Storage of CO_2 in Multi-phase Systems Containing Brine and Hydrocarbons

Project Number: LANL FE-890-18-FY19

Rajesh Pawar (PI)

Bailian Chen

Los Alamos National Laboratory

U.S. Department of Energy

National Energy Technology Laboratory

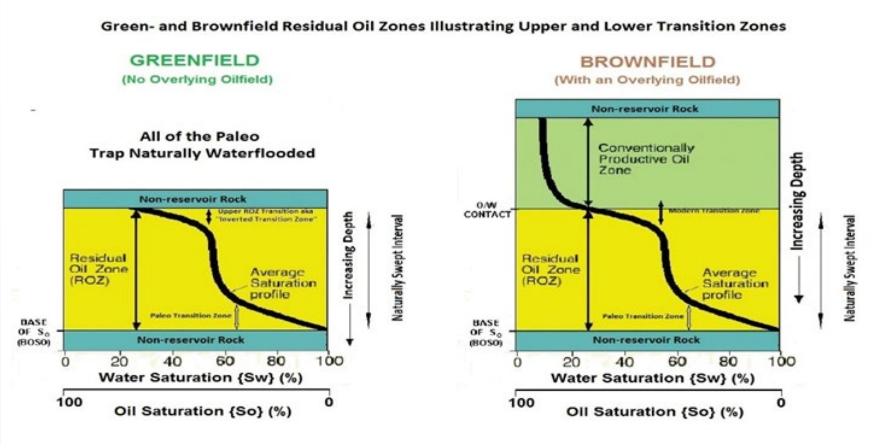
Addressing the Nation's Energy Needs Through Technology Innovation – 2019 Carbon Capture, Utilization, Storage, and Oil and Gas Technologies Integrated Review Meeting

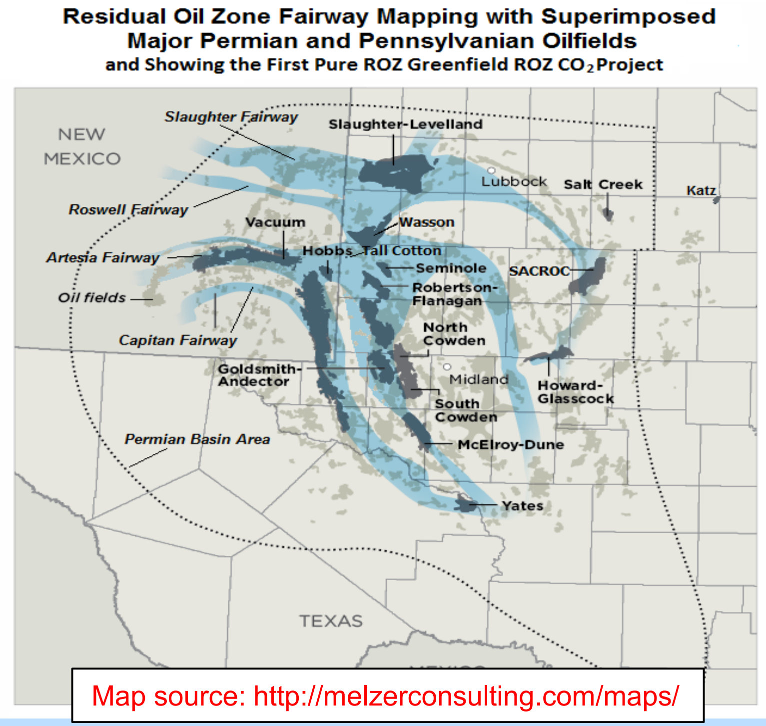
August 26-30, 2019

LA-UR-19-28899

CO_2 Storage in Residual Oil Zones

- Residual Oil Zones (ROZs) are defined as those zones where oil is swept over geologic time period (natural flush) and exists at residual saturation
  - ➢ Brownfield: ROZ underlies a Main Pay Zone (MPZ)
  - ➢ Greenfield: no Main Pay Zone above ROZ
- ROZs are being increasingly exploited using CO_2-EOR
- ROZs are increasingly being studied as potential CO_2 storage option
  - ➢ Large uncertainties in parameters and mechanisms related to CO_2 storage in ROZ





Project Objectives

- Develop quantitative, empirical relationships for predicting storage efficiencies in greenfield ROZs.
  - Develop empirical models for quantifying: CO_2 storage capacity, oil recovery potential, CO_2 fate
  - Assess CO_2 storage capacity and associated oil recovery for different ROZ fields
  - Identify key characteristics
- Characterize multi-phase fluid processes in ROZs.

Approach

- Empirical models & key characteristics:
  - Application of reduced order modeling to develop empirical models
    - Models for CO_2 storage capacity, oil recovery, CO_2 fractionation in oil/gas/water phases
  - Compositional reservoir simulations of CO_2 injection using model for a ROZ field in Permian Basin
  - Importance analysis to identify key characteristics
- Characterization of mechanisms:
  - Core-flooding laboratory experiments with limestone cores simulating ROZ conditions

Technical Status

- Pre-FY19:
  - Developed empirical models, demonstrated applicability using Permian basin field data (Chen & Pawar, Energy, 2019)
  - Identified key uncertain parameters

- FY19:
  - Extended applicability of empirical models: application to Illinois basin
  - Continued work on effect of geologic/operational parameters: permeability heterogeneity, well completions, injection rate, well patterns
  - Assessed optimal management of ROZ under various scenarios
  - Developed laboratory experimental approach

Extension of empirical models

- Prior models developed for deeper fields (~4000 feet): Permian basin
- Rebuilt the models with depth range extended to shallower fields (~2000 feet): Illinois basin
- Applied empirical models to the Kenner West field in Illinois

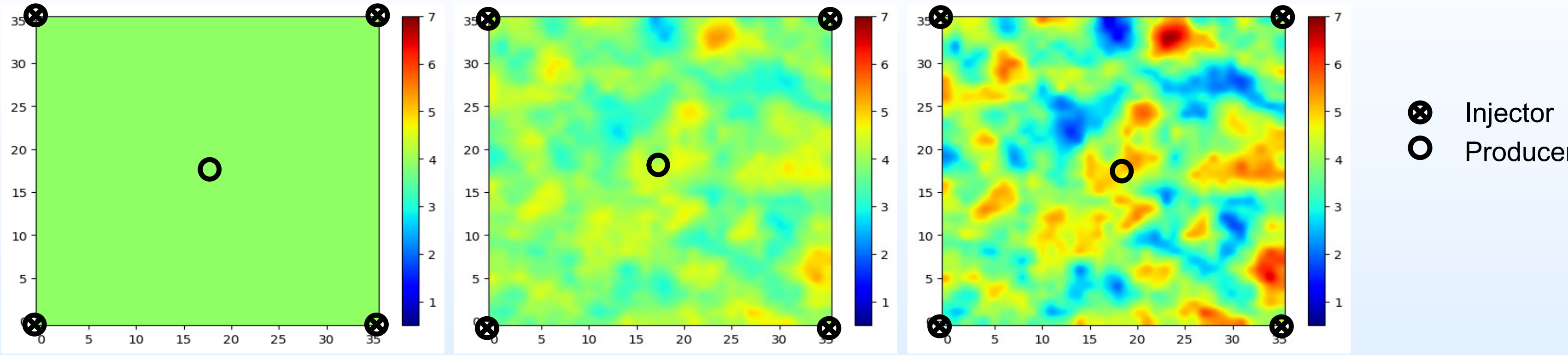
Field name	Thickness (ft)	Depth (ft)	Perm. (mD)	Sor	Injection rate (MM scf/day)	Prod BHP (psi)	Cumulative oil production (MM STB)	Cumulative CO_2 storage (MM Tons)
Kenner West	40	2600	106	0.25	5	400	4.99	0.401
						600	2.96	.554
						800	1.6	.706

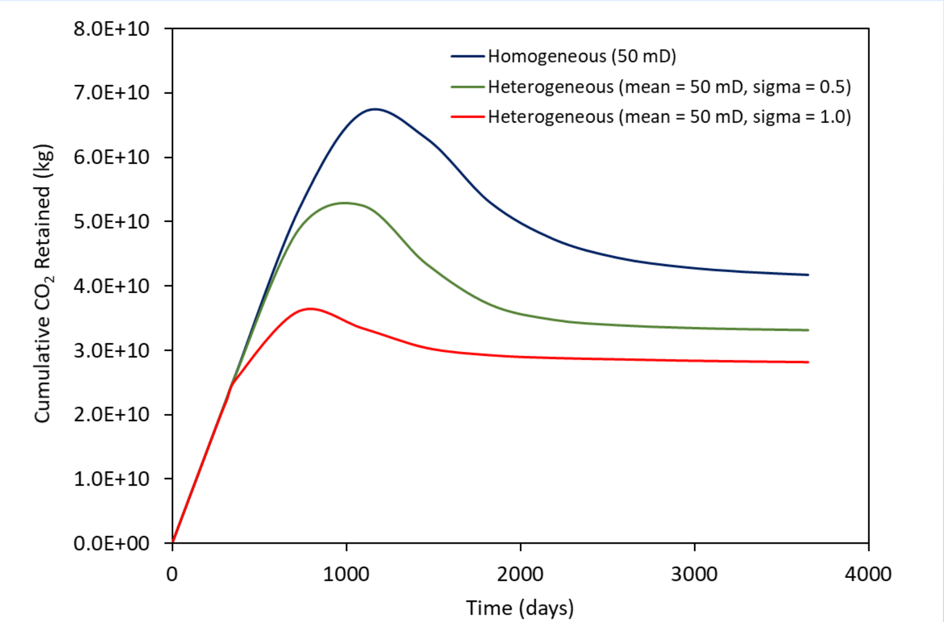
Effect of Permeability Heterogeneity

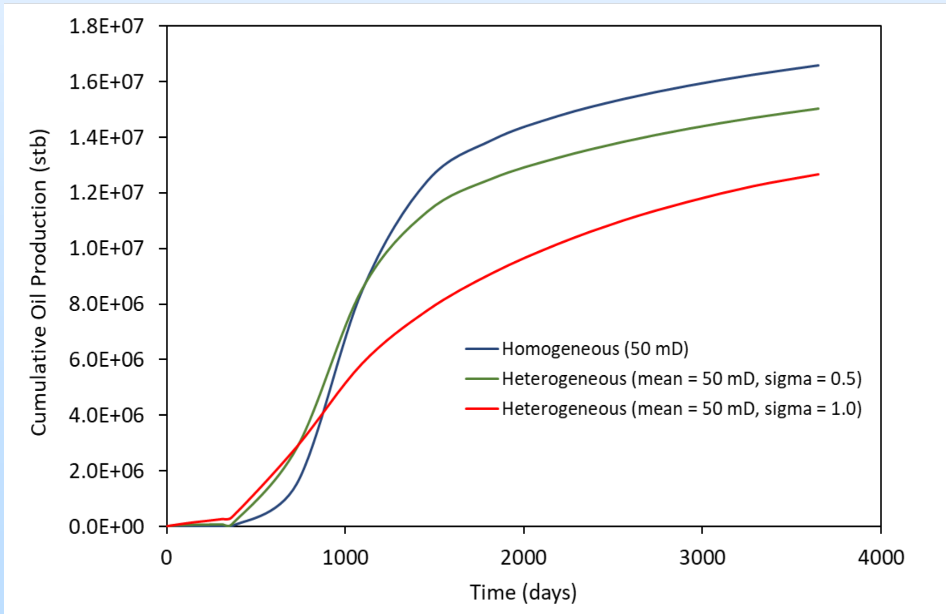
Homogeneous (50 mD)

Heterogeneous (mean 50 mD, sigma 0.5)

Heterogeneous (mean 50 mD, sigma 1.0)



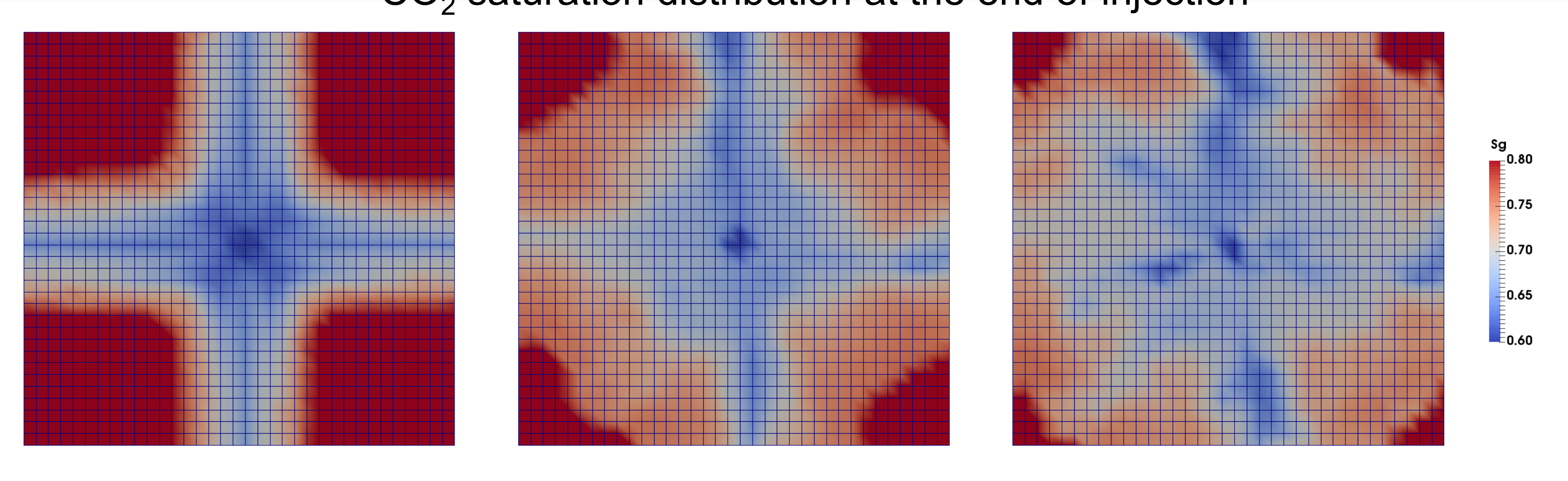


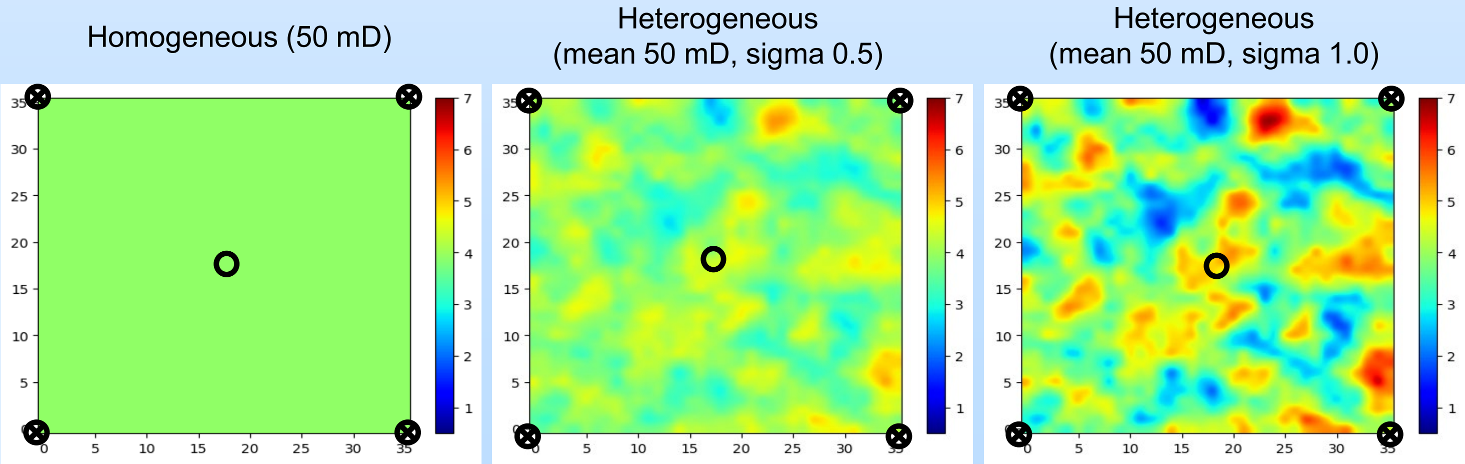


Increased heterogeneity leads to early CO_2 breakthrough, lesser sweep, lower retention and recovery

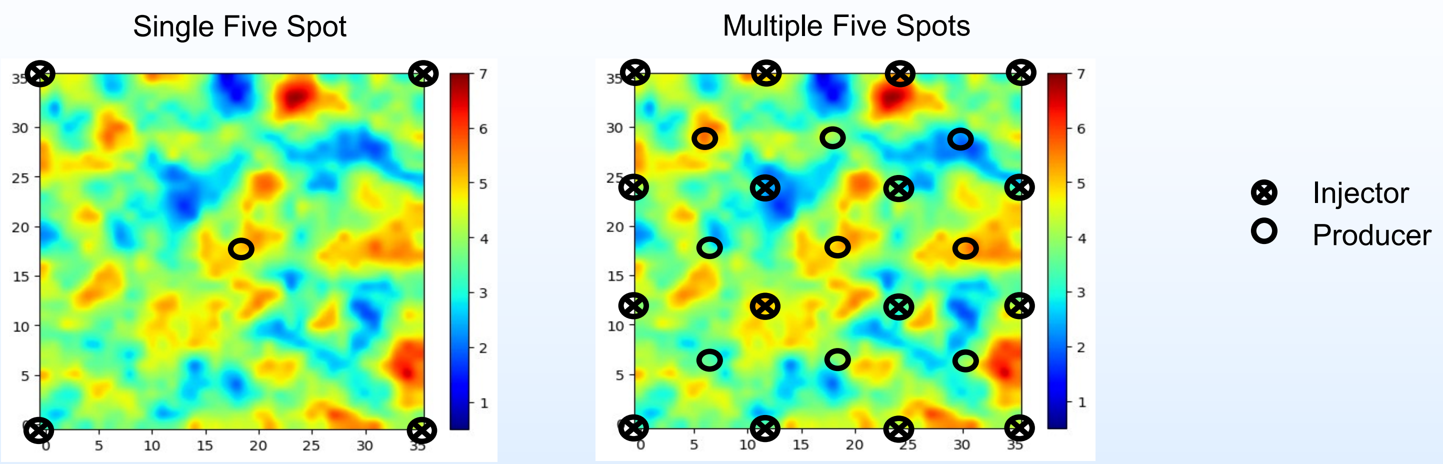
Effect of Permeability Heterogeneity

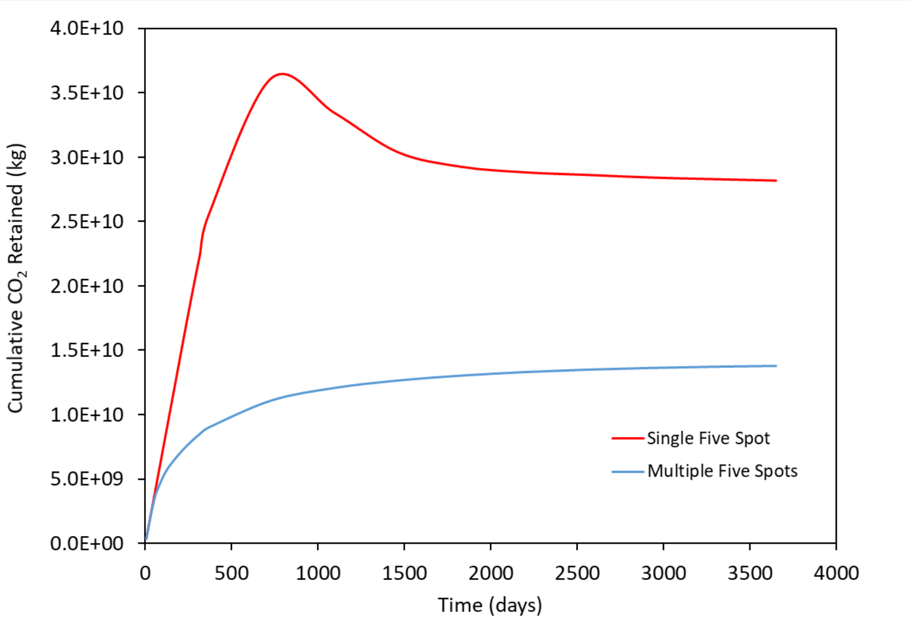
CO$_2$ saturation distribution at the end of injection

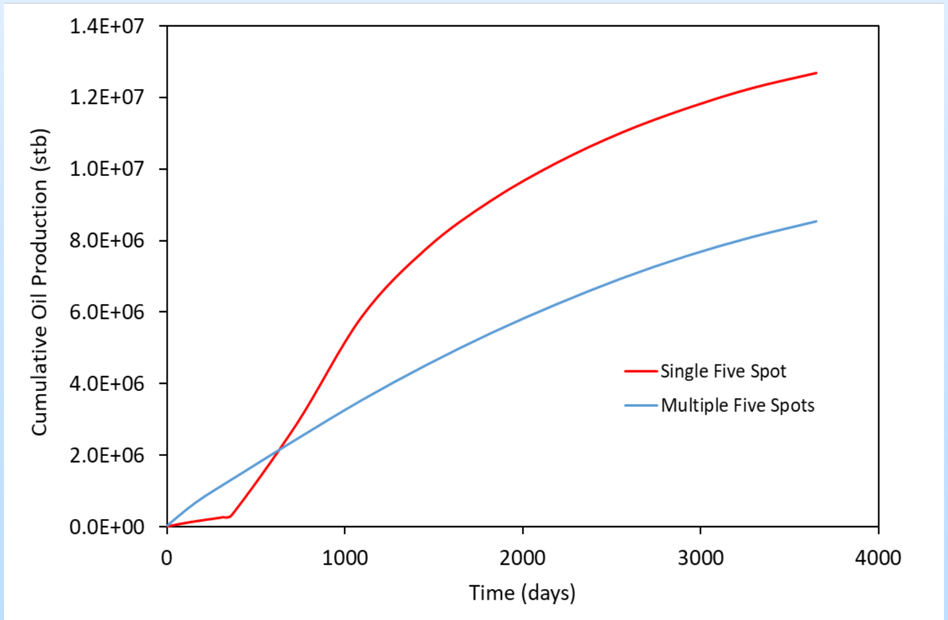




Effect of Well Patterns



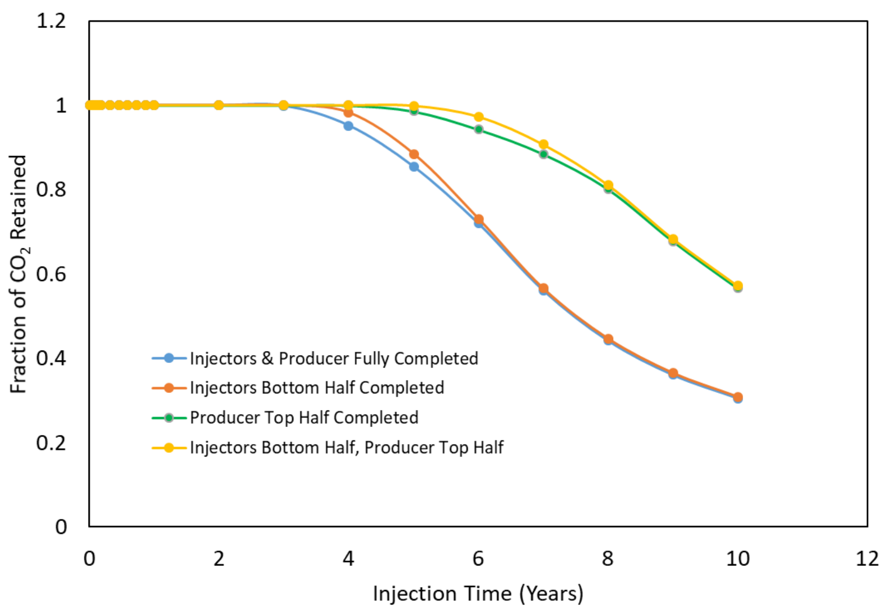


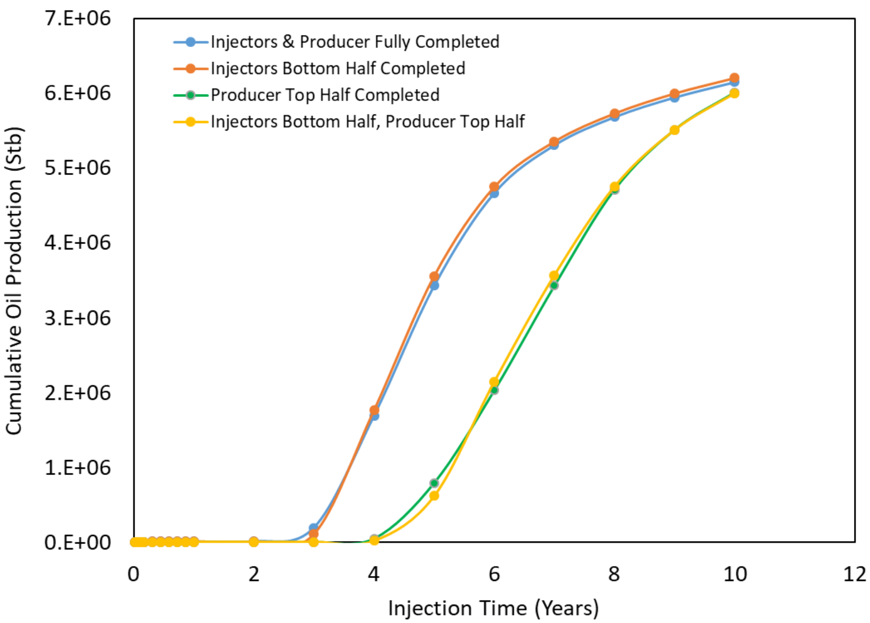


Fewer wells ➡ reduced long-term leakage risk

Effect of Well Completions

- Single five spot well pattern
- Different completion combinations:
  - Injectors & Producer fully completed
  - Injectors bottom half completed, producer fully completed
  - Injectors fully completed, producer top half completed
  - Injectors bottom half completed, producer top half completed
- Homogeneous permeability – 50 mD





Well completions affect CO_2 storage but not necessarily oil production

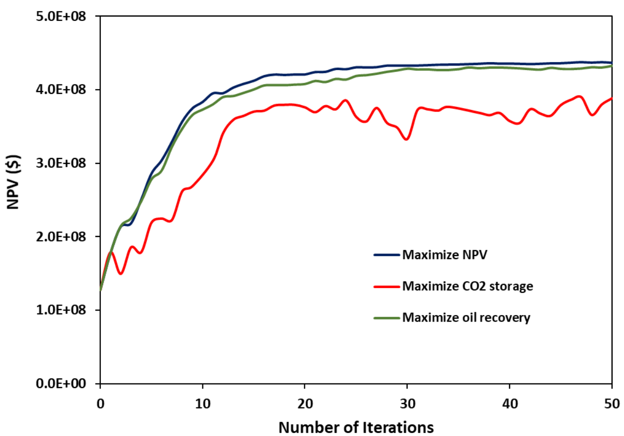
Optimal Reservoir Management Approach

- Single five-spot well pattern
- 6 reservoir layers with different permeabilities:
  - Top 2 layers: 50 mD
  - Middle 2 layers: 10 mD
  - Bottom 2 layers: 100 mD
- Joint optimization of well completions and well controls (producer BHP & CO_2 injection rate)
- Compare Net Present Value (NPV), CO_2 storage, oil recovery:
  - NPV computed as combined revenue from CO_2 credits plus oil recovery minus injected CO_2 costs

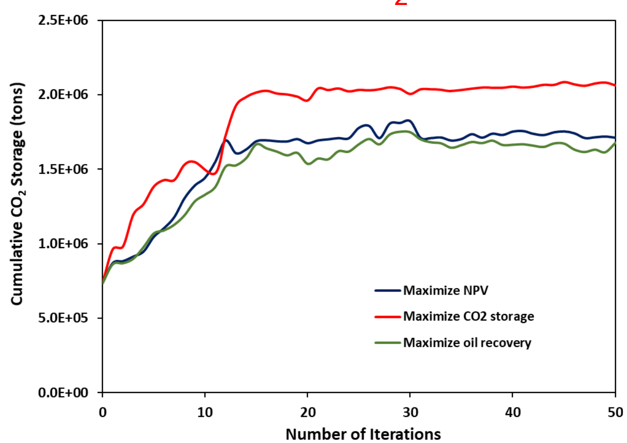
Comparing Different Optimization Objectives

Optimize NPV v/s Maximize CO_2 storage v/s Maximize oil recovery

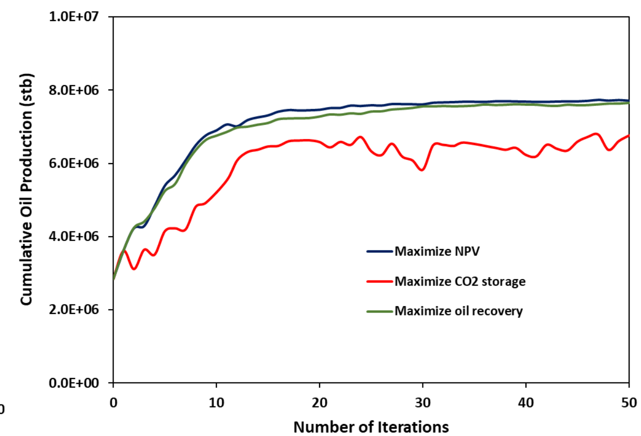
Net Present Value



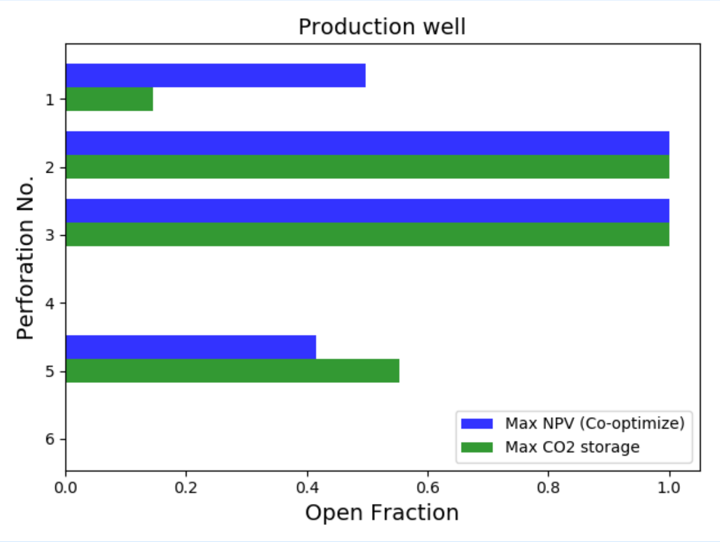
Cumulative CO_2 Retained



Cumulative Oil Production

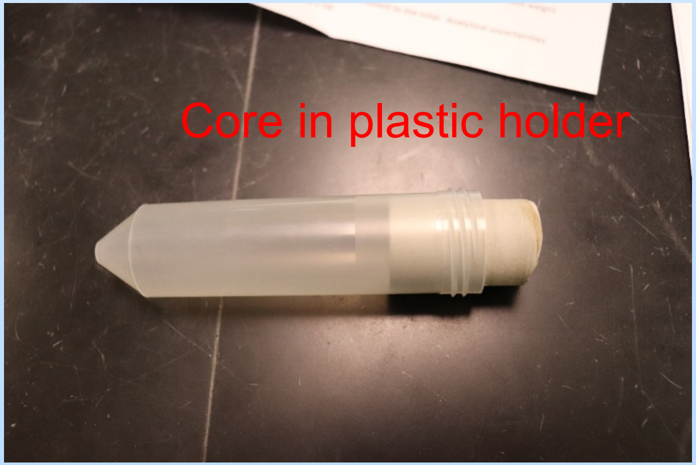


- Both, maximization of NPV and maximization of oil recovery objectives result in higher NPV than maximization of CO_2 storage objective
- Maximization of CO_2 storage objective results in ~20% higher storage
- Optimal completion varies with desired objective



Core-flooding Experiments

- Goal: Characterize multi-phase fluid flow mechanisms in ROZs
- Approach: Simulate CO_2 injection in a residual oil zone using core-flooding experiments
- Challenge: Create residual oil saturation conditions prior to CO_2 flood
- Proposed experimental protocol:
  - Soak rock cores with oil
  - Spin the cores in a centrifuge (take the core to irreducible oil saturations)
  - Flood the cores with water
  - Use careful mass balance to determine the residual oil saturation
- CO_2 flooding experiments at pressures and temperatures typical to residual oil zone containing fields



Accomplishments to Date

- Extended application range of empirical relationships: application to Illinois basin
- Assessed effects of uncertain parameters/operational conditions
- Studied effectiveness of reservoir management optimization
- Developed a laboratory experimental approach to characterize multi-phase mechanisms
- Peer-reviewed publications:
  - Bailian Chen and Rajesh J. Pawar, 2019. Capacity assessment and co-optimization of CO_2 storage and enhanced oil recovery in residual oil zones. *Journal of Petroleum Science and Engineering*,.
  - Bailian Chen and Rajesh J. Pawar, 2019. Characterization of CO_2 storage and enhanced oil recovery in residual oil zones. *Energy*, 183: 291-304.

Lessons Learned

- In spite of increased commercial CO_2-EOR operations in ROZs, critical understanding of CO_2 storage & oil production mechanisms as well as long-term CO_2 fate and risks needs to be further developed
  - ❖ Lack of appropriate data
  - ❖ Large uncertainty
- Proper experimental protocol needed to simulate multi-phase fluid processes in ROZ in laboratory experiments
- Focused field-specific studies needed to improve predictions & predictive capabilities

Synergy Opportunities

- Field data for applying/validating empirical models
- Laboratory characterization comparison with field observations

Project Summary

- Key Findings (FY19):
  - Increased permeability heterogeneity significantly reduces CO_2 retention
  - Larger well spacing leads to higher CO_2 retention and oil recovery: reduced potential for leakage
  - CO_2 retention in ROZ can be significantly increased using optimization of operations
- Next Steps:
  - Extend empirical model application to ROZs from other basins in US
  - Complete experimental characterization
  - Make empirical relationships available to wider community (through EDX)

Appendix

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

Benefit to the Program

- Program goals being addressed:
  - Support industry's ability to predict CO_2 storage capacity in geologic formations with ±30%.
- Project benefit:
  - This project is focused on developing the science basis to characterize CO_2 storage potential in Residual Oil Zones (ROZs). The objective is to help develop a methodology to estimate CO_2 storage capacity, potential oil recovery and long-term fate of CO_2 that is applicable to a wide range of geologic and operational conditions. This will help CO_2 storage program goal of supporting industry's ability to predict CO_2 storage capacity.

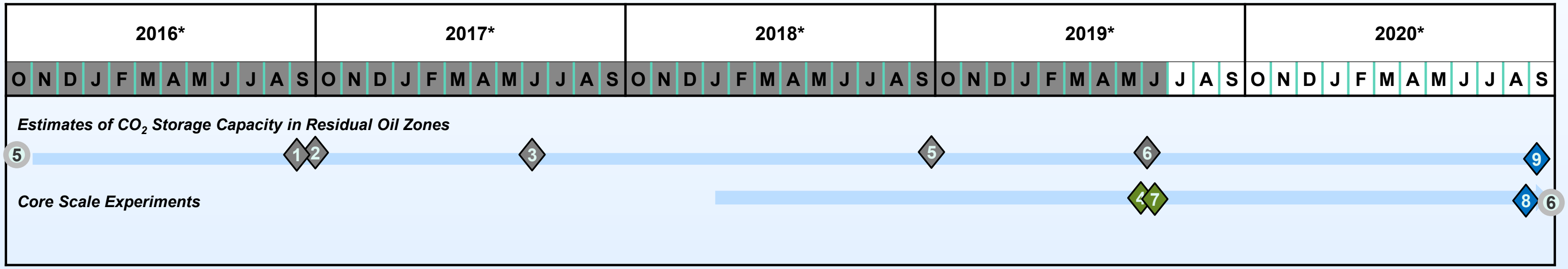
Project Overview
Goals and Objectives

- Characterize CO_2 storage potential:
  - Primarily, Greenfield ROZ
  - Added benefits: e.g. oil recovery potential
  - Long-term CO_2 fate
  - Assess key uncertainties and data needs
  - Develop empirical relationships to assess CO_2 storage and oil recovery potential applicable to wide range of geologic characteristics

Organization Chart

- Rajesh Pawar, PI
- Bailian Chen, Post-doc
- Rachel Atencio, LANL Program Manager

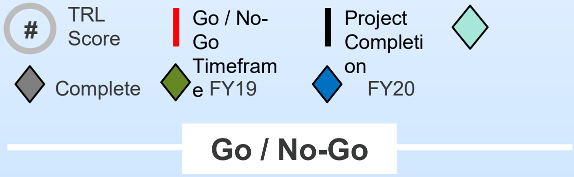
Gantt Chart



Milestones

1. Preliminary estimates of CO_2 storage potential in representative ROZs across US with associated uncertainties.
2. Empirical model to estimate CO_2 storage and utilization potential in ROZs.
3. Re-assessment of ROZ potential in conjunction with CO_2 storage.
4. Strategy to explore uncertain parameters in ROZ fields through core scale experiments.
5. Empirical models for applications to estimate CO_2 storage capacity, long-term fate and oil recovery potential from ROZs including identification of potentially impactful uncertain parameters.
6. Application of empirical models to fields with ROZs.
7. Initial Experiments.
8. Update empirical models based on experimental results.
9. Application of updated empirical models to ROZ fields through synergistic collaborations. Public dissemination of empirical models to CCUS stakeholders.

Chart Key



Bibliography

- Bailian Chen and Rajesh J. Pawar, 2019. Capacity assessment and co-optimization of CO_2 storage and enhanced oil recovery in residual oil zones. *Journal of Petroleum Science and Engineering*.
- Bailian Chen and Rajesh J. Pawar, 2019. Characterization of CO_2 storage and enhanced oil recovery in residual oil zones. *Energy*, 183: 291-304.