

# Stanford Center for Carbon Storage

## 2022 Research Highlights

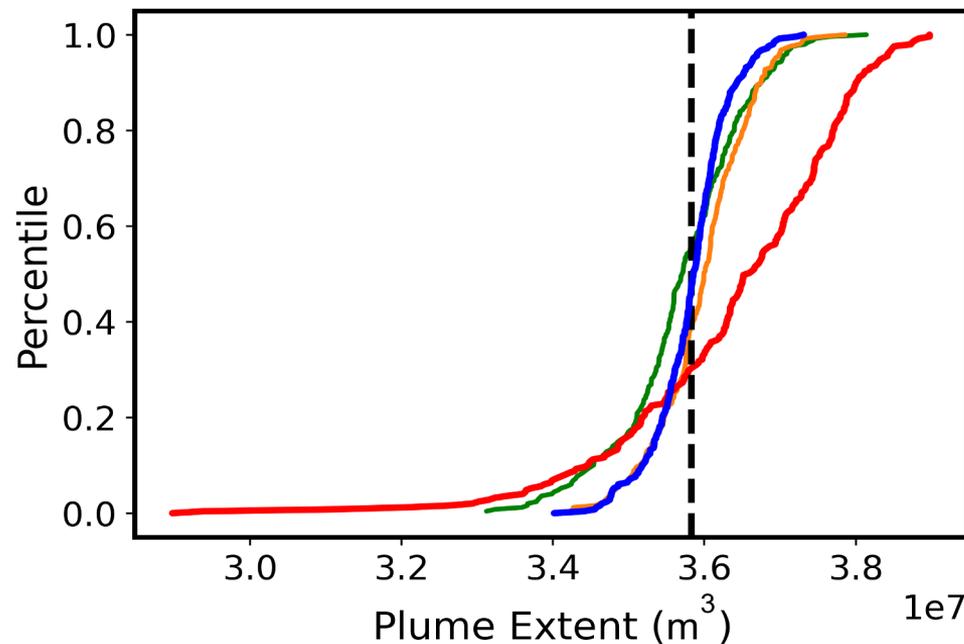
# An Integrated Framework for Optimal Monitoring and History Matching in CO<sub>2</sub> Storage Projects

## Scientific Achievement

This work optimized a CCUS monitoring plan using only a prior understanding of the subsurface. This significantly decreased computational expense.

## Significance and Impact

Work has been successfully and directly utilized in an active CO<sub>2</sub> storage permit in Illinois. It will likely be used in a second permit cycle as well.



## Research Details

- Developed workflow to optimize CCUS monitoring plan to reduce uncertainty in the plume location
- Optimization occurred only on the prior understanding of the subsurface – reducing costs
- Workflow then uses ES-MDA history matching to predict the plume behavior into the future
- Worked closely with the Illinois State Geological Survey to implement workflow for a real-life project

# Development and Application of Saline Reservoir Site Selection Criteria in the Gulf of Mexico

## Scientific Achievement

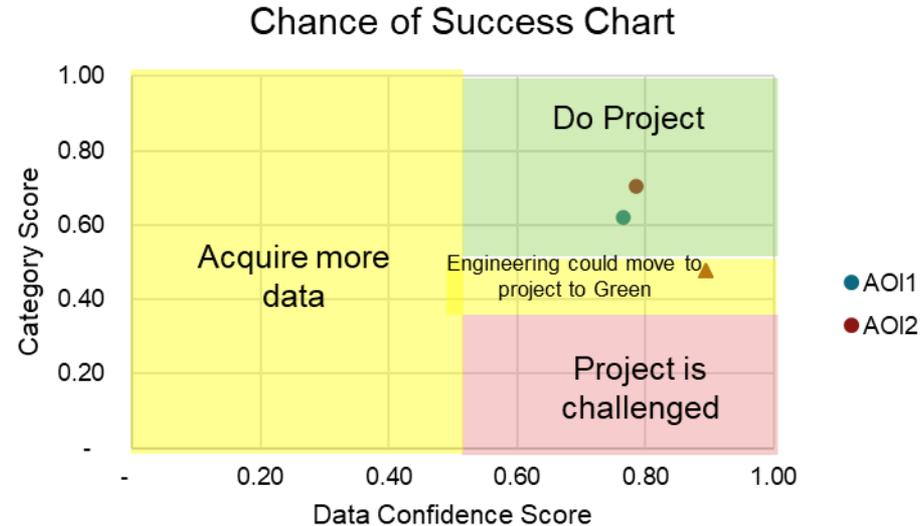
Developed a site selection criteria that will allow for the identification of suitable saline reservoir sequestration sites for hub scale projects in offshore environments with an emphasis on poorly consolidated sediments undergoing dynamic deposition.

## Significance and Impact

Two areas were screened and ranked and one was identified to progress to site characterization

## Research Details

- A multi-stage screening process was developed to screen, eliminate and score potential sites using readily available data for saline reservoirs that incorporates data confidence scores.
- Two saline sites were screened and ranked in the Gulf of Mexico using well logs, seismic lines, porosity logs, and nearby analogs.



# Technoeconomics of CCS Opportunities in the southern San Joaquin Basin

## Scientific Achievement

- Provided technoeconomic analysis with SimCCS using the newly modified 45Q tax credit values in southern California.
- Proposed regional scenarios to deploy optimal CCS projects.

## Significance and Impact

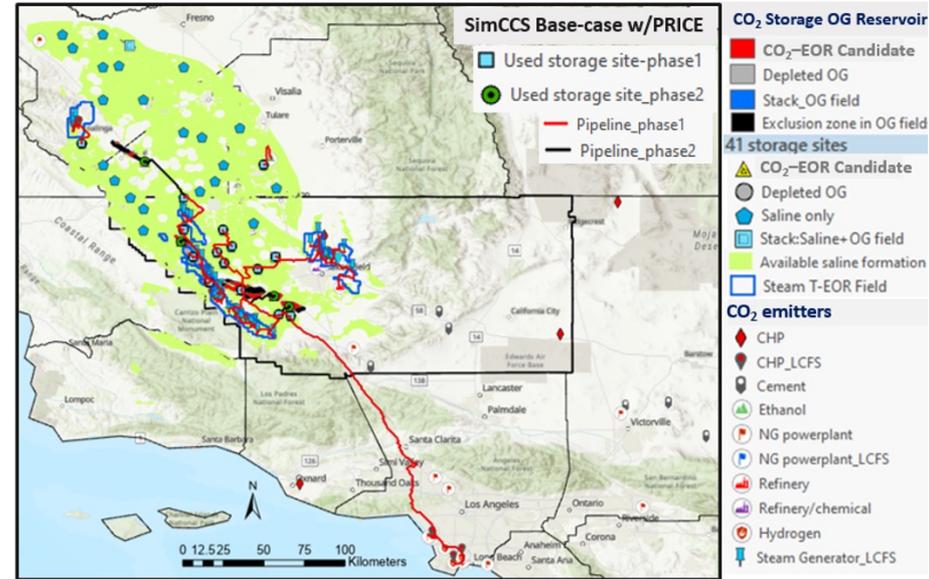
- Assessed capture cost for thermal EOR facilities.
- The storage sites in the southern San Joaquin Basin can serve as storage hubs.

## Research Details

- The capture cost for CHP and SG units was estimated.
  - CHP: \$59 ~ \$78/tCO<sub>2</sub>, -SG: \$58 ~ \$74.5/tCO<sub>2</sub>
- The current updated 45Q credit can capture and store 22 MtCO<sub>2</sub>/y with an economic benefit in the target region.

## Acknowledgment

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**SimCCS base-case scenario using PRICE mode can store 22 MtCO<sub>2</sub>/y. The LCFS credit is \$100/tCO<sub>2</sub> and the project lifetime is 20 years with 12 years of 45Q credit.**

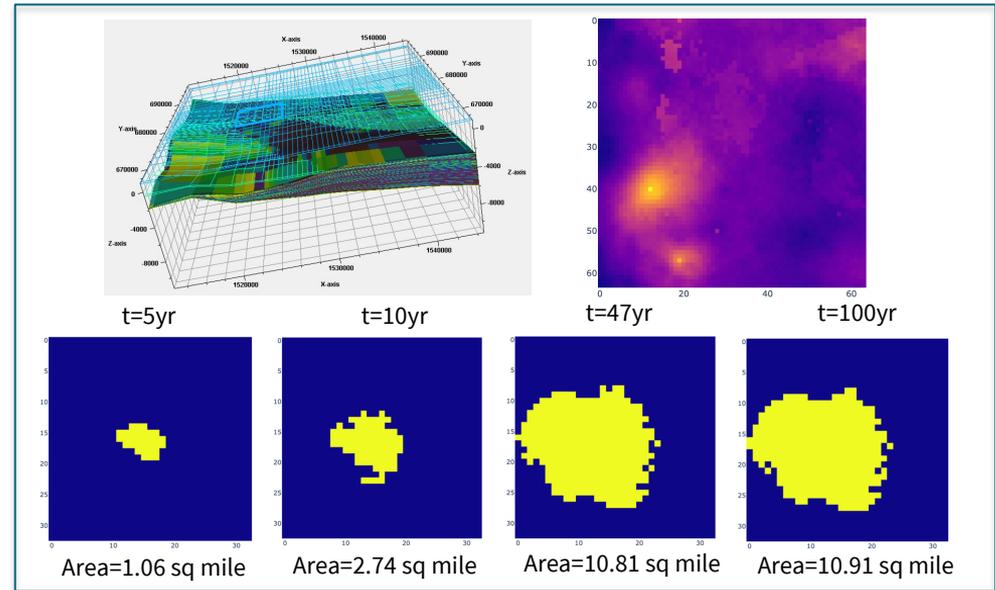
# Dynamic Characterization of Carbon Plumes Based on CCS Site Modeling

## Scientific Achievement

Numerical modeling and simulation with multi-purpose and multi-levels of complexity for CCS activities. Developed a pipeline toolbox to interact with simulator automatically for large amounts of computations.

## Significance and Impact

Characterized carbon plumes for a pilot CCS site. The results are useful for application of EPA VI well permit.



## Research Details

- Demonstrate numerical modeling and simulation based on a CCS pilot project in Central Valley
- Characterize carbon plumes dynamically throughout the entire lifetime of CCS project
- Develop an automatic pipeline toolbox to interact with the numerical simulator
- Describe the plumes migration in the dipped storage formation

# Elastic and viscoplastic behavior of shales in the presence of argon and supercritical CO<sub>2</sub>

## Scientific Achievement

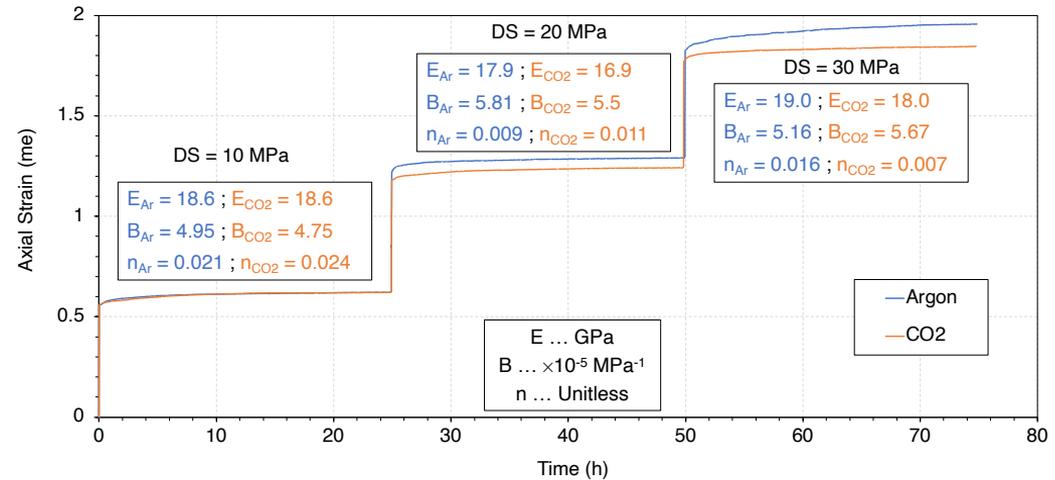
Enhanced creep deformation due to carbonate dissolution resulting in higher  $n$  and  $B$  values. Adsorption of CO<sub>2</sub> in clay/TOC-rich sample, on the other hand, led to loss of ductility due to swelling-induced strain.

## Significance and Impact

Role of mineralogy and pre-existing micro-cracks in the sealing capacity of caprock. Interaction with CO<sub>2</sub> resonates the role of microstructure on viscoplastic properties of shale rocks

## Research Details

- Increase in stiffness after creep deformation due to pore collapse
- Enhanced creep deformation in carbonate-rich sample caused by dissolution-induced new porosity
- Loss of ductility in clay/TOC-rich sample due to swelling-induced strain
- Lower Young's modulus and ductility in micro-cracked sample after exposure to scCO<sub>2</sub>
- Constant  $B$  and  $n$  values in 2-day and 7-day creep tests



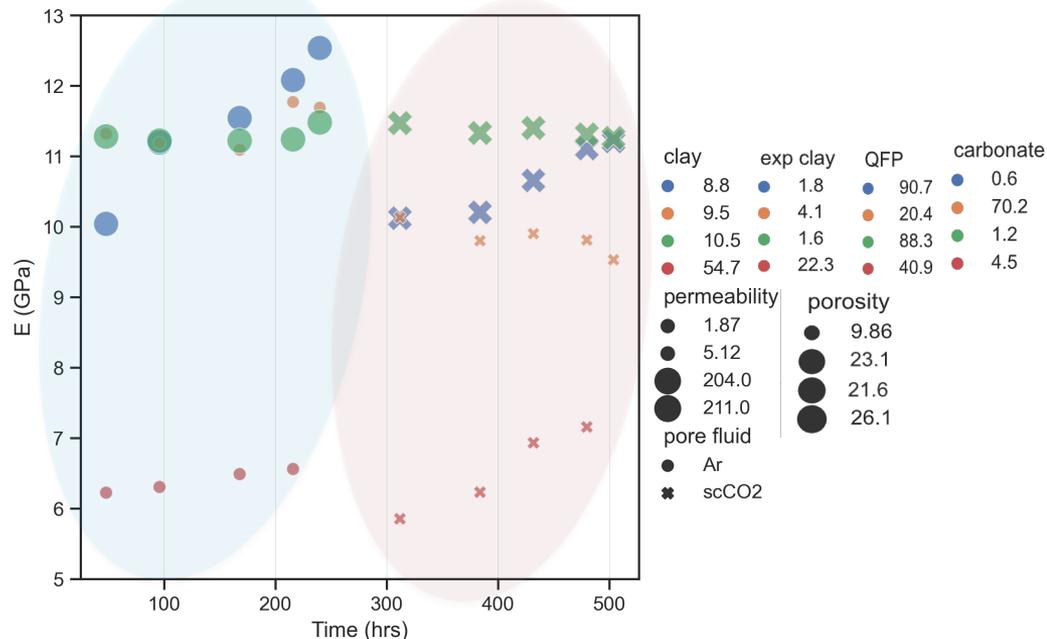
# Poroelastic characteristics of depleted reservoirs in the presence of supercritical CO<sub>2</sub>

## Scientific Achievement

We characterized the poroelastic deformation of four cores derived at relevant depths with various mineral compositions from a field in the Gulf of Mexico.

## Significance and Impact

The poroelastic responses of a reservoir due to depletion and scCO<sub>2</sub> injection were studied. Young's modulus behaves differently when exposed to scCO<sub>2</sub> in QFP-, Clay- and Carbonate-rich samples.



## Research Details

- The poroelastic deformation of cores from the West Delta field in the Gulf of Mexico was characterized experimentally and the impacts of supercritical CO<sub>2</sub> on the specimen were investigated. The experimental program simulated reservoir stress changes due to production-induced depletion and scCO<sub>2</sub> injection through cycling both the confining pressure and pore pressure. We measured the deviatoric stress, volumetric strain, derived the corresponding Young's (E), bulk moduli (K<sub>b</sub>) and Biot coefficient ( $\alpha$ ).

# Fault slip induced by supercritical CO<sub>2</sub> injection

## Scientific Achievement

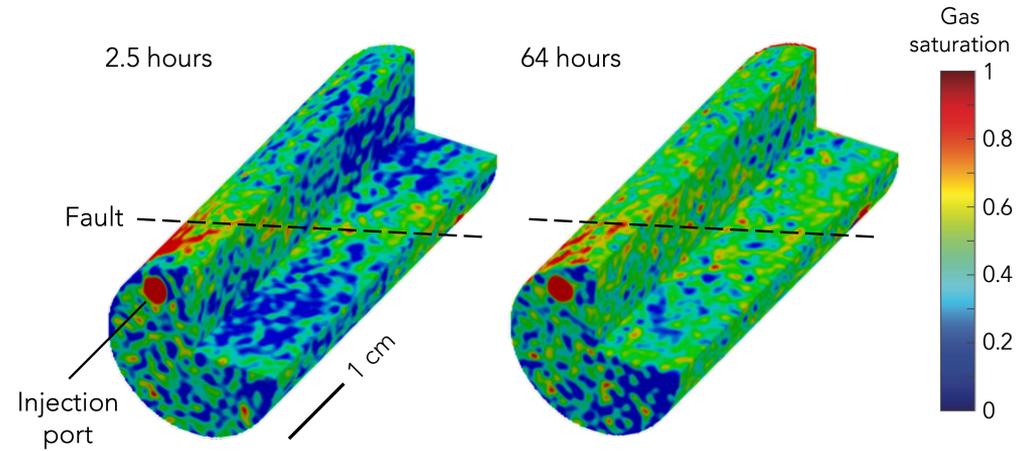
We studied how fault strength, roughness, and permeability change during injection of CO<sub>2</sub> in shale rocks. We also visualized the distribution of CO<sub>2</sub> using X-ray CT and observed off diffusion.

## Significance and Impact

Shale fault permeability is slightly altered after induced slip from CO<sub>2</sub> injection, but the matrix retains its the sealing capacity.

## Research Details

- Fault permeability was measured before/after CO<sub>2</sub> injection and before/after fault slip
- Fault slip was induced in on test by increasing CO<sub>2</sub> pressure and in another by controlling slip rate
- Our results on how CO<sub>2</sub> alters fault strength are currently being utilized in a seismic hazard and fault slip model for a CO<sub>2</sub> storage field site.



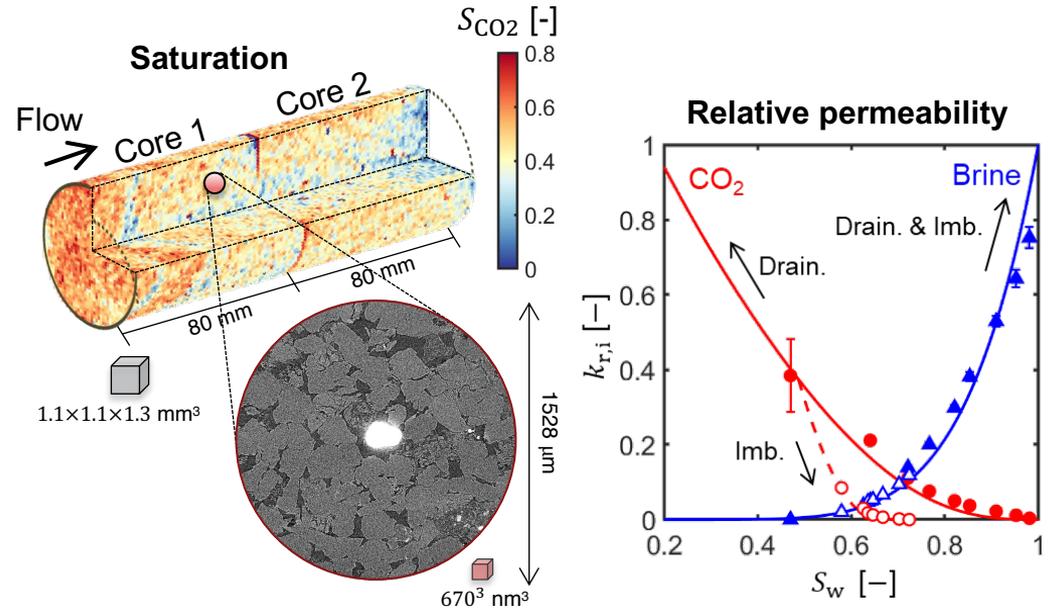
# Laboratory characterization of multiphase flow and capillary trapping of CO<sub>2</sub> in a composite rock core

## Scientific Achievement

Characterized multiphase flow properties to assess the residual trapping efficiency of a composite core taken from a potential CO<sub>2</sub> storage site in the Gulf of Mexico

## Significance and Impact

This work provides an understanding into the impacts of capillary heterogeneity on multiphase flow properties and generate a set of parameters needed in field-scale geomechanical models to further assess the long-term integrity of CO<sub>2</sub> storage



## Research Details

- We conducted steady-state drainage and imbibition experiments of CO<sub>2</sub>/brine system in a composite core at reservoir conditions.
- The workflow allows for the independent characterization of the wetting state and multiphase flow properties on each individual core, as well as their overall effects as a composite system.

# Fueling the California Mobility Market with H<sub>2</sub> from natural gas with CCS

## Scientific Achievement

Evaluation of market demand and regulatory framework for hydrogen production with CCS in California.

Techno-economic assessment of H<sub>2</sub> production with CCS in Northern California

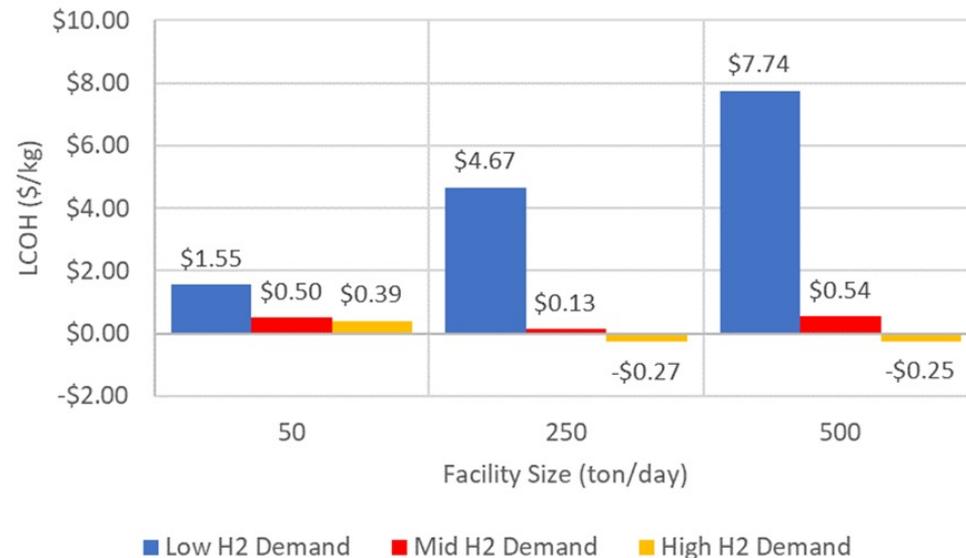
## Significance and Impact

This work will help to guide future investment in hydrogen production infrastructure in California as the state strives to reach its climate goals.

## Research Details

- Existing state and federal policy enable low and potentially negative cost hydrogen production
- A smaller-scale SMR-CCS plant in Northern California has lower risk but also less possible reward with costs depending on how hydrogen demand grows
- SMR-CCS hydrogen production remains lower cost than electrolysis in the near-term even with Inflation Reduction Act incentives

Impact of Facility Size and H<sub>2</sub> Demand Growth on LCOH



# CO<sub>2</sub> Geological Storage Modeling with Machine Learning

## Scientific Achievement

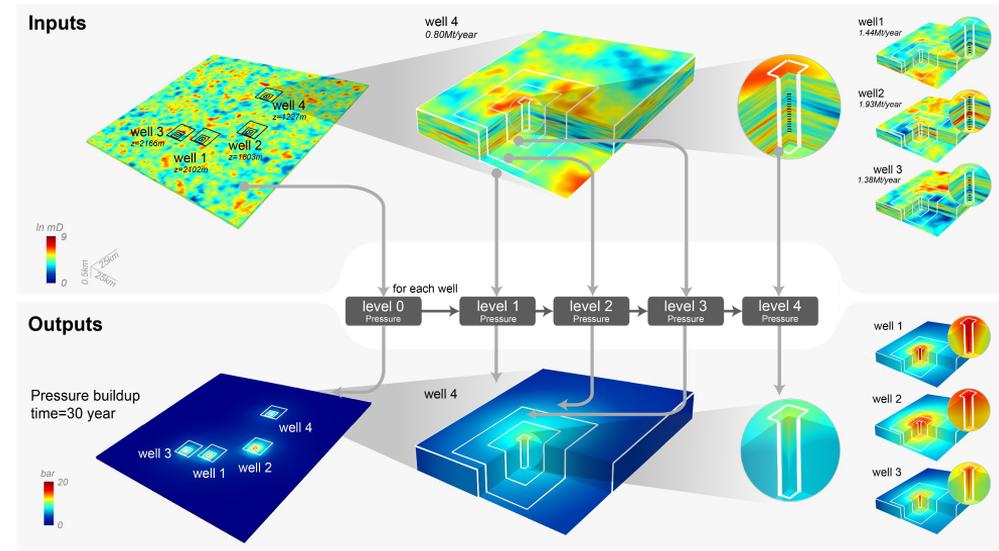
We propose the Nested FNO machine learning architecture to provide real time predictions of high resolution 4D basin scale pressure buildup and CO<sub>2</sub> gas saturation.

## Significance and Impact

Access to fast and accurate predictions of reservoir dynamics greatly reduces the uncertainty. The predictions can help many important engineering decisions.

## Research Details

- We combine the Fourier Neural Operator (FNO) with Local Grid Refinement (LGR) approach to achieve unprecedented high resolution prediction.
- Our model predicts with variable injection scheme (number of wells, injection rate, perforation interval), permeability distribution, dip angle, reservoir depth, and reservoir temperature.
- Nested FNO's predictions are up to 700,000 times faster than numerical simulation.



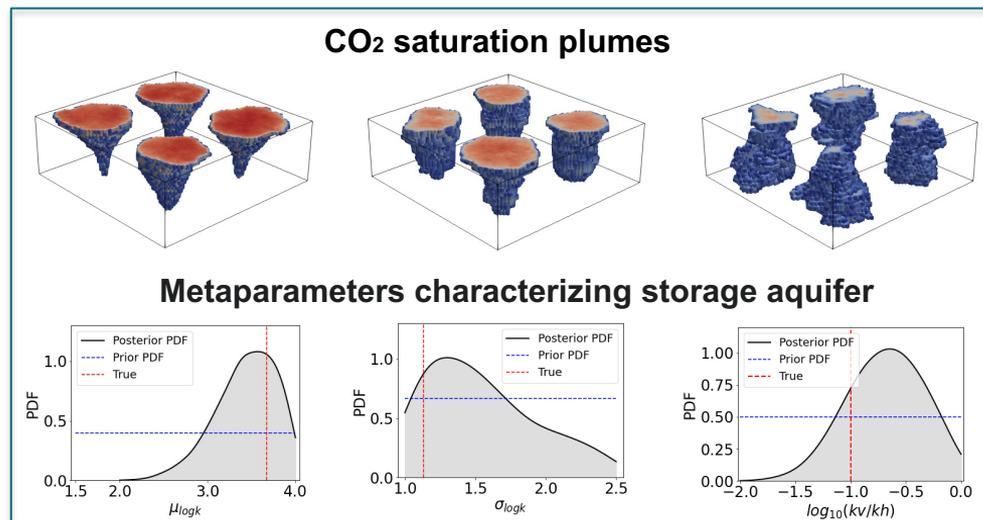
# Surrogate Model for Geological CO<sub>2</sub> Storage and Its Use in MCMC-based History Matching

## Scientific Achievement

Surrogate model is extended, and MCMC-based history matching workflow is developed to reduce uncertainty in metaparameters characterizing storage aquifer.

## Significance and Impact

History matched metaparameters provide insights into properties of aquifer and can be used in optimizing new injection wells.



## Research Details

- GEOSX runs only involve flow at this point (geomechanics will be included in future work). Realizations are drawn from geological scenarios characterized by a set of six metaparameters. Recurrent R-U-Net surrogate model (Tang et al., 2022) is extended to treat additional effects.
- Surrogate model successfully used in Markov-chain Monte Carlo history matching workflow.

# Hydrogen Storage in Porous Media: a Numerical Simulation Study

## Scientific Achievement

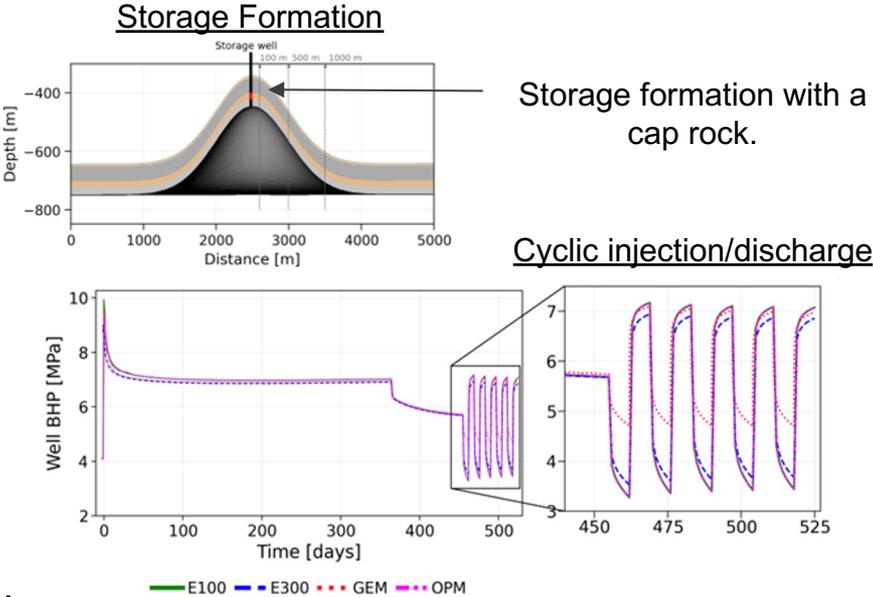
A comparison of various numerical simulators was performed to assess hydrogen storage simulation capability. There was substantial agreement found between results predicted from the different simulators.

## Significance and Impact

Differences in simulation results arise from treatment of fluid properties and discretization approaches. The intercomparison builds confidence in the use of simulation models for H<sub>2</sub> storage.

## Research Details

- Five different simulators were tested for hydrogen (H<sub>2</sub>) storage on four test case scenarios of increasing physical complexity.
- Transport processes were studied, but not the effects of reactions or geomechanics.
- Limitations to black oil simulators were identified.



# Integrated Framework for Optimization of Horizontal/Deviated Well Placement and Control for Geological CO<sub>2</sub> Storage

## Scientific Achievement

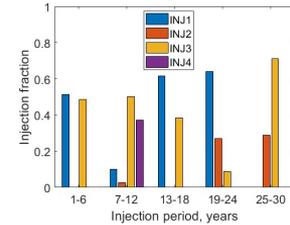
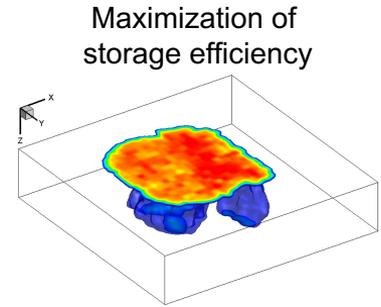
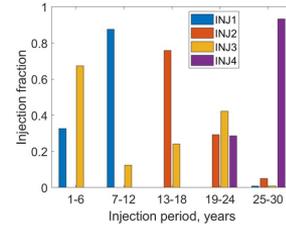
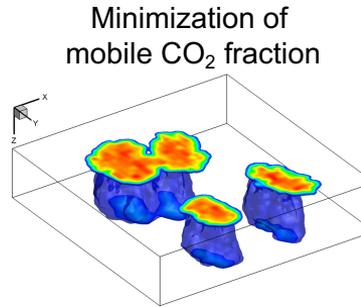
Developed and applied a general optimization framework for determining the locations and time-varying injection rates of 3D horizontal and deviated monobore wells for geological carbon storage

## Significance and Impact

Realistic objective functions and constraints considered. A new multifidelity optimization approach is introduced and shown to be effective

## Research Details

- Objective functions: minimization of mobile CO<sub>2</sub> fraction and maximization of storage efficiency
- Constraints: well configuration geometry, injection rates, BHPs, plume location
- Derivative-free optimization algorithms: particle swarm optimization (PSO) and differential evolution (DE)
- Multifidelity approach involving three levels of grid resolution shown to outperform all-fine-scale optimization
- Optimized well configurations and injection rates, and resulting CO<sub>2</sub> plumes, differ for the two objective functions



# How Green Can Blue Hydrogen Be?

## Scientific Achievement

Established a methodology to quantify the climate benefit of carbon capture applied to steam methane reformed hydrogen.

## Significance and Impact

This work will help improve understanding on the climate impact of blue hydrogen development.

## Research Details

- Hydrogen will play a large role in the global transition to a renewable future, and blue hydrogen is a leading near/intermediate term solution to increase production capacity
- Handful of public literature on the benefit of CCS with drastically different conclusions
- This work performs transparent, lifecycle emissions analysis to quantify the climate benefit of blue hydrogen while exploring the impact of several key assumptions on the results.

