

Field Test and Evaluation of Engineered Biomineralization Technology for Sealing Existing wells



Project Number: FE0009599

Robin Gerlach

Al Cunningham, Lee H Spangler

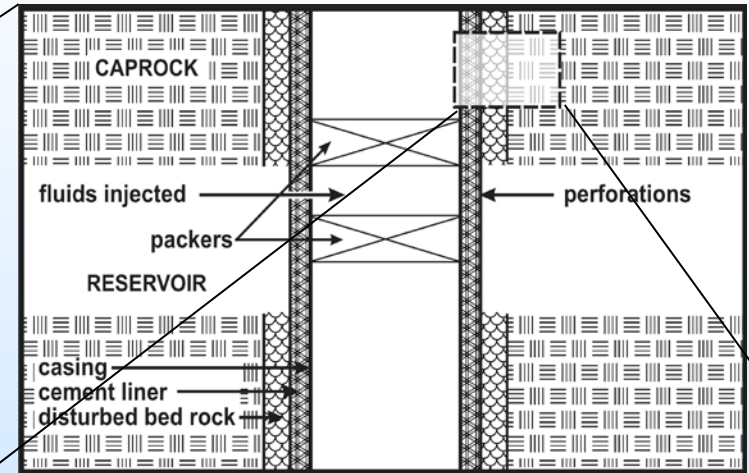
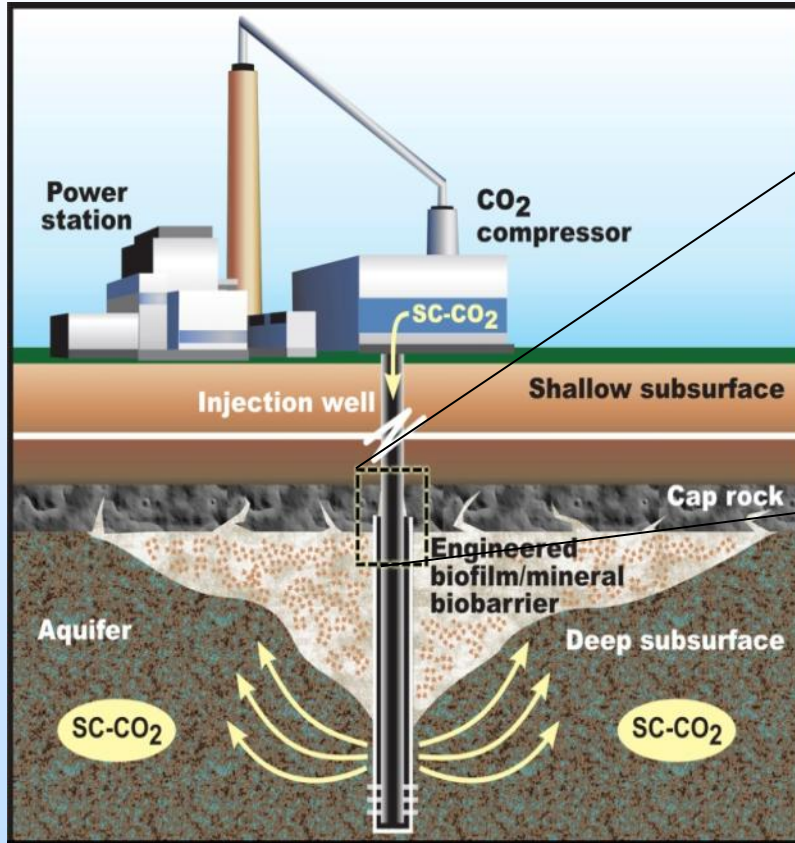
Montana State University

U.S. Department of Energy
National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and
Infrastructure for CCS
August 20-22, 2013

Presentation Outline

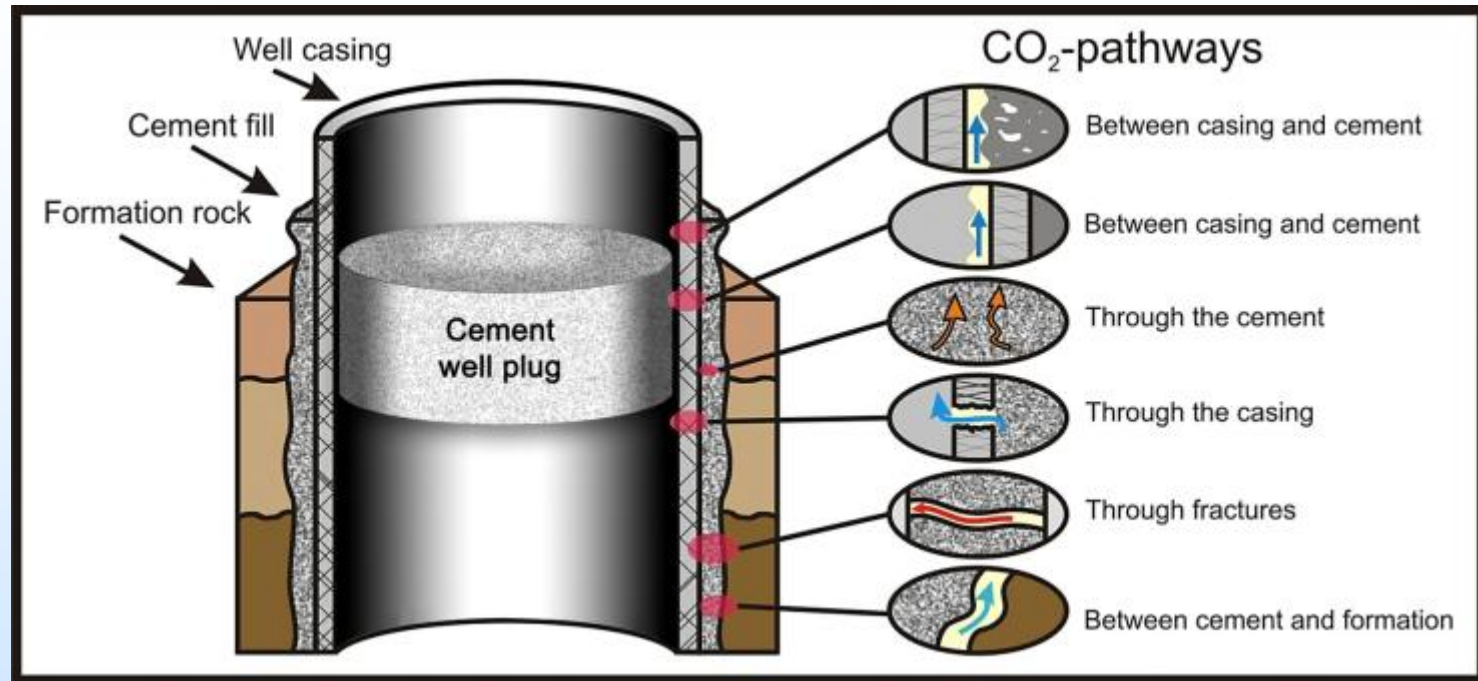
- Motivation & Benefit to the Program (required)
- Benefit to the Program and Project Overview (required)
- Background information
 - Project Concept (MICP)
 - Ureolytic Biomineralization, Biomineralization Sealing
- Accomplishments to Date
 - Site Characterization
 - Site Preparation
 - Experimentation and Modeling
 - Field Deployable Injection Strategy Development
- Summary

Motivation



Project Concept

-MICP sealing with low-viscosity fluids-



After Nordbotten and Celia, Geological Storage of CO₂, 2012

- Cement is a good technology for large aperture leaks, but can be too viscous to plug small aperture leaks (small fractures or interfacial delaminations).
- In some cases it is also desirable to plug the rock formation near the well.
- A missing tool is a plugging technology that can be delivered via low-viscosity fluids

Benefit to the Program

Program goals being addressed.

Develop technologies to demonstrate that 99 percent of injected CO₂ remains in the injection zones.

Project benefits statement.

The Engineered Biomineralized Sealing Technologies project supports Storage Program goals by developing a leakage mitigation technology for small aperture leaks that can be delivered via low viscosity solutions. The technology, if successfully applied, could provide an alternative technology to cement for plugging preferential CO₂ leakage pathways in the vicinity of wellbores.

Project Overview: Goals and Objectives

The **goal** of this project is to demonstrate the biomineralization technology for sealing preferential flow pathways in the vicinity of injection wells, thus addressing the DOE goal of storage permanence. This goal will be accomplished with the following **objectives**:

- (1) Characterize the Alabama well test site.
- (2) Design protocol for field injection test.
- (3) Perform field injection test
- (4) Evaluate results of field test.

Technical Status

- Focus the remaining slides, logically walking through the project. Focus on telling the story of your project and highlighting the key points as described in the Presentation Guidelines
- When providing graphs or a table of results from testing or systems analyses, also indicate the baseline or targets that need to be met in order to achieve the project and program goals.

Well Leakage Mitigation Using Biomineralization

A. Phillips, J. Eldring, E. Lauchnor, R. Hiebert, R. Gerlach,
A. Cunningham, L. Spangler

Energy Research Institute

Center for Biofilm Engineering

Montana State University

Bozeman MT, 59717



Schlumberger

Richard Esposito – Southern Company

Jim Kirksey – Schlumberger Carbon Services

Andreas Busch, Claus Otto, Joe Westrich, and Bart Lomans –
Shell International Exploration and Production B.V.



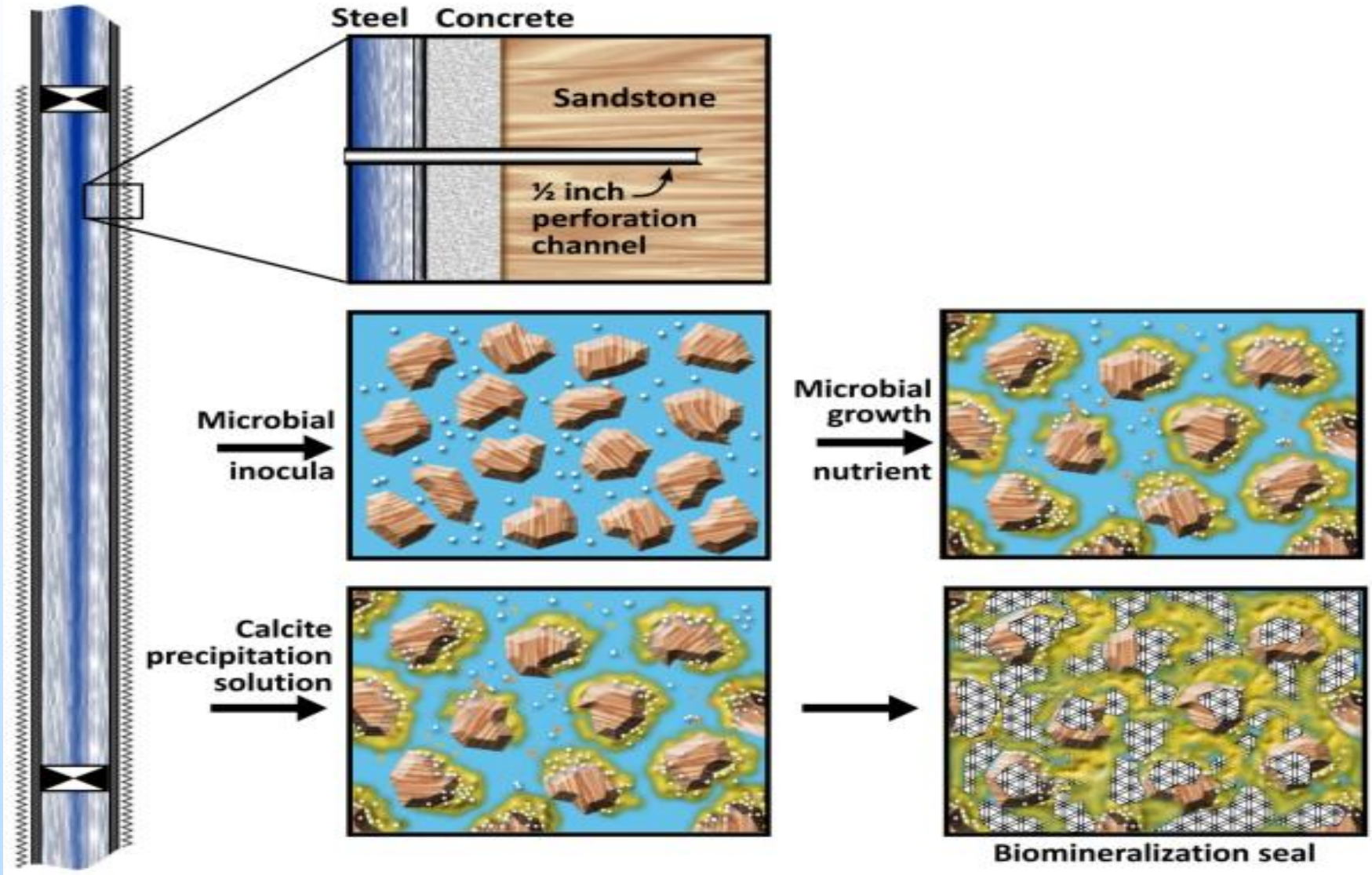
Rainer Helmig, Holger Class, Johannes Hommel – University of Stuttgart



Project Concept Summary

- An advanced method for sealing wells will be evaluated in the field at a fully cased well located at the Gorgas Power Plant in Walker County, Alabama.
- The sealing method is based on engineering microbial biofilm formation, together with precipitation of calcium carbonate minerals (i.e. calcite), to plug preferential flow paths outside the well casing (Microbially Induced Calcite Precipitation, MICP).
- The project will integrate mesoscale laboratory experiments together with simulation modeling to develop the protocol for conducting the field test.
- Effectiveness of the biomineralization seal will be evaluated in the field using pre- and post mineralization pressure testing.
- Following the field test additional mesoscale laboratory experiments/simulation modeling will be performed to thoroughly evaluate the injection protocol, delivery system and performance of the biomineralization seal.

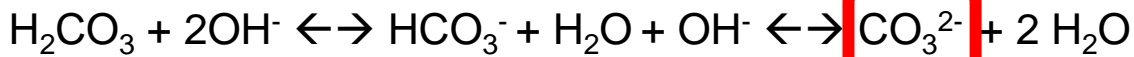
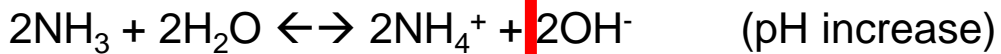
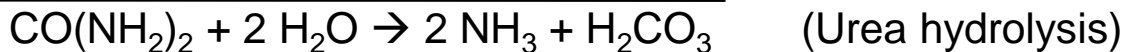
Project Concept



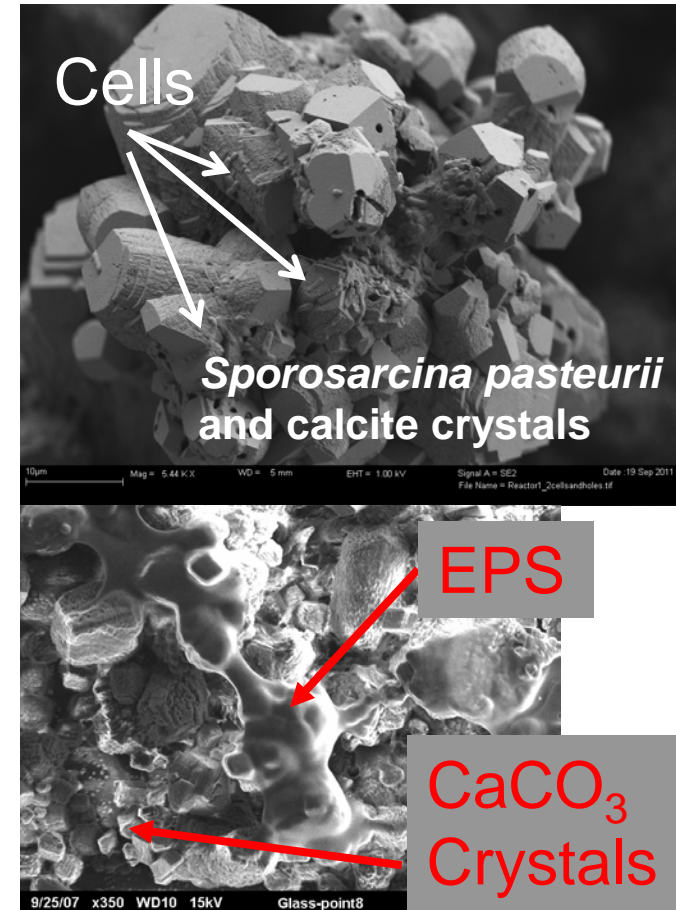
Underlying Biogeochemistry

Urea hydrolysis increases alkalinity and thus the saturation state of many minerals (e.g. calcium carbonate)

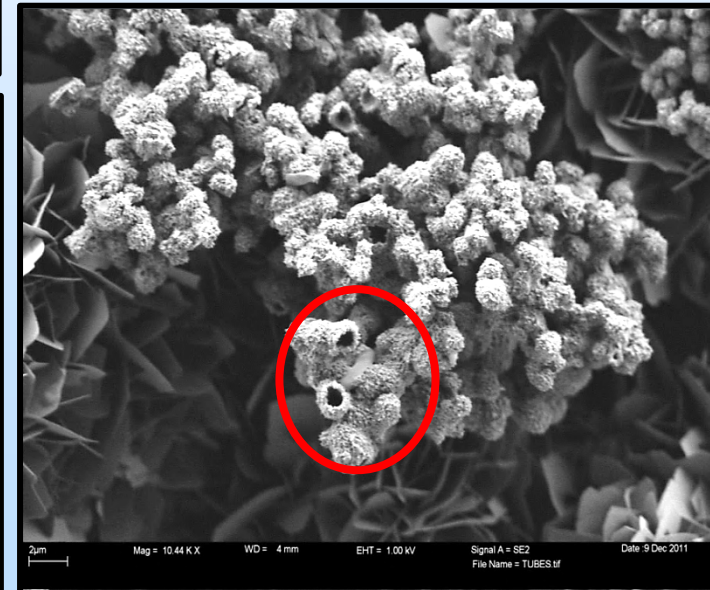
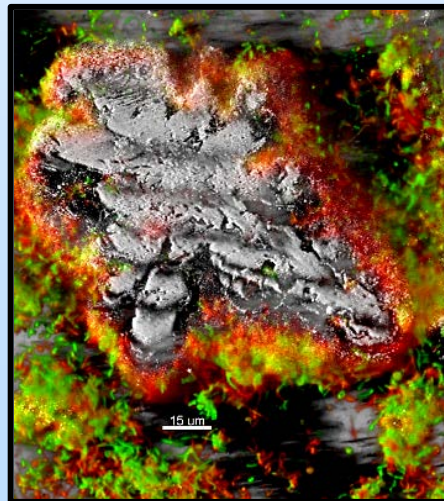
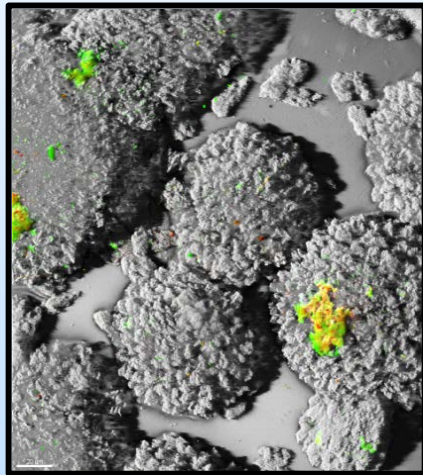
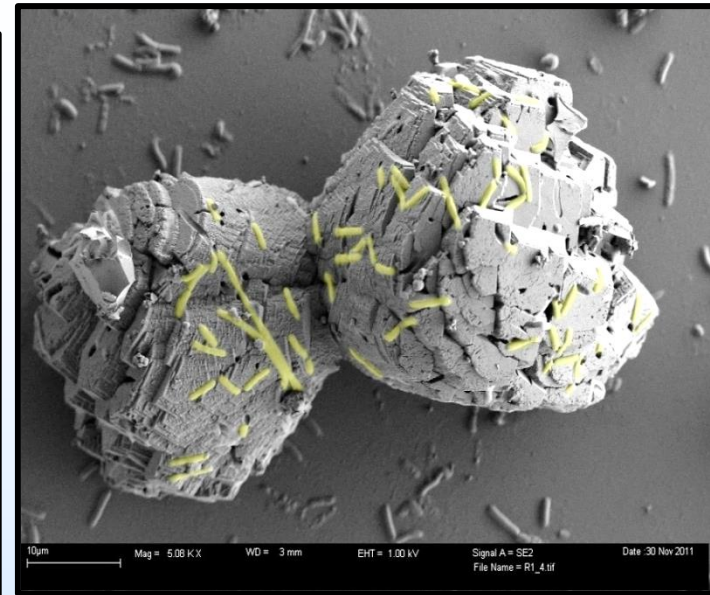
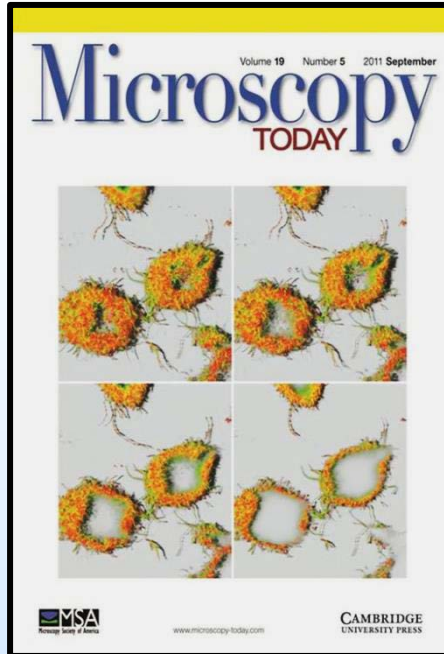
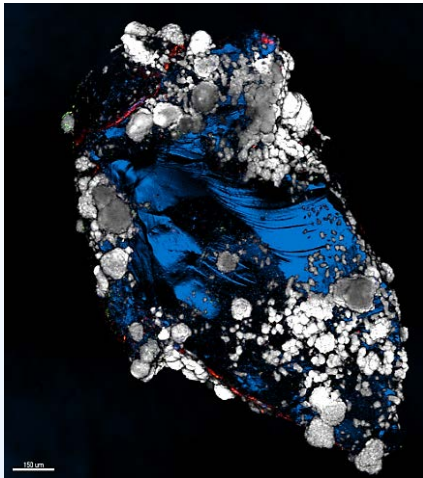
urease



Mitchell AC, Dideriksen K, Spangler LH, Cunningham AB Gerlach R. (2010). *Environ Sci Technol.* 44(13):5270-5276. doi: 10.1021/es903270w



Calcium Carbonate Biomineralization



Bio-Cemented Sand



Project tasks

- Task 1.0 Project Management and Planning (Months 1-24)**
- Task 2.0 Characterize the Alabama Well Test Site (Months 1-15)**
- Task 3.0 Experimental Simulation Modeling of
Biom mineralization Processes (Months 1-24)**
- Task 4.0 Develop Experimental Protocol for
biomineralization testing in the field (Months 1-19)**
- Task 5.0 Perform Field Test (Months 7-19)**
- Task 6.0 Evaluate Field Test Results (Months 19-24)**

Task 2.0 Characterize the Alabama Test site



1. Area Map



2. Topo Map



3. Gorgas Plant

Task 2.0 Characterize the Alabama Test site



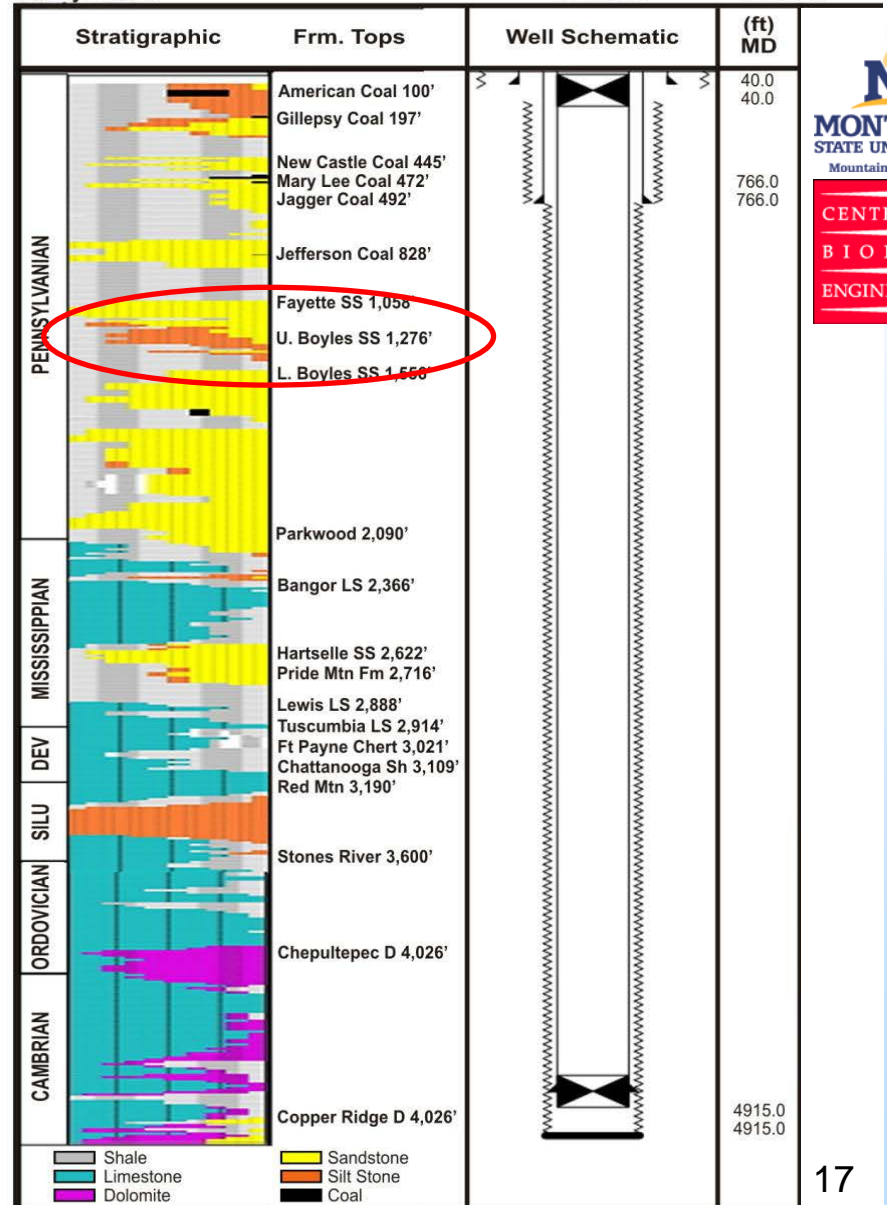
Characterize the Alabama Test site



Total well depth 4915 ft
 Test will be conducted at around 1115 ft, highest permeability based on well log

Client: Alabama Power Company
 Well: Gorgas #1
 Field: Wildcat
 State: Alabama
 County: Walker

Latitude: 33.648584975
 Longitude: -87.197051067
 Reference Datum: Ground Level
 Elevation: 376.10 ft



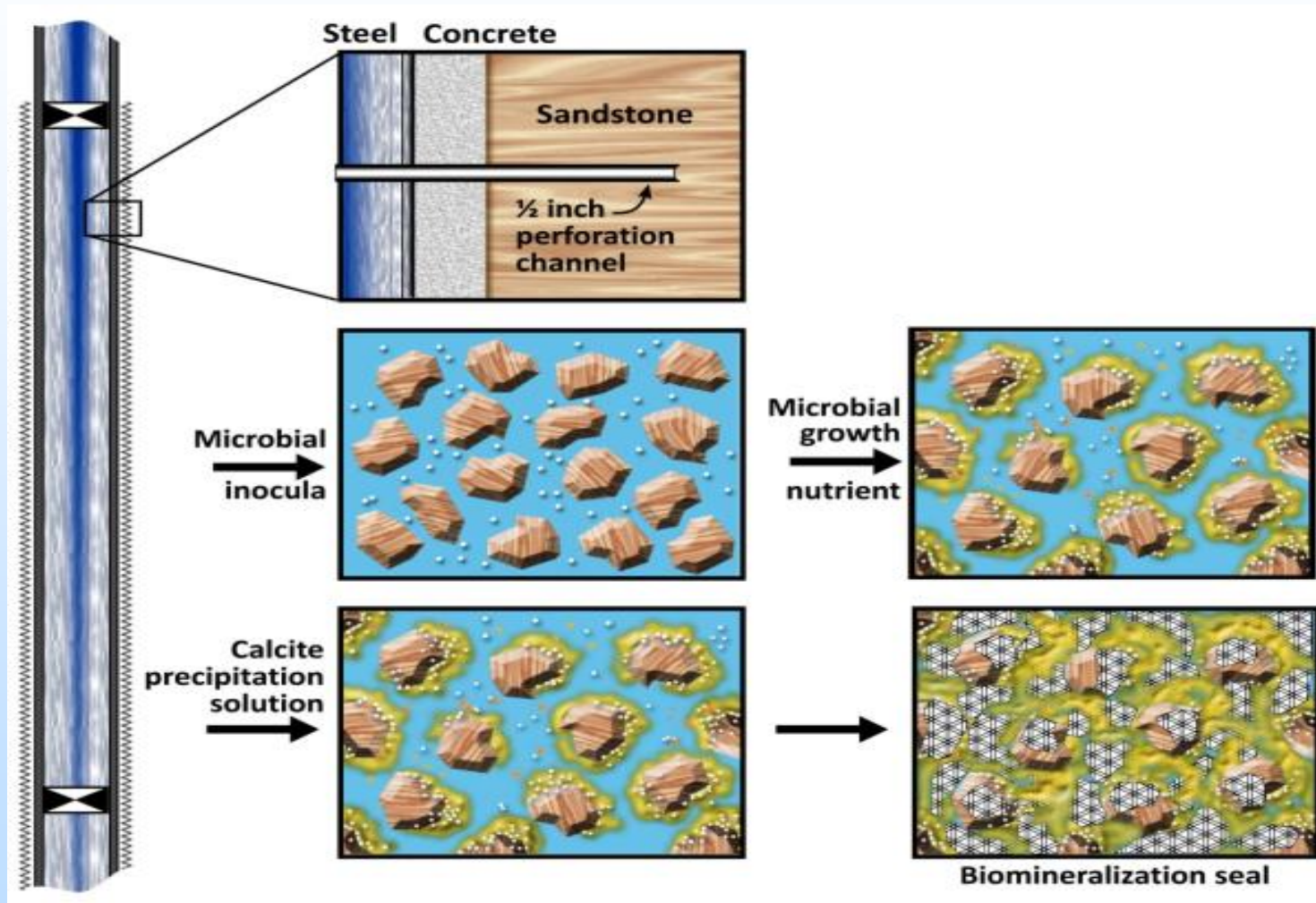
Characterize and Prepare the Alabama Test site



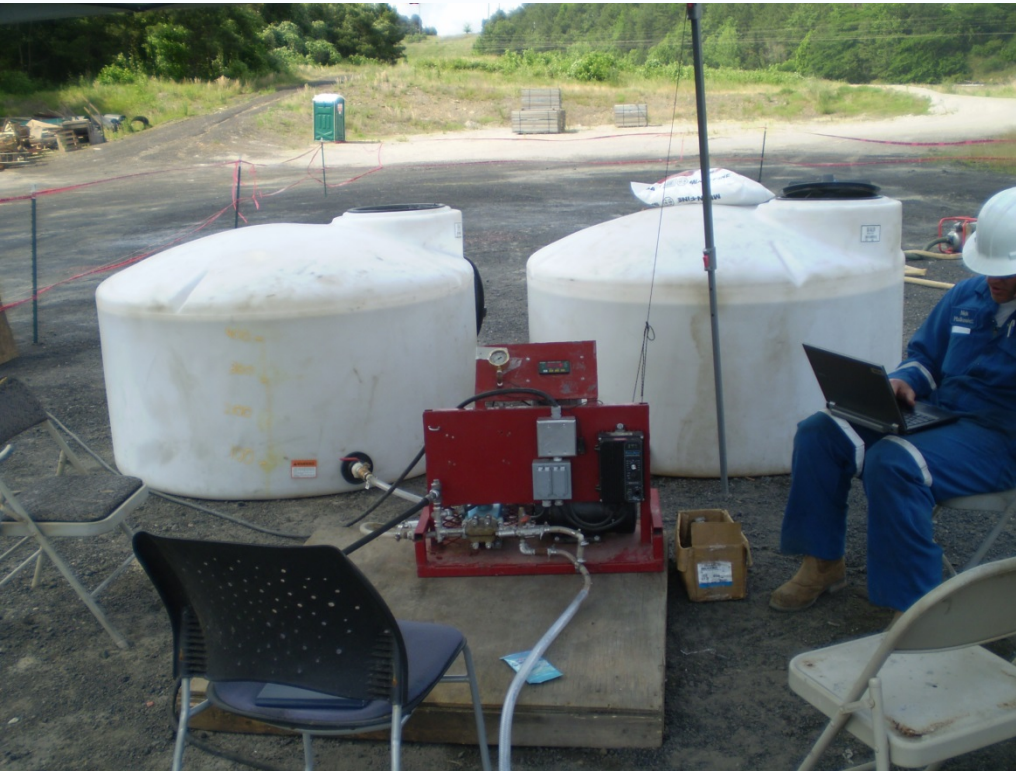
Characterize and Prepare the Alabama Test site



Field Test - Concept



Characterize the Alabama Test site

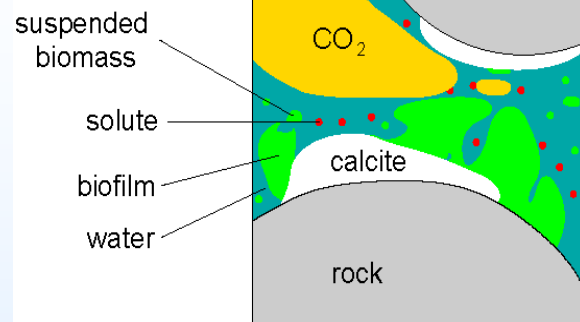
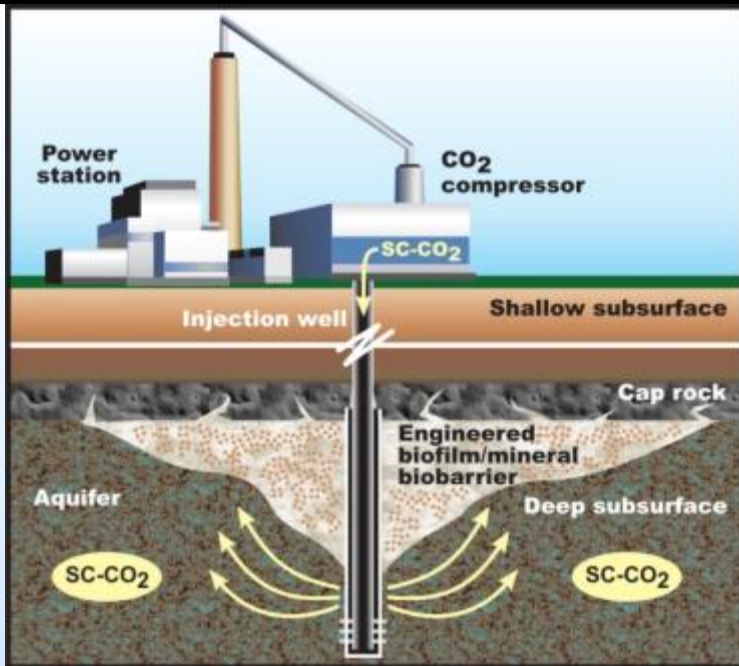


Characterize and prepare the Alabama Test site

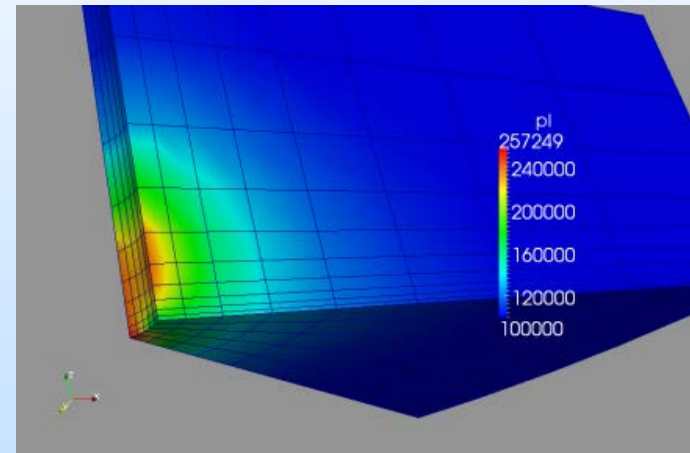
- Injection test
- Formation fractured at approx. 1350 psi – pancake fracture at around 1115 ft
- Injection test at 0.5 gpm for 4.5 hours at just over 500 psi (519 psi to 539 psi)
- Falloff analysis indicates approx. 11 mD formation permeability

Task 3.0 Experimental Simulation

Modeling of Biomineralization Processes



EBIGBO et al. (2010) AWR. 33:762–781. doi: 10.1016/j.advwatres.2010.04.004
EBIGBO et al. (2012) WRR. 48, W07519, doi:10.1029/2011WR011714



Phillips et al. (2013): Potential CO₂ Leakage Reduction through Biofilm-Induced Calcium Carbonate Precipitation. *Environmental Science and Technology*. 47(1):142–149. DOI: [10.1021/es301294q](https://doi.org/10.1021/es301294q)

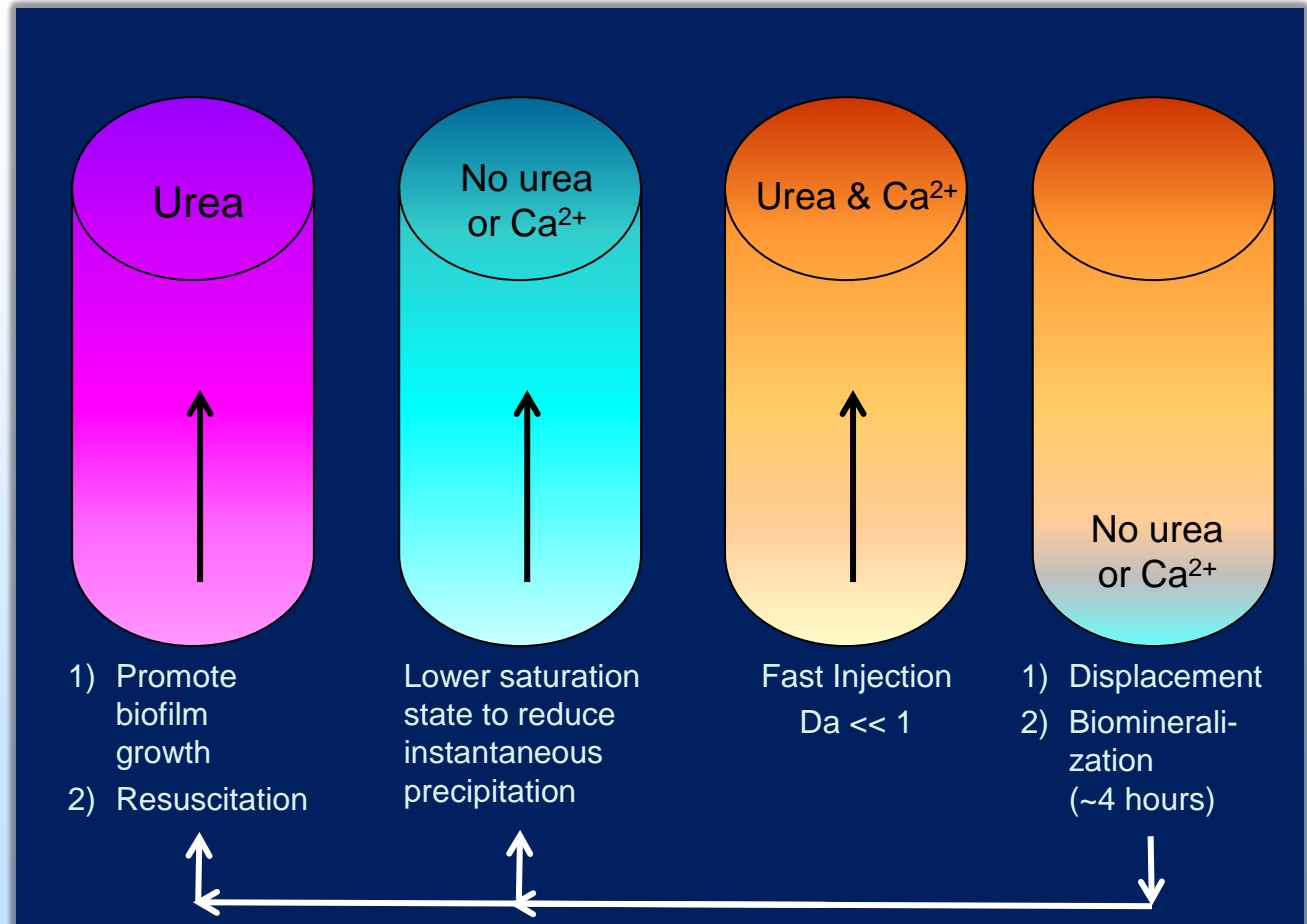
Injection strategy development

Promote homogeneous distribution

Prevent near-injection-point plugging

Promote efficient precipitation

Manipulating saturation state



Ebigbo, A; Phillips, A; Gerlach, R; Helmig, R; Cunningham, AB; Class, H; Spangler, LH. Darcy-scale modeling of microbially induced carbonate mineral precipitation in sand columns. *Water Resour. Res.* 2012, 48 (7), W07519.

Task 4.0 Develop Experimental Protocol for biomineralization testing in the field

The Laboratory-based protocol which has been demonstrated to deposit calcium uniformly with length is as follows:

- 1) Rock core is inoculated with *Sporosarcina pasteurii* and growth medium for a period of 18 hours to develop a biofilm.
- 2) Calcium-rich (1.25 M calcium) medium (including urea) is injected to initiate biomineralization. This injection lasts for 2 PV.
- 3) The core is then flushed for 2 PV with calcium-free media with urea prior to re-injecting 2 PV fresh calcium-rich medium.
- 4) Periodically, the biofilm is refreshed by injecting (2 PV) fresh growth medium without calcium.

**Uniform calcite distributions achieved in 60 cm columns,
5 cm rock cores, ~30 cm radial fracture, meter-scale
sandpack around simulated perforations**

Task 4.0 Develop Experimental Protocol for biomineralization testing in the field

60 cm column



5 cm rock cores
high P

30 cm radial fracture
high P



sandpack around simulated perforations
high P

Task 4.0 Develop Experimental Protocol for biomineralization testing in the field

At least three feasible approaches for inoculation and pulsed injection

1. Injection through 2.875 inch tubing – disadvantage large volumes to be exchanged to change fluids
2. Injection of one fluid through 2.875 inch tubing and placement of inoculum as well as the other fluids by bailer delivery – disadvantages: limited amount of biomineralization fluids can be delivered, significant time needed for bailer runs.
3. Injection through different 0.5 inch tubing attached to the outside of 2.875 inch tubing – disadvantage: expensive and labor intensive; advantage: high control over which fluid is injected when.

Combination of (2.) and (3.) is possible and currently being considered

Summary & Accomplishments to Date

- Field site characterization and preparation completed
- Field test scheduled for late March/early April 2014
- Field deployable injection protocol development in progress
- Continued development and refinement of computational modeling tools to predict mineral distribution
- Completed biomineralization experiment with horizontal perforation-like injection tubes as analog to field site
- Evaluating alternatives to obtaining 70 cm diameter, 35 cm thick fractured cores (working with Schlumberger)

Summary

- **Task 2.0 Characterize the Alabama Well Test Site**
 - Subtask 2.1 Determine the location for injection in field well. – **complete**
 - Subtask 2.2 Identify ureolytic microbes suitable for use in field test. – **in progress, one organism identified**

Summary

- **Task 3.0 Experimental Simulation Modeling of Biomineralization Processes**
- Subtask 3.1 Pre- field experimental modeling – **in progress**
- Subtask 3.2 Post-field experimental modeling – **not started**

Summary

- **Task 4.0 Develop protocol for Field Experiment**
- Subtask 4.1 Design mesoscale rock core analogue experiment – **in progress**
- Subtask 4.2 Perform mesoscale rock core analogue experiment – **in progress**
- Subtask 4.3 Perform preparatory steps for well test – **in progress**

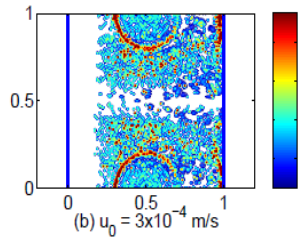
Summary

- **Task 5.0 Perform Field Test**
- Subtask 5.1 Prepare well for injection of test materials – **in progress**
- Subtask 5.2 Perform injection in accordance with field test protocol – **not started**

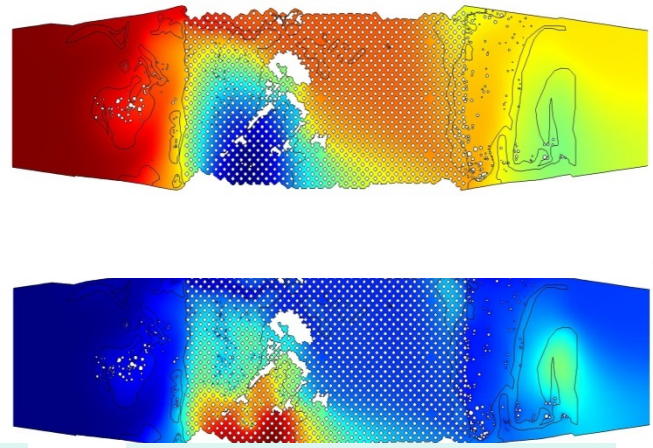
Summary

- **Task 6.0 Evaluate Field Test Results**
- Subtask 6.1 Repeat mesoscale analogue test – **not started**
- Subtask 6.2 Perform simulation modeling to evaluate field and mesoscale test results – **not started**

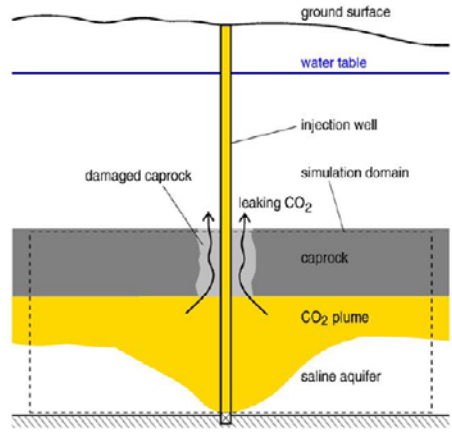
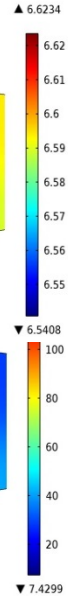
Scales of experimentation and modeling



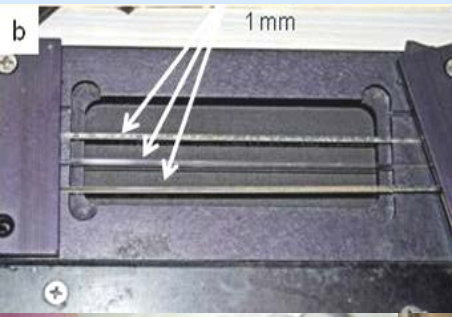
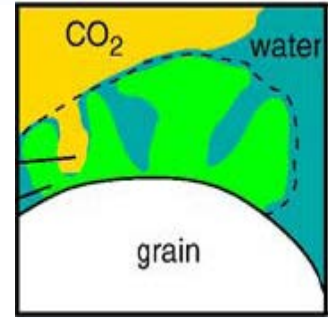
nm to cm



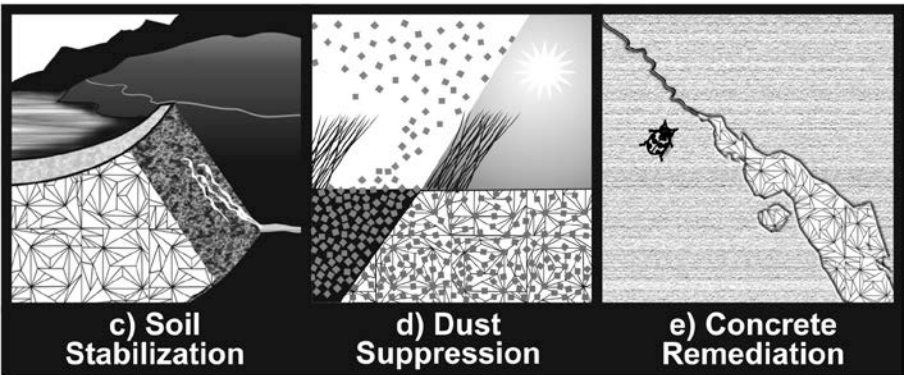
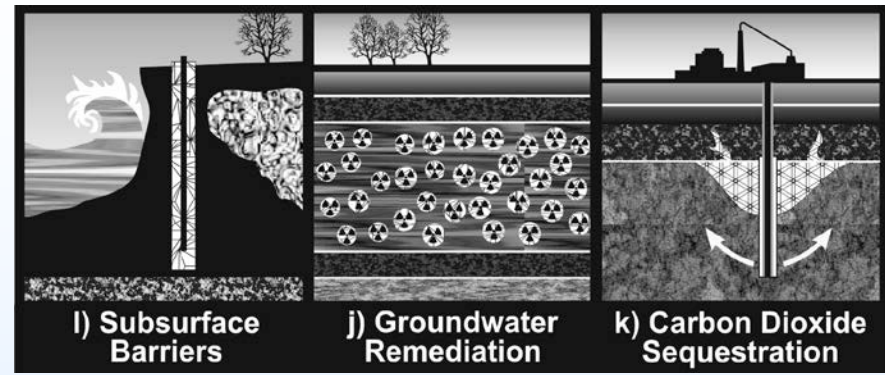
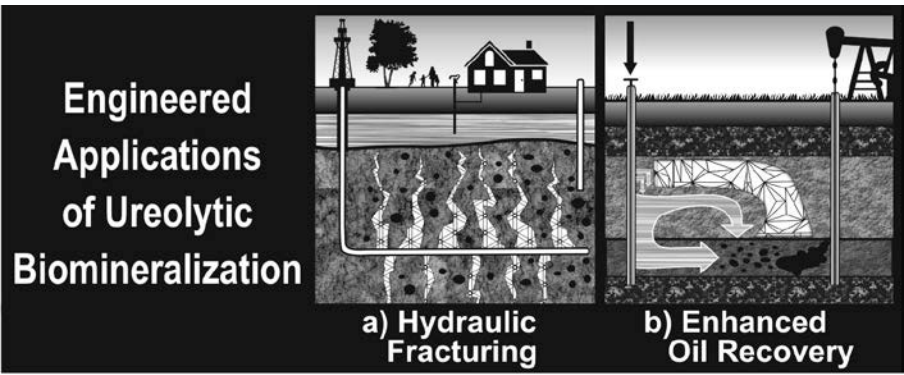
μm to dm



cm to 100s of m



Engineered Applications of MICP



Phillips, A.J.; Gerlach, R.; Lauchnor, E.; Mitchell, A.C.; Cunningham, A.B.; Spangler, L. Engineered applications of ureolytic biomineralization: a review. *Biofouling*. 29(6): p. 715-733. DOI:

[10.1080/08927014.2013.796550](https://doi.org/10.1080/08927014.2013.796550)

Peg Dirckx, 2012

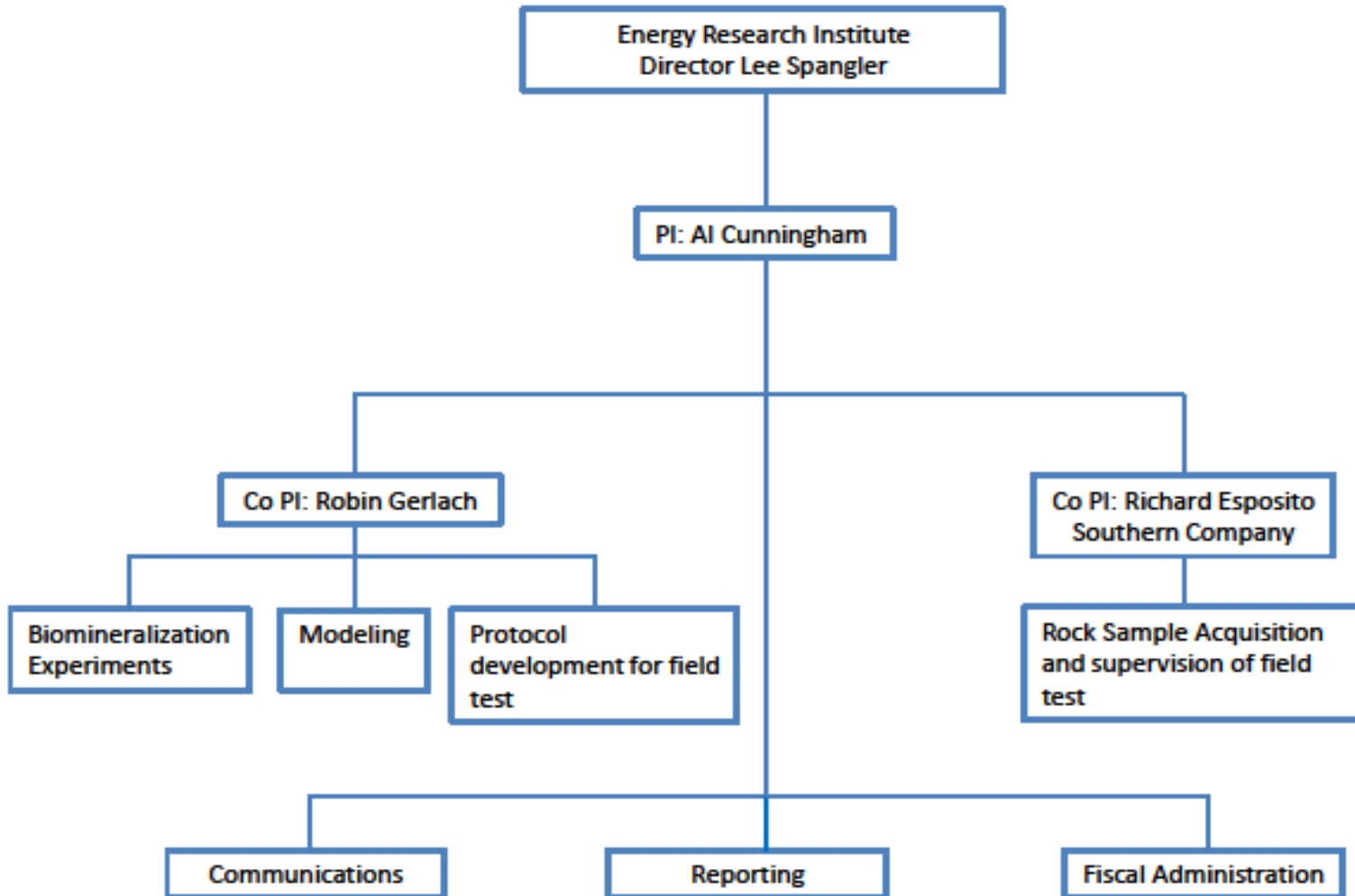
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Appendix

- These slides will not be discussed during the presentation, **but are mandatory**

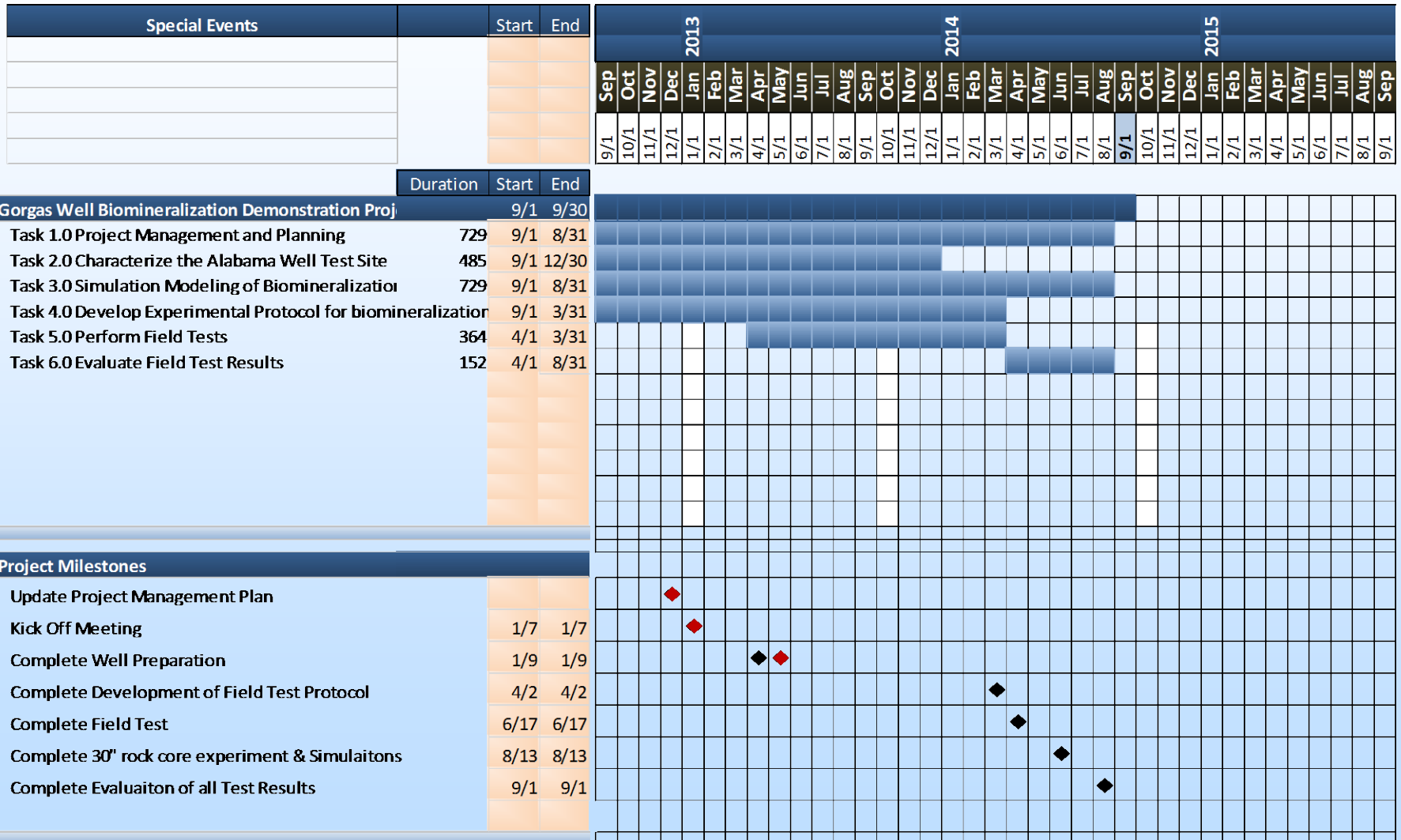
Organization Chart



Gantt Chart

- Provide a simple Gantt chart showing project lifetime in years on the horizontal axis and major tasks along the vertical axis. Use symbols to indicate major and minor milestones. Use shaded lines or the like to indicate duration of each task and the amount of that work completed to date.

Gantt Chart



Bibliography

1. Connolly, J.; Kaufman, M.; Rothman, A.; Gupta, R.; Redden, G.; Schuster, M.; Colwell, F.; Gerlach, R. (2013): Construction of two ureolytic model organisms for the study of microbially induced calcium carbonate precipitation. *Journal of Microbiological Methods*. [94\(3\):290-299](#). DOI: [10.1016/j.mimet.2013.06.028](#)
2. Cunningham, A.B.; Lauchnor, E.; Eldring, J. Esposito, R.; Mitchell, A.C.; Gerlach, R.; Connolly, J.; Phillips, A.J.; Ebigbo, A.; Spangler, L.H. (2013): Abandoned Well CO₂ Leakage Mitigation Using Biologically Induced Mineralization: Current Progress and Future Directions. *Greenhouse Gas Sci. Technol.* 2:1–10. DOI: [10.1002/ghg.1331](#)
3. Lauchnor, E.G.; Schultz, L.; Mitchell, A.C.; Cunningham, A.B.; Gerlach, R. (2013): Bacterially Induced Calcium Carbonate Precipitation and Strontium Co-Precipitation under Flow Conditions in a Porous Media System. *Environmental Science and Technology*. 47(3):1557–1564. <http://dx.doi.org/10.1021/es304240y>
4. Mitchell, A.C.; Phillips, A.J.; Schultz, L.N.; Parks, S.L.; Spangler, L.H.; Cunningham, A.B.; Gerlach, R. (2013): Microbial CaCO₃ mineral formation and stability in an experimentally simulated high pressure saline aquifer with supercritical CO₂. *International Journal of Greenhouse Gas Control*. 15(July):86-96. DOI: [10.1016/j.ijggc.2013.02.001](#)
5. Phillips, A.J.; Gerlach, R.; Lauchnor, E.; Mitchell, A.C.; Cunningham, A.B.; Spangler, L. Engineered applications of ureolytic biomineralization: a review. *Biofouling*. 29(6): p. 715-733. DOI: [10.1080/08927014.2013.796550](#)