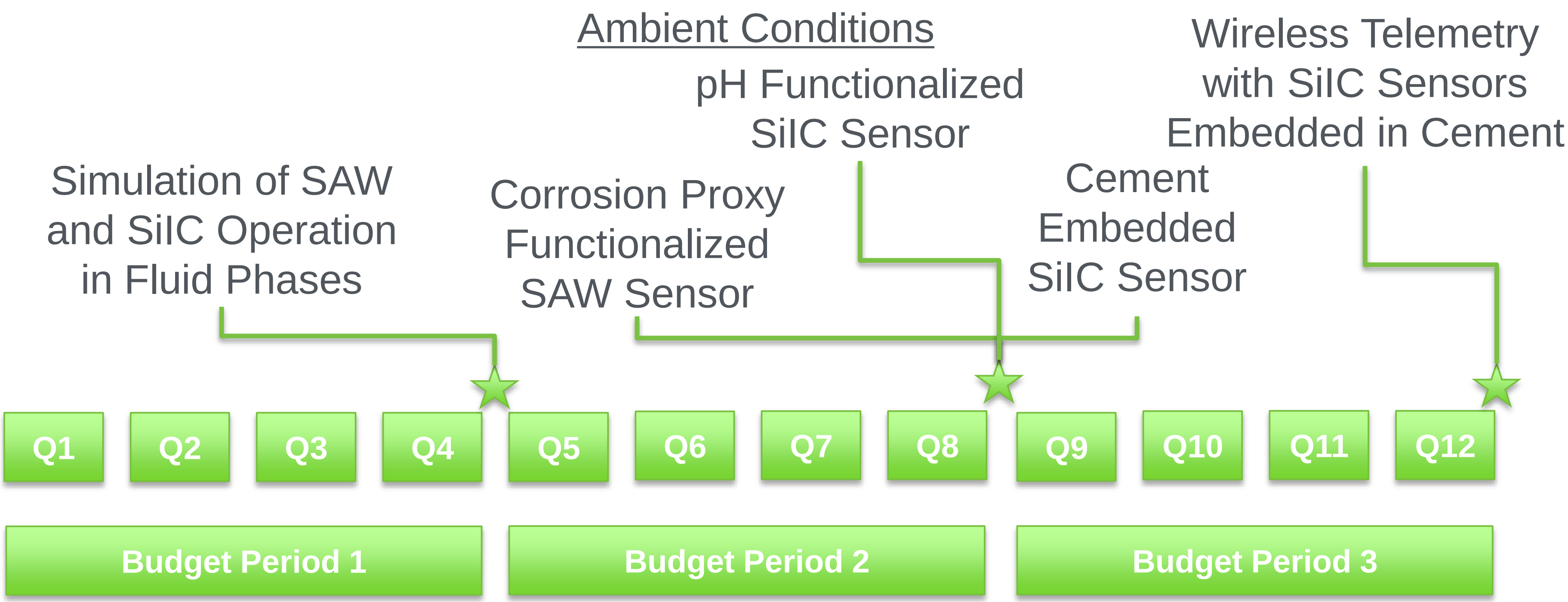
Previous Wellbore Testing of CO_2 Sensors

Task 4: Multi-Functional Optical Fiber Sensor Development

Approach:

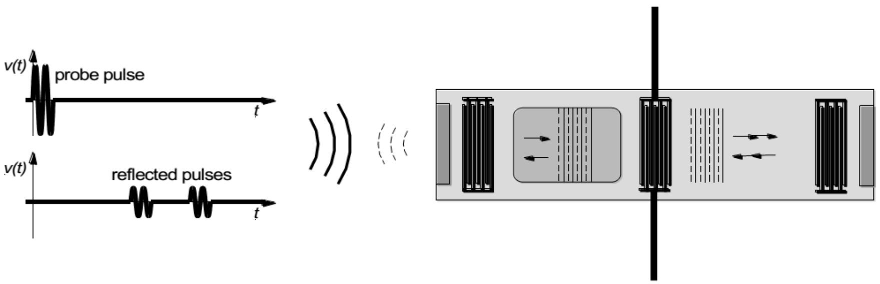
Development, functionalization, and embedding of Surface Acoustic Wave (SAW) and Silicon Integrated Circuit (SiIC) based sensor devices.

Theoretical and experimental demonstrations of wireless telemetry.

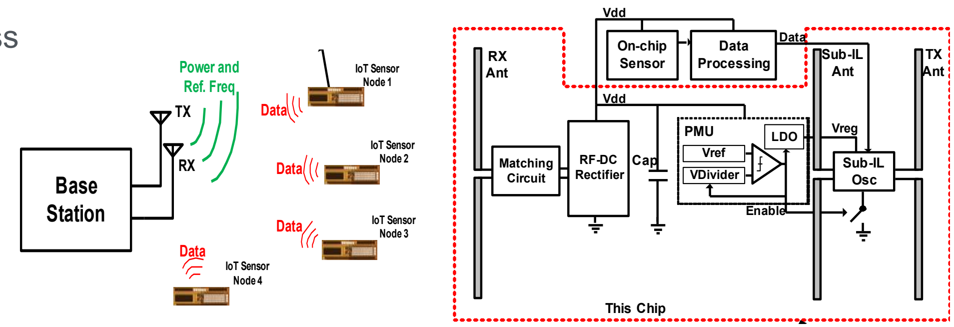


Task 5: Multi-Functional Wireless Sensor Development

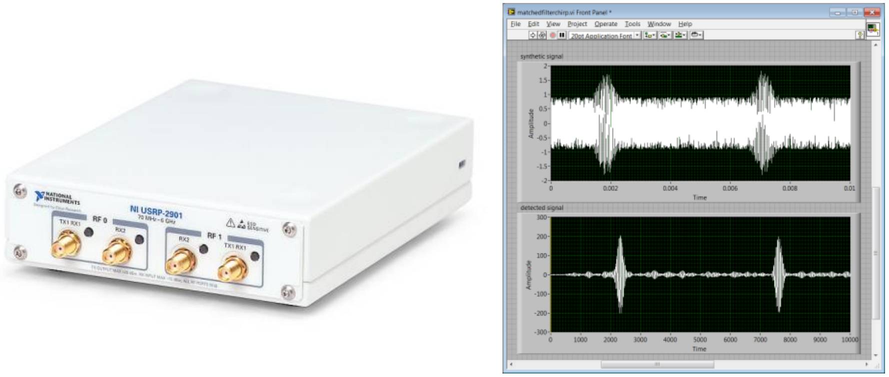
"Surface Acoustic Wave Devices for Harsh Environment Wireless Sensing," *D. W. Greve et al., Sensors 2013, 13(6), 6910-6935*



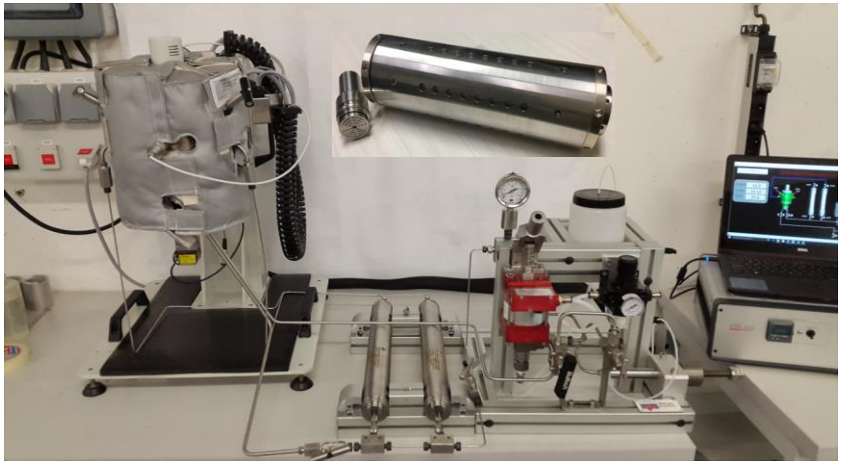
Functionalized Surface Acoustic Wave Based Sensors Approach.



Example of a Wireless Sensor Base Station Layout and Interrogation Methodology



Novel Antennae Designs and Advanced Wireless Interrogation Methodologies.



Pressurized Flow Through System and Electromagnetic Chamber for Testing.

Task 5: Multi-Functional Wireless Sensor Development

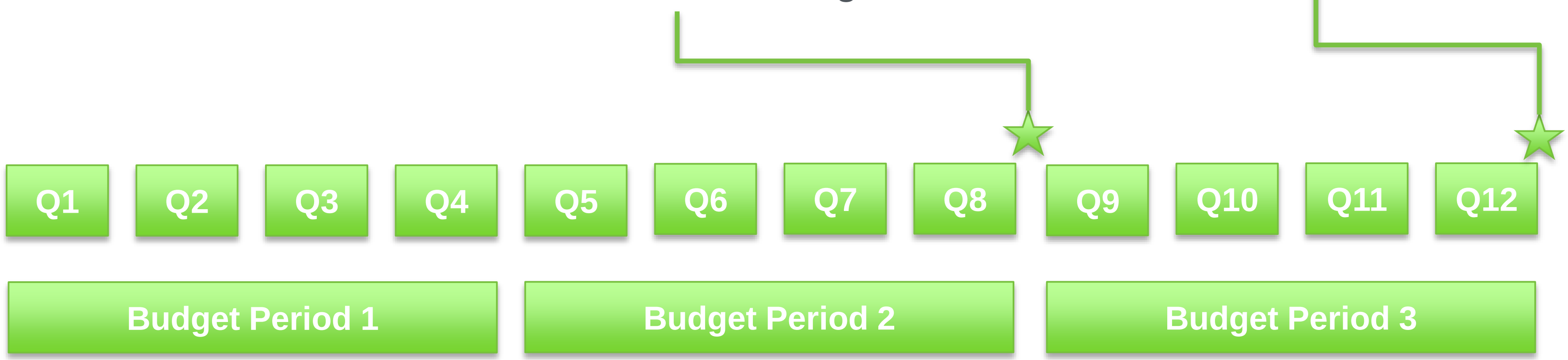
Approach:

Mechanical property, corrosion, and fluid permeation testing of baseline and sensor integrated cements and casings under relevant conditions.

CT scanner based imaging of sensor embedded cements and casings.

Characterization of 1st Generation Optical Fiber and Wireless Sensor Integrated Cements and Casings.

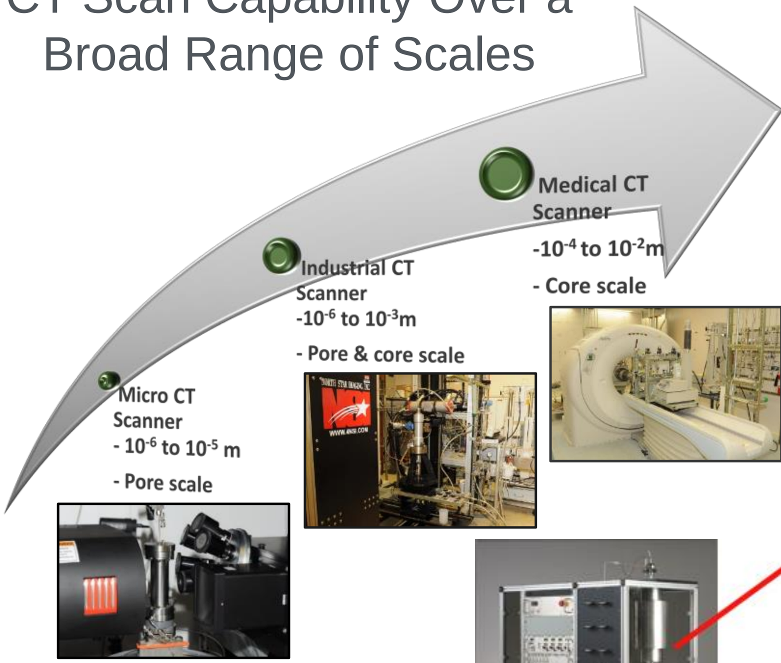
Characterization of 2nd Generation Optical Fiber and Wireless Sensor Integrated Cements and Casings.



Task 6: Sensor-Infused Wellbore Material Characterization

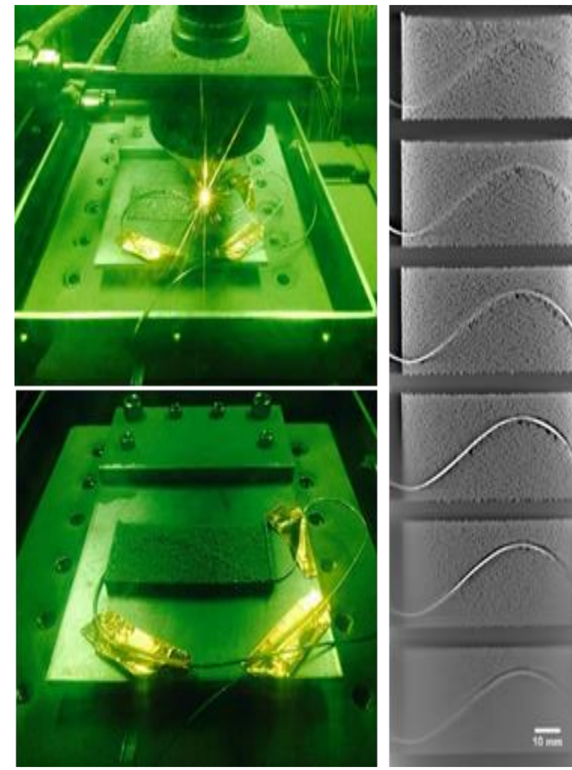
Methods/Approach

CT Scan Capability Over a Broad Range of Scales



Permeation Testing

CT Scan of Additively Embedded Optical Fibers.



Mechanical Property Testing

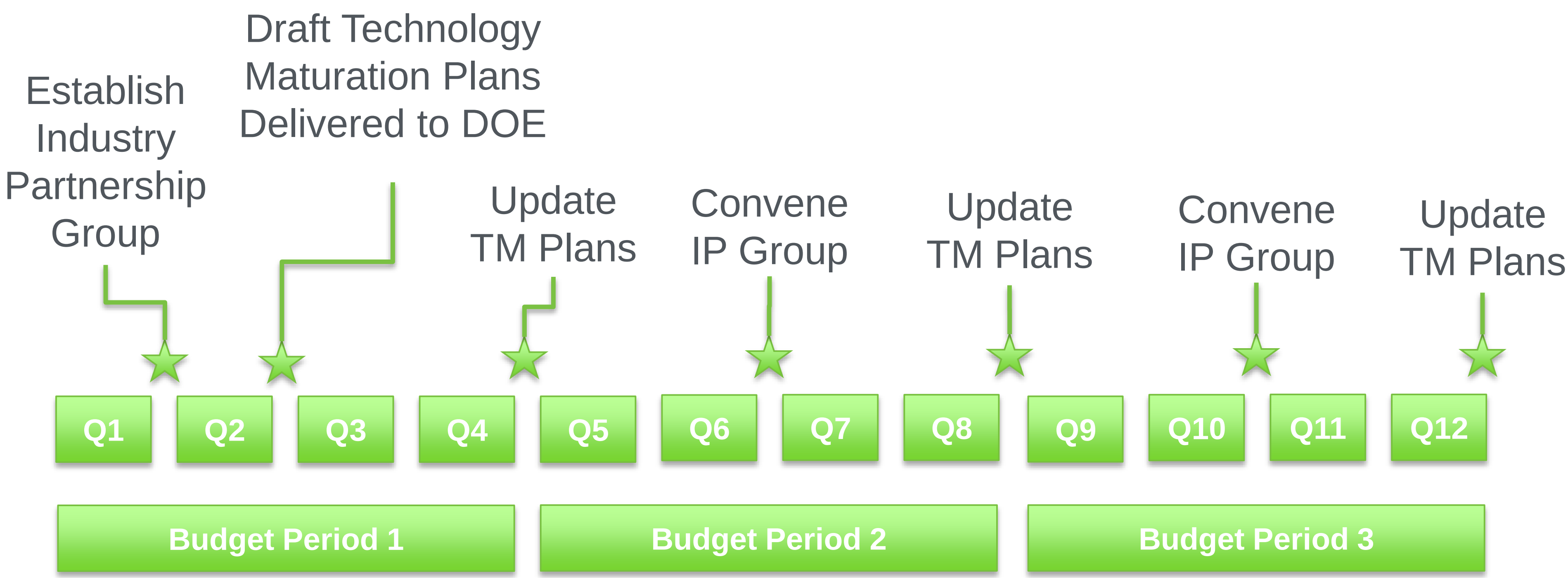
NETL Research & Innovation Center Laboratory Facilities are Well Equipped for Mechanical Property, Corrosion, Permeation Testing and CT Scans.

Task 6: Sensor-Infused Wellbore Material Characterization

Research Collaboration and Technology Transfer

Approach:

An industry partnership group will be established at the beginning of the program to review the proposed technology development and to provide industrial perspective and insight into the proposed metrics and objectives.



Task 2: Technology Maturation Plan & Industry Engagement

Technical Progress / Future Directions

- Contract Negotiations are Undergoing Finalization
- Anticipated Project Start Date is January 1, 2018
- Key Project Milestones and Deliverables to Be Satisfied Include:
  - Budget Period 1:
    - A Technology Maturation Plan for Each Technology to Be Developed
    - Successful Simulations and Designs of SAW and SiIC Devices in Fluids
    - First Optical Fiber Based pH Sensors Demonstrated
  - Budget Period 2:
    - Functionalized Optical Fiber Sensors in Cements at Laboratory Scale
    - Successful Experimental Demonstration of SAW and SiIC Devices in Fluids
    - First Field Deployment of an Optical Fiber pH Sensor
  - Budget Period 3:
    - Wireless Telemetry with Embedded SiIC Devices in Cements
    - Demonstration of Robust Sensor-Infused Cements and Casings
    - Second Field Deployment of an Optical Fiber pH Sensor

Mandatory Summary Slide

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Ubiquitous embedded sensors can enable early detection of incipient failures, chemical sensing (i.e. pH and corrosion) is a key technology gap
- We have established an integrated DOE laboratory, industry, academia and state laboratory team to address the challenge
- Three sensing technologies will be pursued which eliminate the wiring and electrical contacts at the sensing node
  - Optical fiber based sensors
  - Surface acoustic wave based sensors
  - Silicon integrated circuit based sensors
- The team will pursue field deployments of the optical fiber based pH sensor technology to move the technology into the field
- An industry partnership group is being established to inform and guide the technology development, please contact me to join!

Dr. Paul R. Ohodnicki, Jr., paul.ohodnicki@netl.doe.gov, 412-386-7389

Additional Information

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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