Japan Collaboration on Fiber-Optic Technology

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U.S. Department of Energy

National Energy Technology Laboratory

Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting

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Technical Status

- The growing interest in CCS has stimulated the need to develop monitoring approaches for assuring that:
  - (i) CO_2 is safely stored, (ii) CO_2 is not migrating beyond site boundaries, (iii) no leakage, and (iv) and help reservoir engineers to predict long term containment.
- The **research project is advancing fiber-optic sensing technology** (TRL 3-5 to 6-7) for monitoring of storage projects. Distributed Optical Fiber Sensors (DOFS):
    - continuously measure temperatures and strain along a single fiber installed in monitoring wells and/or in trench at the surface on several kilometers,
    - use low-cost telecommunication grade optical fiber which offer a multitude of advantages, such as reduced weight and dimensions, strong immunity to electromagnetic interference, environmental robustness, long-gauge measurements, and low cost.

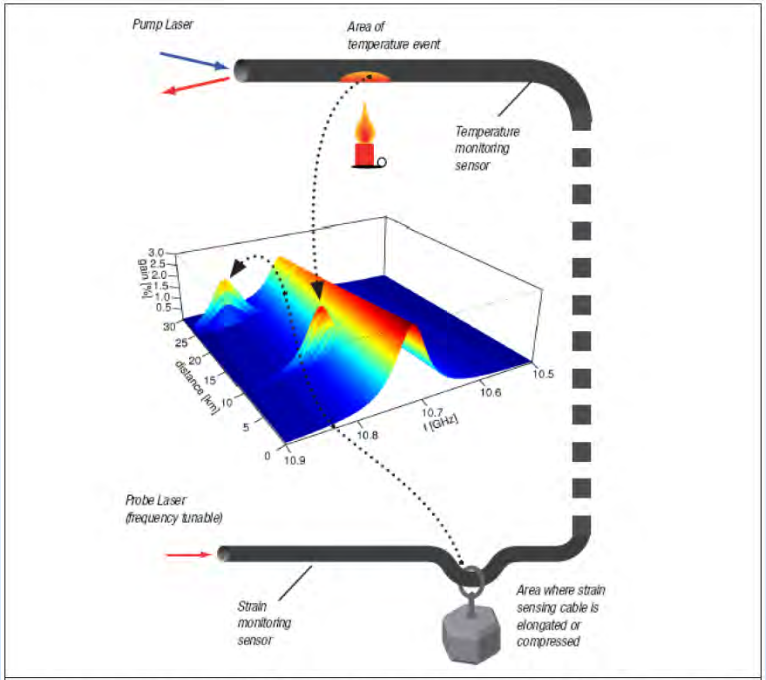
DOFS Benefits

- Distributed Optical Fiber Sensors (DOFS) can be used to:
    - evaluate the wells integrity,
    - detect leakage along the wells,
    - Calibrate geomechanical model. Static deformations occurring during injection can be used by reservoir engineers to calibrate and validate hydro-mechanical simulation models of CO_2 plume migration and predict long term containment.

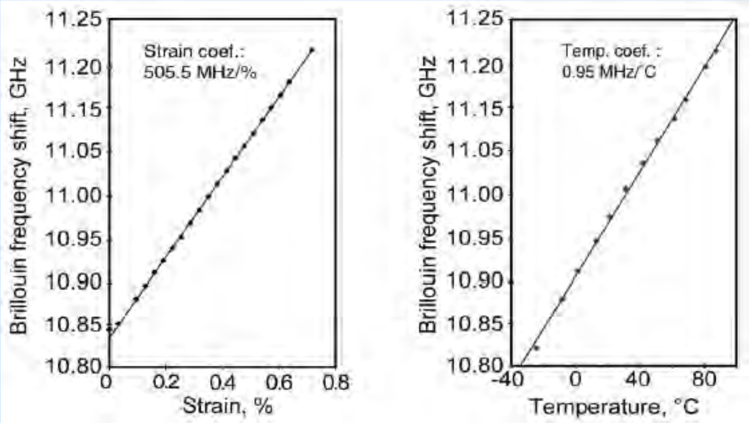
Major R&D Challenges

- The major challenges associated with this technology are to quantify and to improve the amount of strains captured by the optical cables caused by the deformations of the rock formations during CO_2 injection. There is a need to better understand:
  - the influence of the measurement cable design and the deployment methodology on the measurements,
  - the coupling between casing, cement, optical fiber and rock formations,
  - and how a strain measurement in one direction (along the cable) can provide information on the full 3D strain tensor.
  - What is the best physic to be used: Rayleight Scattering (RITE) versus Brillouin Scattering (LBNL)

DOFS: Brillouin Scattering

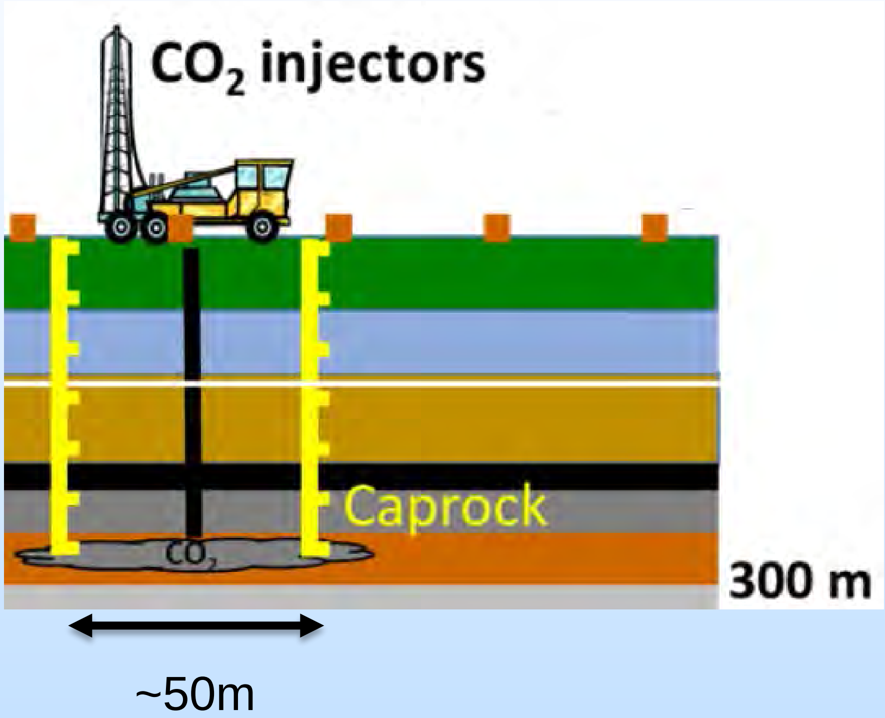


Schematic representation of the time and frequency domain acquisition for the detection and localization of 2 spots.

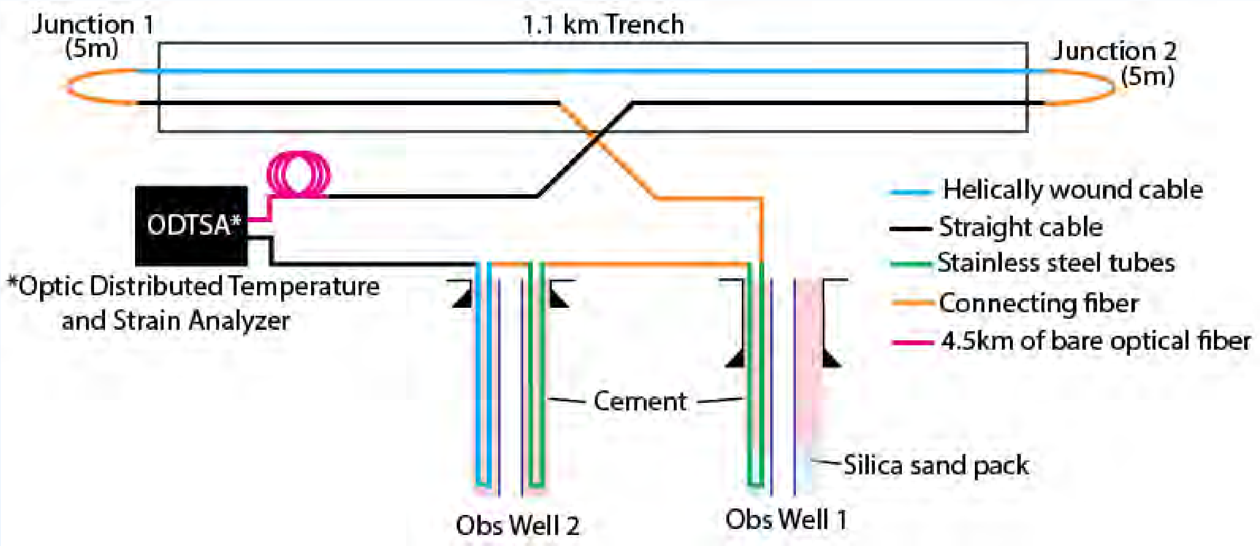


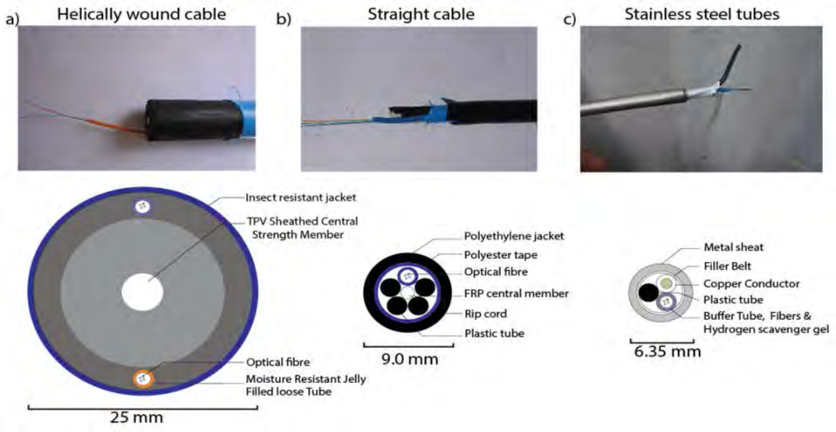
- When light is sent through an optical fiber, a small amount of the incident light is back scattered at a specific frequency.
- Variation in temperature and strain slightly change the fiber density and locally modify the index of refraction.
- Standard performance for DOFS
  - Distance range: 50km
  - Distance resolution: 0.1m
  - Number of points: 100,000
  - Resolution: 0.1°C and 2με
  - Spatial resolution (the smallest detectable event measured with 100% accuracy) up to 0.5 m but typical values are :1m at 20km, 2m at 30km, 3m at 50km.

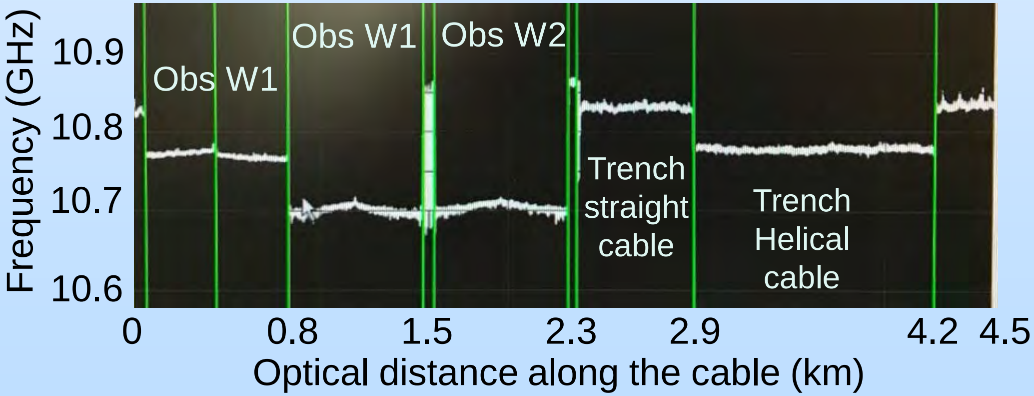
CO_2 injection at the Containment and Monitoring Institute (CaMI) Field Research Station in Canada.



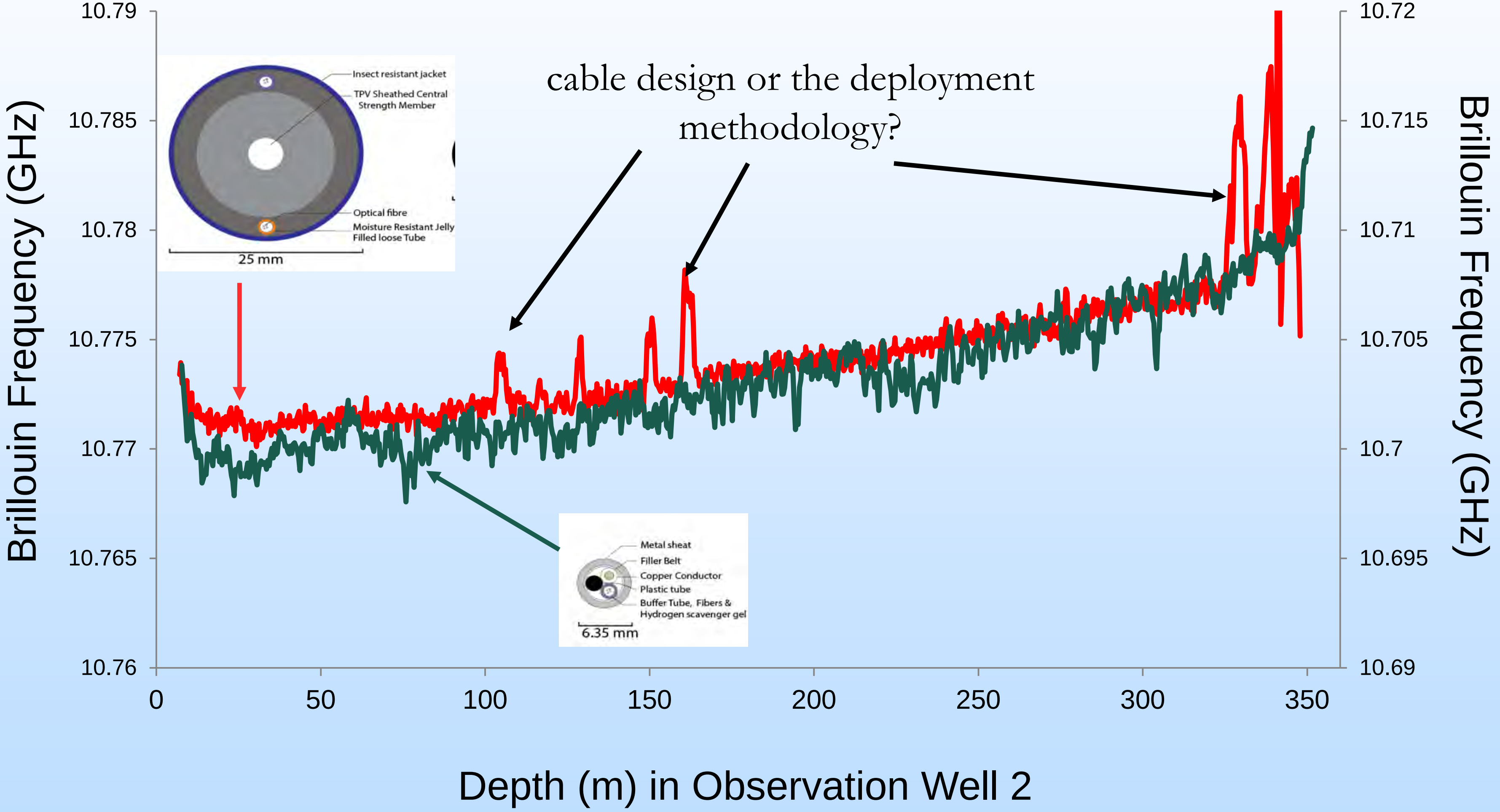
Schematic of the fiber network installed at CaMI.





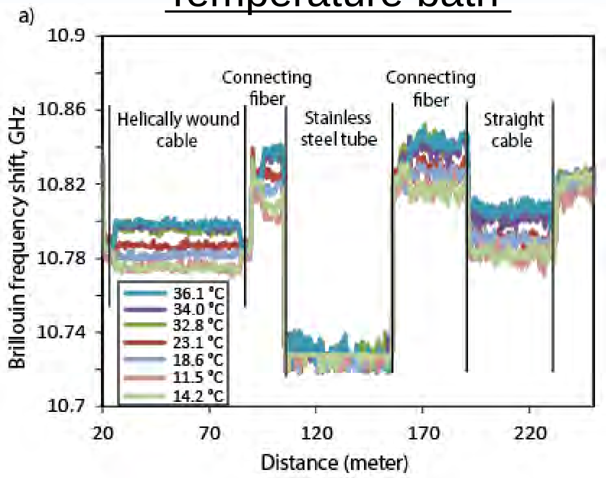


Comparison between Brillouin frequency shift monitored along two optical cables installed in the same well.

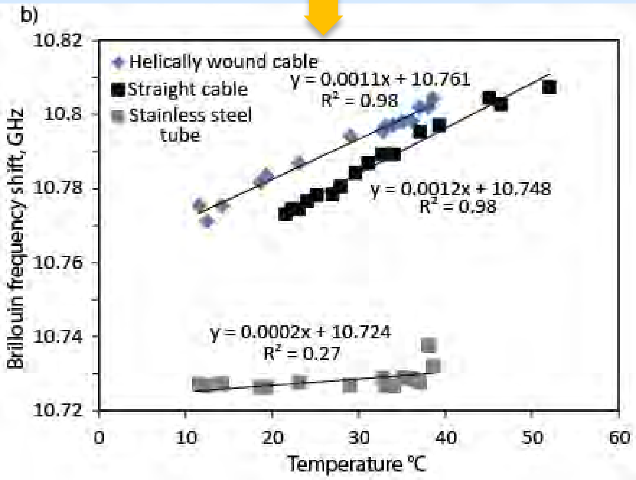

cable design or the deployment methodology?

Laboratory Temperature and Strain Calibration Tests

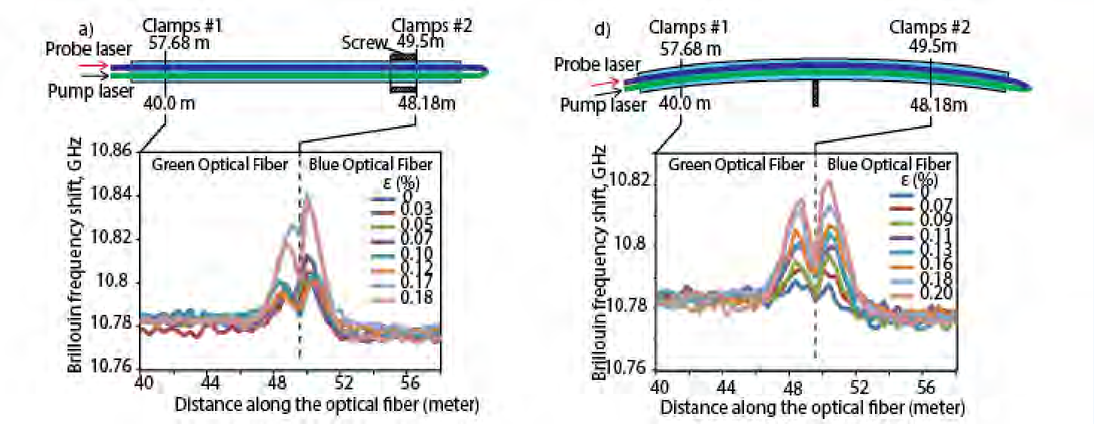
Temperature bath



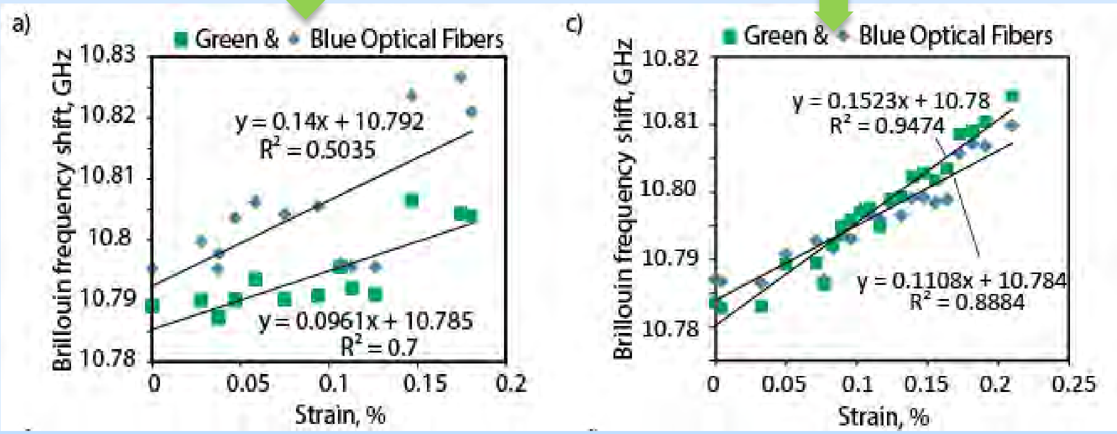
Temperature coefficients for the three cables



Example of **Tensile and Bending tests** on the straight cable

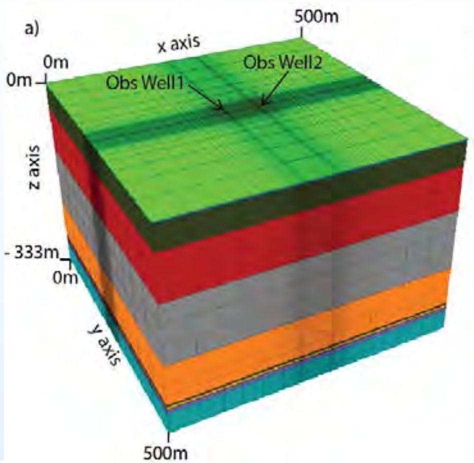


Tensile and bending coefficients for two optical fibers composing the straight cable

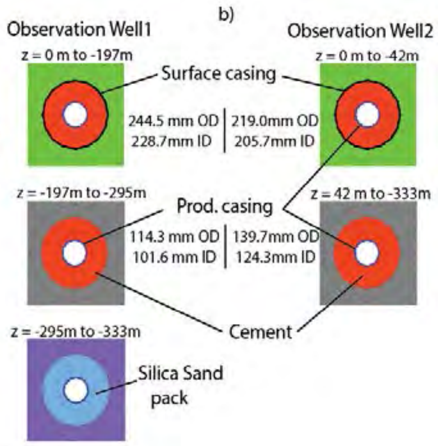


Coupled fluid flow and geomechanical numerical modeling

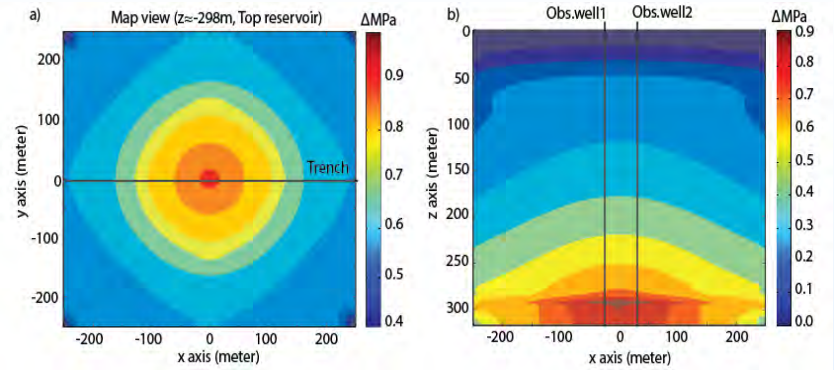
1)Geological model



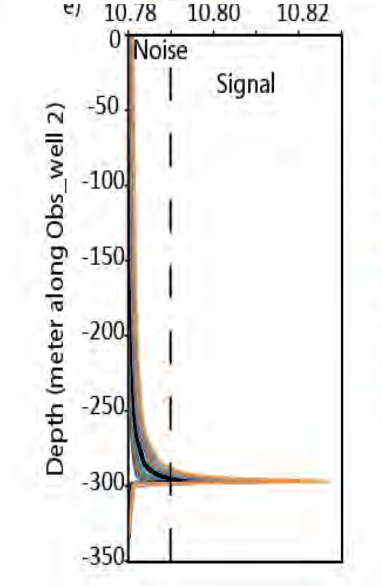
2)Well design

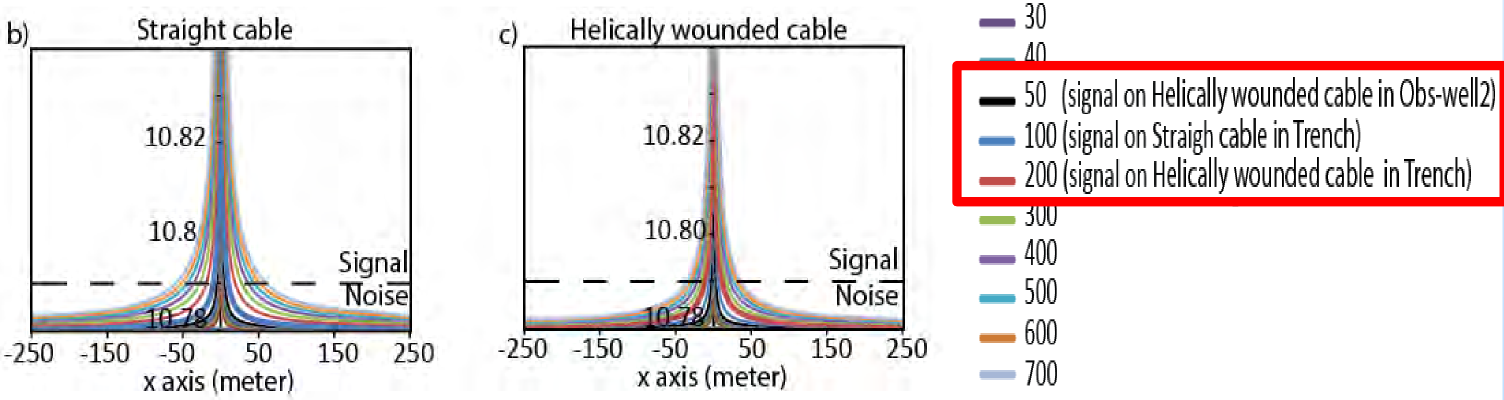


3)ΔP after 700 days of injection (1000 T/y)



4) Estimation of Brillioun frequency shift along the cable in the trench and in the wells over time.





The use of differ optical cables with the same temperature coefficient into the same well can strongly improve our ability to characterize the causes of the Brillioun frequency shift.

Accomplishments to Date

- Installed a fiber network 9 km long composed of several different optical cables.
- Performed strain and temperature calibration tests on the different optical cables in laboratory.
- Developed a 3D geomechanical model of the CaMI FRS Site with detailed discretization of storage, cap rock formations and wells designs.

Lessons Learned

- Research gaps/challenges:
  - There is a need to better characterize in-situ the mechanical coupling between the casing, the cement, the optical cable and the rock formations.
  - There is a need to develop cables robust enough to be install behind casing without creating permanent deformation along the cable itself but soft enough to capture micro-strain due to reservoir deformation.
  - Or there is a need to improve the deployment methodology.

- Technical disappointments.
  - Difficulties to install the optical cable behind casing without damaging the cable itself.
  - Difficulties to inject the CO2 and build up the pressure into the reservoir.

Synergy Opportunities

- Distributed Optical Fiber Sensors is going to be used in several project:
  - Assessment of Leakage Pathways Using Joint EM-Seismic, Borehole and Surface Technologies - Lawrence Berkeley National Laboratory (Wednesday - 4:55PM)
  - The Eagle Ford shale project: improve oil and gas recovery
  - The Mont-Terri experiment (FS-B) for monitoring fault leakage during CO2 Injection (Thursday, 2:20 PM- On the Relationship between Fault Reactivation and Leakage Potential: Controlled Injection Experiments at Mont Terri)
  - Laboratory experiment with the SIMFIP probe

Project Summary

- **Key Findings**.
  - We need to design cables which are robust enough to be install behind casing without having permanent deformation along the fibers but flexible enough to capture the micro-strain during the injection.
  - The use of differ optical cables into the same well strongly improve our ability to characterize hydro-mechanical processes associated with CO2 injection
- **Next Steps.**
  - Monitoring micro-strain and changes in temperature during injection in 2018-2019.
  - Compare data collected by both RITE and LBNL teams to understand similarities and differences between the strain monitoring system based on Brillouin and Rayleigh technologies.
  - Characterize in-situ and in laboratory the coupling between casing, cement, optical fiber and rock formations.

Acknowledgment

– Funding for LBNL was provided through the Carbon Storage Program, U.S. DOE, Assistant Secretary for Fossil Energy, Office of Clean Coal and Carbon Management through the NETL.

Appendix

– These slides will not be discussed during the presentation, but are mandatory.

Benefit to the Program

- The research project is advancing fiber-optic sensing technology for monitoring carbon sequestration to:
    - Ensure 99 percent storage permanence by reducing leakage risk through early detection mitigation.
    - Improve reservoir storage efficiency while ensuring containment effectiveness by advancing monitoring systems to control and optimize CO2 injection operations.
    - Contributing to the Best Practice Manuals for monitoring, verification, and accounting (MVA) with regard to IMS.
    - Reduce overall storage cost.
    - Increase monitoring sensitivity.
    - Reduce project risk during and after the injection of CO2.

Project Overview

Goals and Objectives

- The technology, when successfully demonstrated, will provide the possibility to continuously measure temperatures and strain at thousands of points with a high spatial resolution along a single fiber installed in monitoring wells and/or in trench at the surface on several kilometers at a relatively low cost.

- This technology can significantly improve our ability to evaluate the wells integrity and detect leakage along the wells and provide critical information on static deformations occurring during injection. Information which can be used by reservoir engineers to calibrate and validate hydro-mechanical simulation models of CO_2 plume migration and predict long term containment.

Project Overview

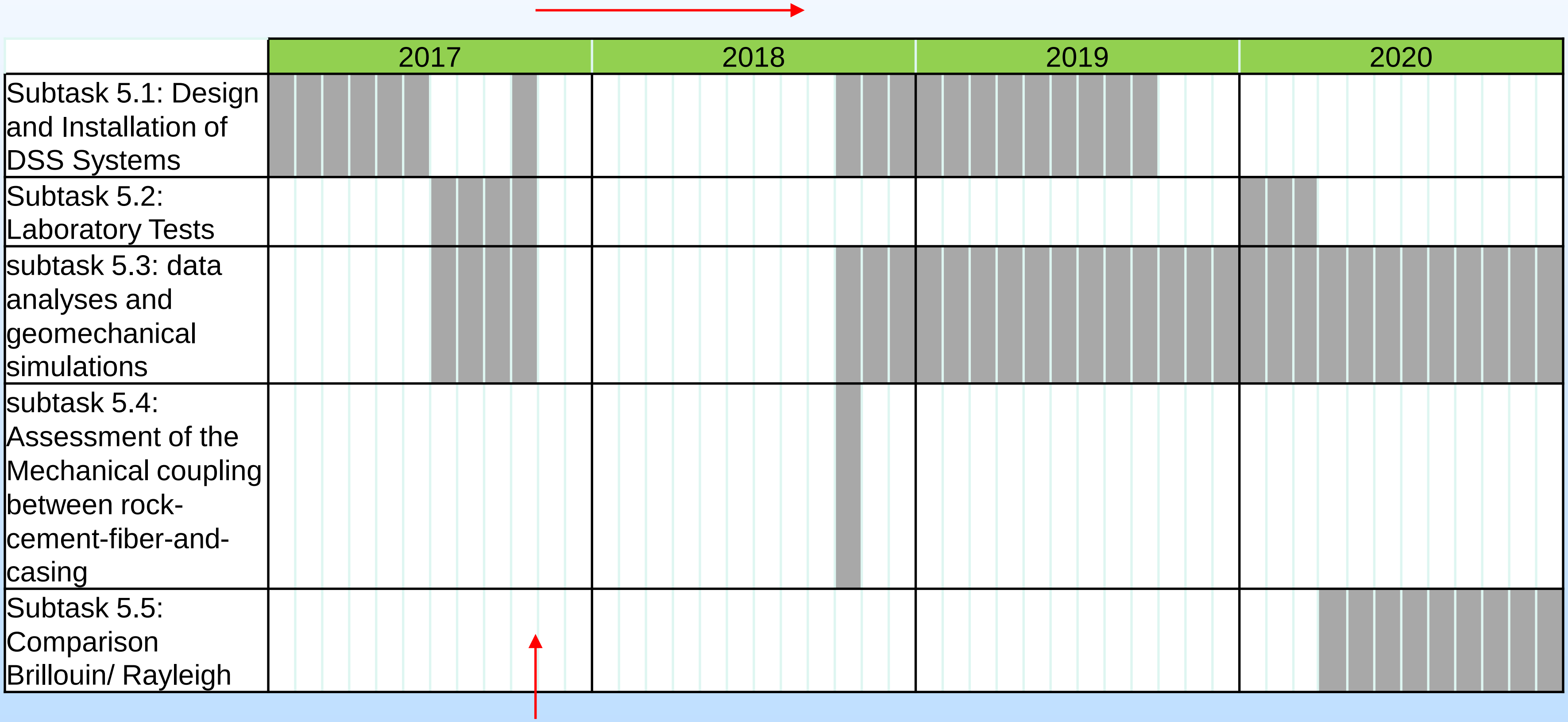
Goals and Objectives

The success criteria for this task involve assessing the delivery of our two planned subtasks, which are (1) analyze, interpretation and simulation of the available monitoring data and (2) In-situ assessment of the Mechanical coupling between rock-cement-fiber-and-casing. The second success criteria is if the data collected is of sufficient quality to achieve project monitoring objectives, and the continued use of the technology throughout the life of the FRS is accepted by the project team. A decision point is determination end of 2018 if volume of CO_2 injected for detectability is high enough.

Organization Chart

- Team Members and their role:
  - P. Jeanne, PI and Project Scientist;
  - B. Freifeld. Field Work Support;
  - M. Robertson, Field Work Support;
  - P. Cook, Scientific Engineering Associate

Gantt Chart



No injection or
monitoring

	2017												2018												2019												2020											
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Subtask 5.2: Laboratory Tests							▨	▨	▨	▨																											▨	▨	▨									
subtask 5.3: data analyses and geomechanical simulations							▨	▨	▨	▨												▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
subtask 5.4: Assessment of the Mechanical coupling between rock-cement-fiber-and-casing																						▨																										
Subtask 5.5: Comparison Brillouin/ Rayleigh																																								▨	▨	▨	▨	▨	▨	▨	▨	▨

Milestone

Bibliography