The coupled effects of microbial and physic-chemical processes on geological carbon storage

Center for Frontiers of Subsurface Energy Security

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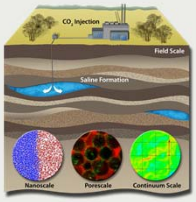
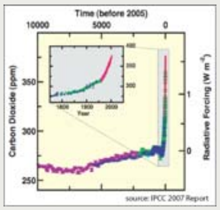
Introduction

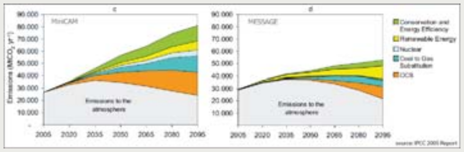


The Center for Frontiers of Subsurface Energy Security (CFSES) is pursuing scientific understanding of multi-scale, multi-physics processes to ensure safe and economically feasible storage of CO_2 and other byproducts of energy production without harming the environment. The research presented here focuses on CFSES studies that examine the interplay between geological carbon storage and subsurface microbiology.

Geological carbon storage

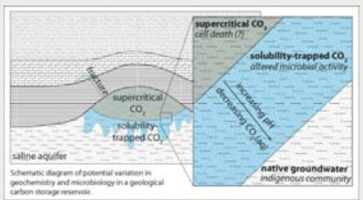
Fossil fuel consumption has caused a dramatic increase in atmospheric CO_2 levels (graph to the right). Consequences of the increase in CO_2 and other greenhouse gases include global warming, sea level rise, and ocean acidification. Multiple strategies are required to address this problem (graph below). Geological carbon storage has been identified as part of the solution.





Microbes and carbon storage

The long-term success of geological carbon storage and other subsurface energy applications will depend heavily on the chemical and physical properties of the subsurface. Biological controls are also important to consider, however, because microbes strongly influence subsurface chemical and physical properties. The interplay between microbiology and injected CO_2 will be complex and spatially variable (figure below). A basic understanding of this interplay is necessary for the development of strategies to enhance carbon storage.



Schematic diagram of potential variation in geochemistry and microbiology in a geological carbon storage reservoir.

Acknowledgements

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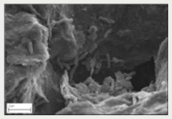
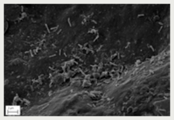
Mineralogy and cell survival

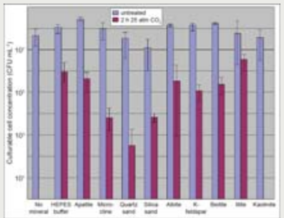
Aims: Understanding how CO_2 injection will affect cell survival is central to the question of whether microbes can be used to enhance CO_2 trapping. This study considers the relationship between mineralogy and cell survival.

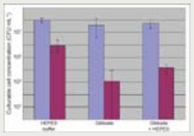
Methods and results: Cells of an iron reducing bacterium were grown for 3 days and then exposed to 25 atm CO_2 for 2 to 8 h. The presence of minerals generally improved cell survival (bar charts below), with the exception of most clay minerals.



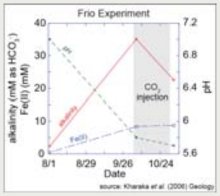
Conclusions: Minerals can enhance cell survival by providing surfaces for attachment and pH buffering. Release of metals and semi-metals by mineral dissolution, however, can limit cell survival.







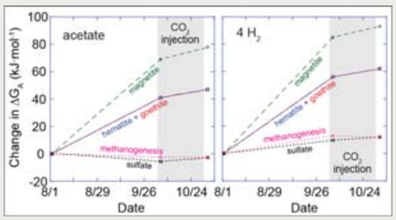
Energy for microbial metabolisms



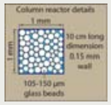
Aims: Injecting CO_2 into the subsurface triggers reactions that alter aquifer and groundwater composition, as shown to the left. This analysis considers how these changes could affect what reactions microbes carry out in the subsurface.

Methods and results: Using data collected during a CO_2 injection experiment in the Frio Formation, we calculated how energy available for groups of subsurface microbes changed as a result of CO_2 injection. Energy available for microbial iron reduction increased sharply as a result of CO_2 injection and varied little for other groups considered (graphs below).

Conclusions: Energy available for individual microbial reactions influences the rate at which those reactions can proceed. The increase in energy available for iron reducers, therefore, could allow the rate of iron reduction to increase. This finding implies that iron reducers may be best to use in biological strategies to enhance CO_2 trapping.

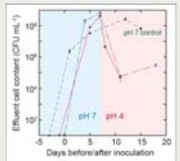


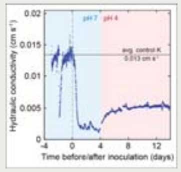
Bio-clogging porous media



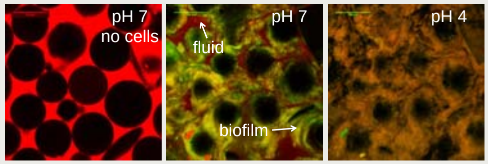
Aims: Microbial activity in the subsurface can limit the groundwater flow through sediment and bedrock by clogging pores. This analysis examines how groundwater acidification following CO_2 injection will affect the stability of microbial biofilm in porous medium.

Methods and results: We grew biofilms in columns filled with glass beads (figure above) until significant biological clogging occurred. Next, the pH of fluid flowing through the column was lowered to 4. As a result, culturable cell levels decreased sharply (graph to the right) and hydraulic conductivity increased slightly. The columns remained significantly clogged (lower right graph), however, because most of the biomass remained intact (images below).



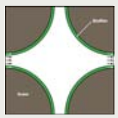


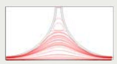
Conclusions: Biofilms can withstand exposure to acidified groundwater and may provide a strategy to improve trapping in CO_2 storage reservoirs.



Numerical simulations

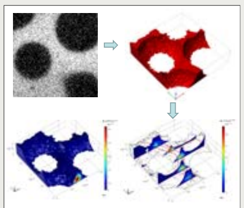
Aims: Our understanding of microbial biofilm is based on pore-scale observations, which are difficult to implement in field-scale applications. This analysis aims to identify upscaling parameters by developing numerical models that couple biofilm and porous medium hydraulic properties at different spatial scales.

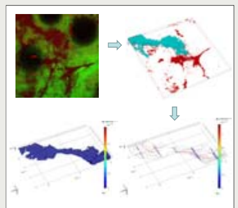




Methods and results: For preliminary models, a finite-element mesh of pore space was constructed from confocal microscopy images and Navier-Stokes equations for flow were solved using multiphysics software (figures below). No flow was assumed to occur in biofilm. Efforts are in progress to use Navier-Stokes equations coupled to the Brinkman equation to solve for flow within open pores and biofilm, respectively (figures on left).

Conclusions: Preliminary findings illustrate the importance of scale and indicate that accounting for flow through biofilm can be important.


Hydraulic conductivity = 2.4x10^{-3} cm s^{-1}


Hydraulic conductivity = 5.6x10^{-7} cm s^{-1}