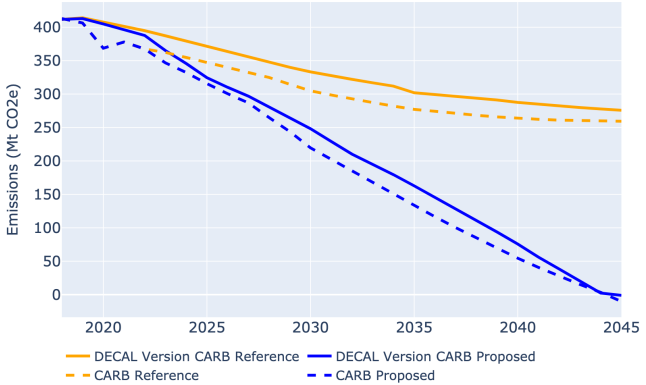
2023 SCCS Research Highlights

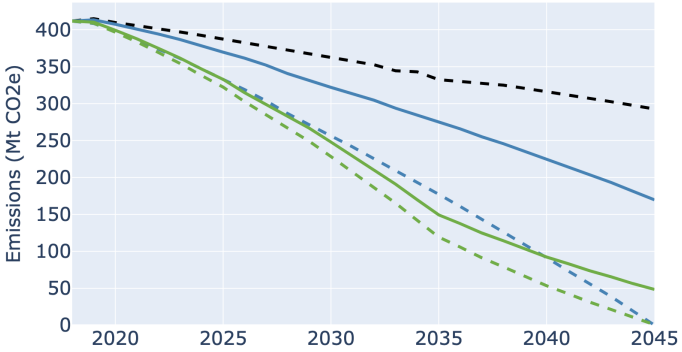
Nov 2023

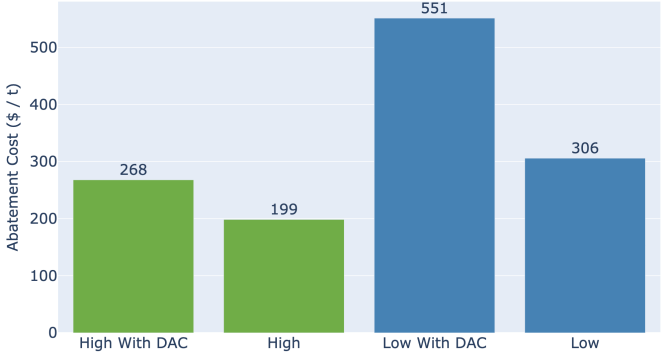
Stanford | Doerr School of Sustainability | Stanford Center for Carbon Storage

Pathways to Carbon Neutrality in California



- We've built a bottom-up, detail rich, economy-wide model called DECAL
- DECAL can be used to explore the feasibility and economic effectiveness of carbon neutral pathways in California
- The model aligns well with the CARB Scoping Plan





- Low and High Effort scenarios were used to explore the bounds of emissions
- We find that 50 Mt – 170 Mt of carbon dioxide removal will be needed by 2045

- Furthermore, we find that going faster is cheaper on an abatement cost basis
- We spotlight high leverage technologies in which further development is needed, including DAC, CCS, clean heavy-duty vehicles, and low GWP refrigerants

Stanford | Doerr School of Sustainability

Josh Neutel, advisor: Prof. Sally Benson

Pilot Scale CCS Site Modeling and Well Design Optimization

Scientific Achievement

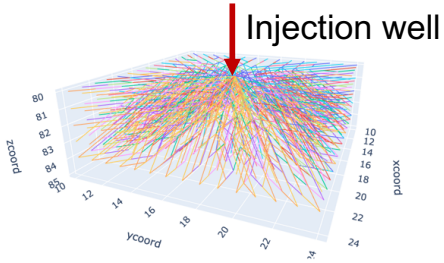
- **Fully coupled geomechanics modelling for a pilot scale CCS site (Kern Co. CA)**
- **Well design optimization to address large injection rates (1+Mt/year)**

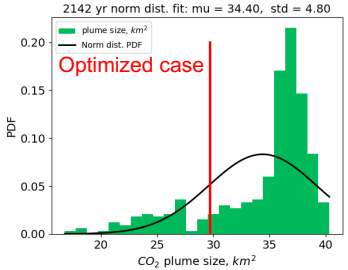
Significance and Impact

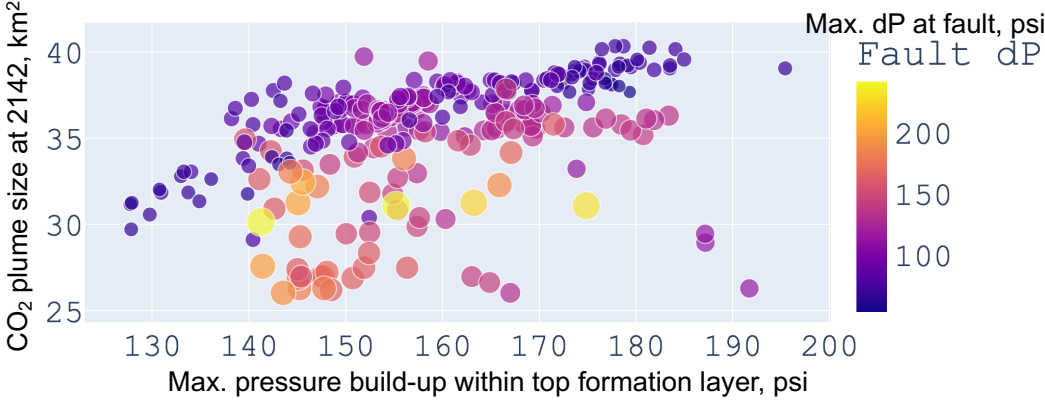
- **Pipeline automation for CCS dynamic characterization**
- **Prototype potential use of InSAR for CCS surveillance**

Research Details

- Run 800+ well trajectory designs
- Characterize CO_2 plume shape and size
- Define pressure footprints
- Pressure responses at the faults







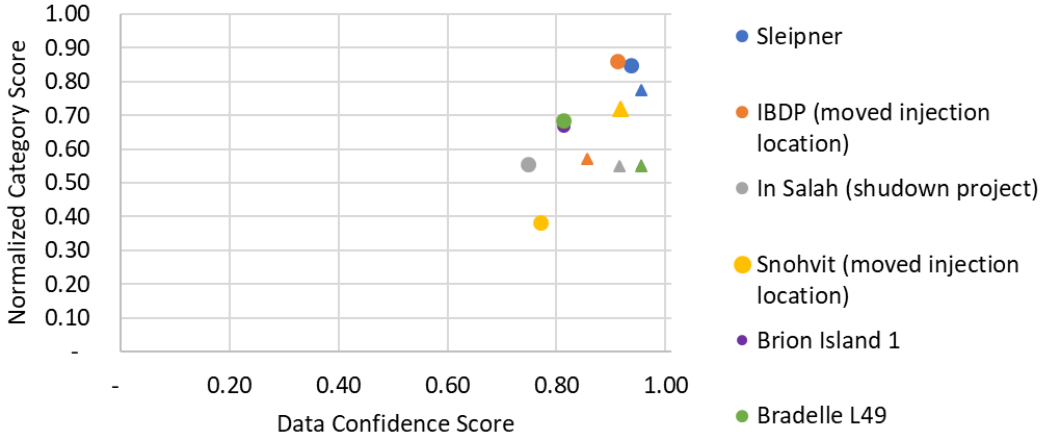
Application of Carbon Storage Site Selection Criteria to Existing Projects and Saline Reservoirs in Quebec

Scientific Achievement

Developed a site selection criteria that will allow for the identification of suitable saline reservoir sequestration sites for hub scale projects in different geological and geographical environments

Significance and Impact

- **Four existing carbon storage projects were screened and ranked and two projects that were successful ranked highly while the projects that struggled would have not passed our stage 1**
- **Two sites in Quebec passed the screening stage and ranked in stage 2**



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.
- Four existing projects were screened and ranked as well as multiple saline reservoirs in Quebec

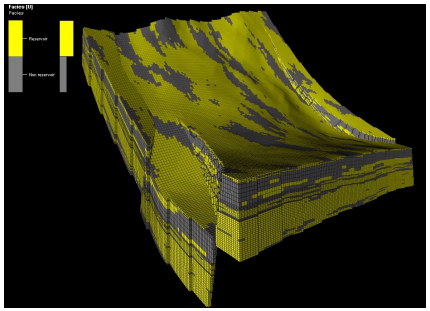
Numerical modeling of CO_2 storage in the West Delta in the GOM

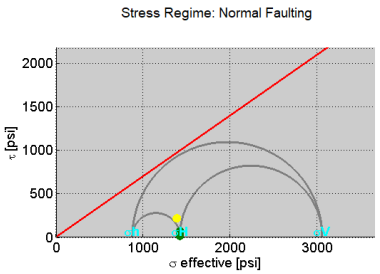
Scientific Achievement

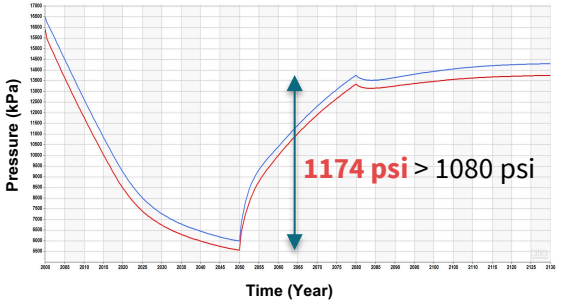
- **Developed a numerical model to assess the feasibility of CO_2 storage in the soft sediments of the West Delta field in the Gulf of Mexico. The model includes predictions for pressure change and the potential activation of faults, which may result in induced seismicity**

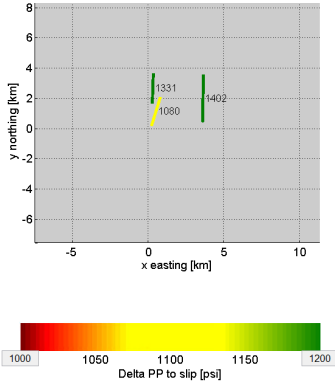
Significance and Impact

- **The poroelastic deformation of cores from the WD field was characterized experimentally and used in the numerical model**
- **The injection of 1 MT/y of CO_2 surpasses the slip threshold for pore pressure in one of the existing faults**
- **The fault slip is primarily influenced by SH^{max} orientation, gradients of Pp and Sh^{min}**









Research Details

- The geologic model of the reservoir served as the foundation for constructing a coupled geomechanics-flow model to evaluate the potential for storing of CO_2 in soft sediments of WD in the Gulf of Mexico
- The results of poroelastic deformation tests (e.g. Biot coefficient, Bulk and Young's moduli) were employed to refine the numerical models (using Petrel, CMG). Finally, Fault Slip Potential (FSP) was used for probabilistically screening faults near the injection wells

Stanford Doerr School of Sustainability | Stanford Center for Carbon Storage
Energy Science & Engineering

Sam Hashemi, Anthony Kovscek & Mark Zoback

Induced seismicity hazard assessment for a CO_2 storage site

Scientific Achievement

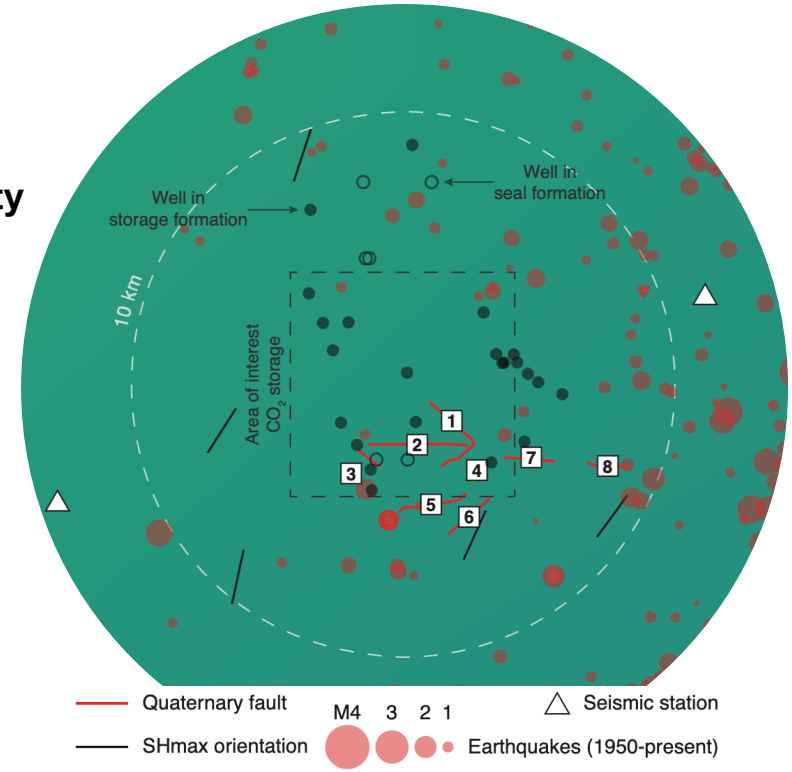
- **Geomechanical model of CO_2 storage site**
- **Calculated pressure to slip on mapped faults**
- **Probabilistic fault slip model incorporating uncertainty**

Significance and Impact

- **Built earthquake catalog and assessed data needs**
- **Fault slip model constrains safe injection conditions**
- **Traffic light response system specific to CO_2 storage**

Research Details

- Stress, seismicity and fault map
- Probability of fault slip in space and time
- Monitoring criteria for distinguishing induced events



Stanford Doerr School of Sustainability | Stanford Center for Carbon Storage | Energy Science & Engineering

Arjun Kohli, Yunan Li, Tae Wook Kim & Anthony Kovscek

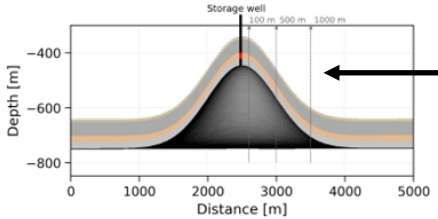
Intercomparison of numerical simulation models for hydrogen storage in porous media using different codes

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.**

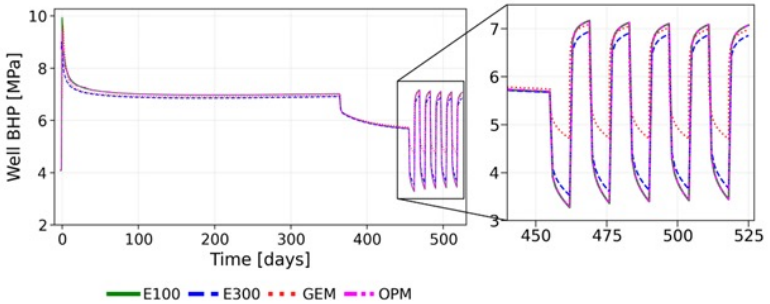
Significance and Impact

- **The 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_2 storage.**



Storage formation with a cap rock

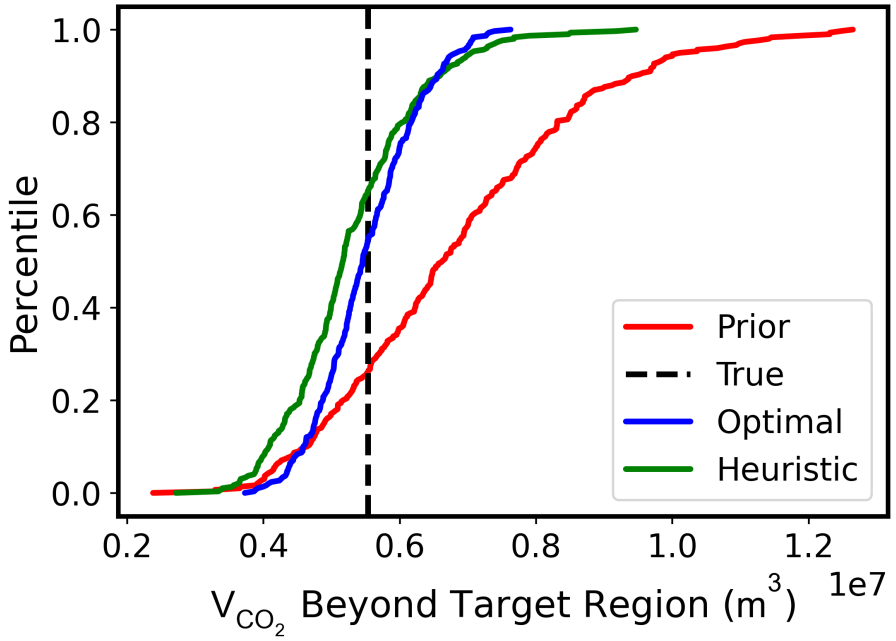
Cyclic injection/production



Research Details

- Five different simulators were tested for hydrogen (H_2) storage on four test case scenarios of increasing physical complexity
- Transport processes were studied, but not the effects of chemical reactions or geomechanics
- Limitations to black oil simulators were identified

Enhanced Framework for Monitoring and History Matching in CO_2 Storage Projects



Scientific Achievement

- **Optimize CCUS monitoring plan using simulation results from prior geomodels**
- **Introduce refined gridding in the optimization to improve accuracy**

Significance and Impact

- **Work has been successfully utilized for active CO_2 storage permit in Illinois, USA**
- **Will soon be used in a second permit cycle**

Research Details

- Developed workflow to optimize CCUS monitoring plan to reduce uncertainty in the plume location
- Optimization is applied prior to performing any history matching
- Optimization entails multiple steps, including use of local grid refinement in prior simulation runs
- Applied ES-MDA history matching to predict the plume behavior based on monitoring well data

Stanford Doerr School of Sustainability | Stanford Center for Carbon Storage, Energy Science & Engineering

Dylan Crain & Louis Durlofsky

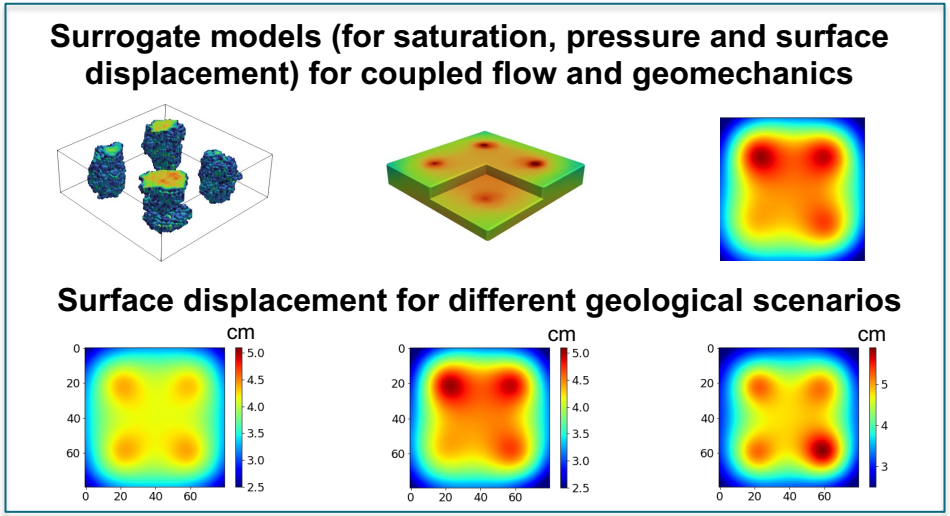
Surrogate Model for CO_2 Storage with Coupled Flow and Geomechanics and its Use for History Matching

Scientific Achievement

Extended surrogate model for fully coupled flow and geomechanics. Use transfer learning to reduce the number of expensive coupled flow-geomechanics training runs required.

Significance and Impact

The transfer learning procedure provides significant computational savings. The resulting surrogate model enables accurate MCMC history matching to be applied.



Research Details

- GEOS simulations involving coupled flow-geomechanics are expensive, and many such runs are required for history matching. Surrogate model enables detailed history matching to be performed
- Use Markov chain Monte Carlo history matching with the surrogate model to estimate parameters characterizing geological scenarios. Allows us to assess the impact of various types of observations.

Stanford Doerr School of Sustainability | Stanford Center for Carbon Storage
Energy Science & Engineering

Yifu Han and Louis Durlofsky

Optimization of horizontal/deviated well placement and control for CCS using upscaled models

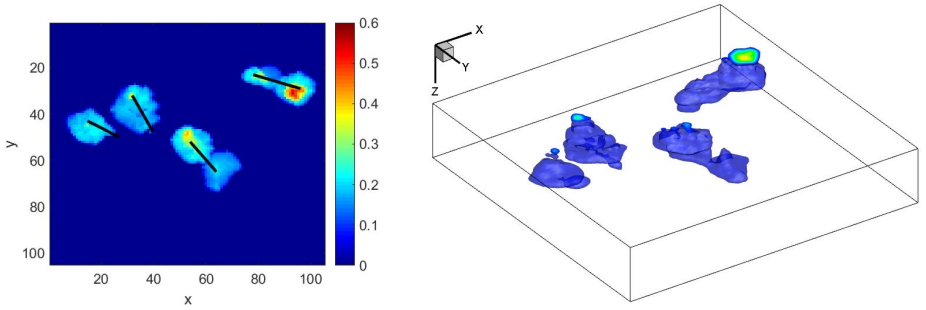
Scientific Achievement

- **Implemented a transmissibility upscaling approach with near-well local grid refinement (LGR) for CCS models**
- **Upscaled models are used in a multifidelity framework to determine optimal locations and time-varying injection rates for multiple wells**

Significance and Impact

- **Developed and tested new upscaling method**
- **Demonstrated advantages of the multifidelity approach relative to optimizing using only high-fidelity (fine-scale) models**

Minimization of time-averaged mobile CO_2 fraction



Research Details

- Objective function: minimization of time-averaged mobile CO_2 fraction
- Constraints: realistic constraints on well configurations, injection rates, BHPs, and plume location
- Derivative free optimization algorithm (particle swarm optimization) applied
- Multifidelity approach involving upscaled and high-fidelity models shown to outperform all-fine-scale optimization in terms of final objective function value and computational efficiency

Stanford Doerr School of Sustainability | Stanford Center for Carbon Storage, Energy Science & Engineering

Amy Zou and Louis J. Durlofsky