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

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Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration:
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Presentation Outline

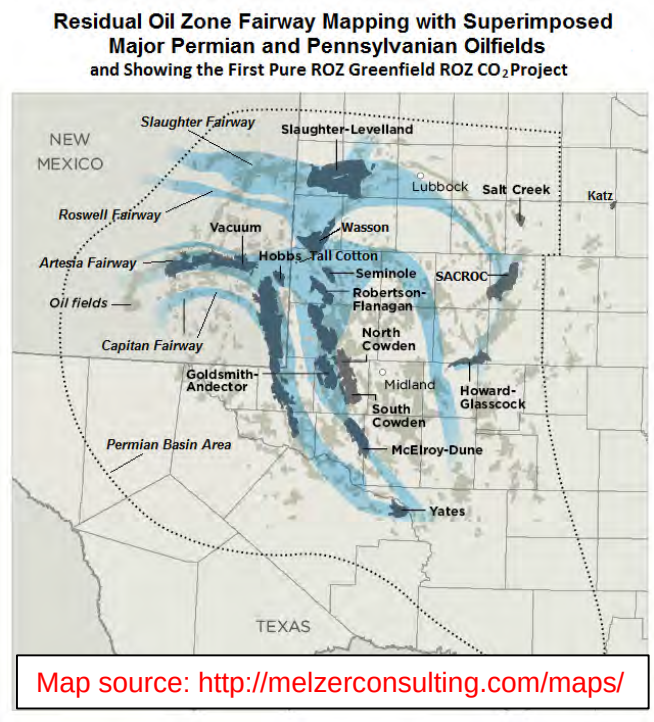
- Project Objective
- Approach & Technical Status
- Project Summary
- Synergy Opportunities

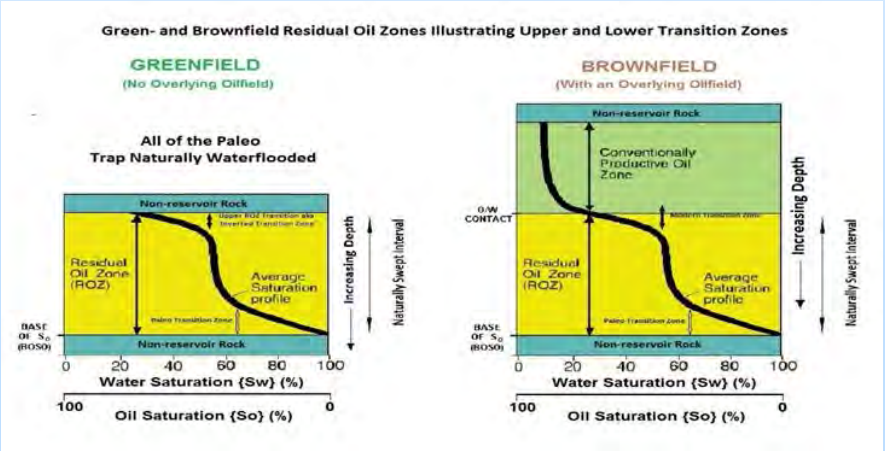
Project Objective

- Develop improved quantitative relationships for predicting storage and trapping efficiencies in environments where both a brine and hydrocarbon fluid are present (primarily, unconventional reservoirs such as ROZs).
  - Identify key characteristics
  - 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
  - Focused on greenfield ROZs with potential applicability to other unconventional settings such as brownfield ROZs.

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:
  - Multiple on-going commercial field operations in Permian Basin
- Greenfield ROZs can be potentially explored for CO_2 storage with a side benefit of incremental oil recovery





Approach & Technical Status

- Approach:
  - Utilize numerical simulations using Eclipse compositional simulator
  - Develop empirical models for CO_2 storage capacity, oil recovery, CO_2 fate using results of numerical simulations
  - Apply empirical models to fields with ROZ

- FY17 Outcomes:
  - Developed numerical models based on field data from Permian Basin
  - Performed initial characterization of CO_2 storage in ROZs

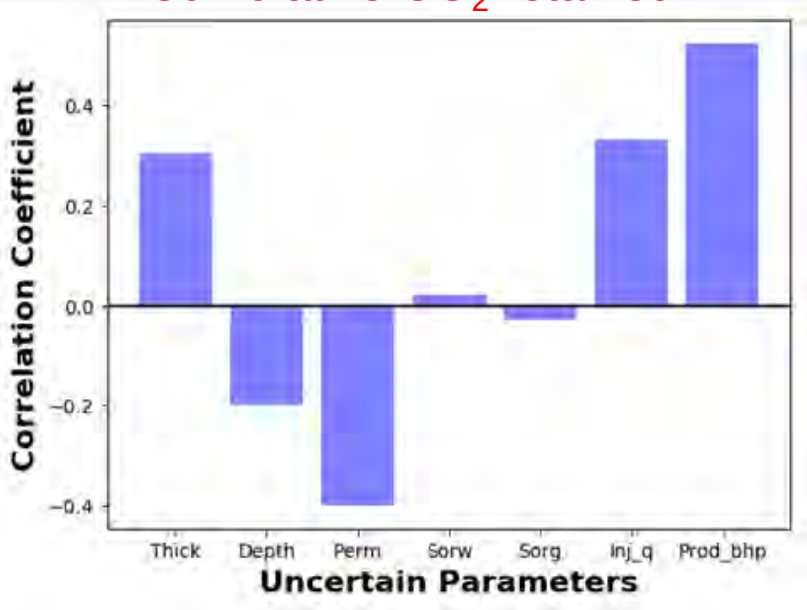
FY18: Numerical simulations

- Reservoir model based on data for Goldsmith-Landreth San Andres Unit (GLSAU) in the Permian Basin: ARI study, History matched
- Monte-Carlo simulations: 15 years operation (10 years injection, 5 years post-injection)
- Multiple uncertain parameters
- Multiple injection modes: Continuous CO_2 and WAG
- Multiple well patterns: five-spots (sparse, dense), line drives
- Two ML algorithms for empirical model development: SVR & MARS

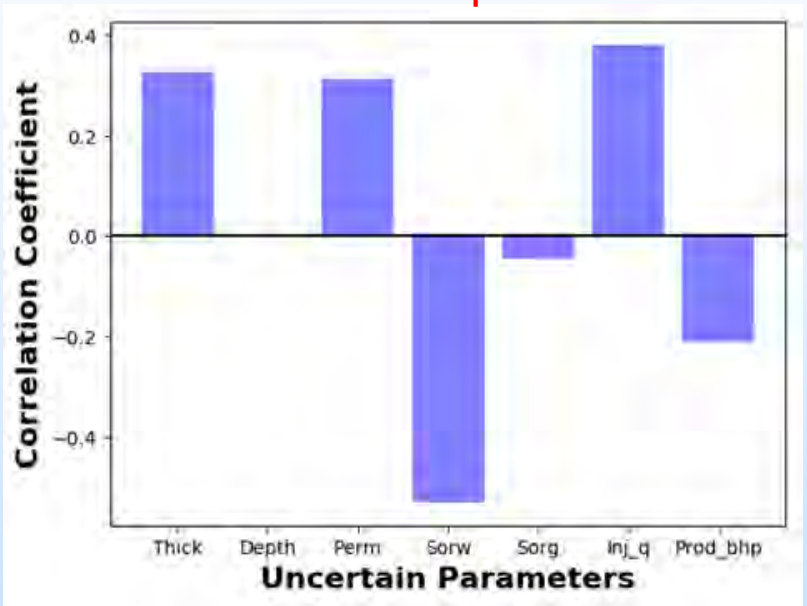
Uncertain parameters	Lower bound	Upper bound	Units	Correlations
Thickness (h)	50	300	ft	$\emptyset = 0.082 \times K^{0.216}$ $P = 14.7 + 0.433 \times D$ $T = 60 + 0.015 \times D$
Depth (D)	4000	6000	ft	
Permeability (K)	0.01	200	mD	
Sorw	0.2	0.4	--	
Sorg	0.1	0.2	--	
CO_2 injection rate	5	20	MM scf/day	
Producer BHP	100	1500	psi	

Key characteristics affecting CO_2 storage & oil recovery

Cumulative CO_2 retained



Cumulative oil production



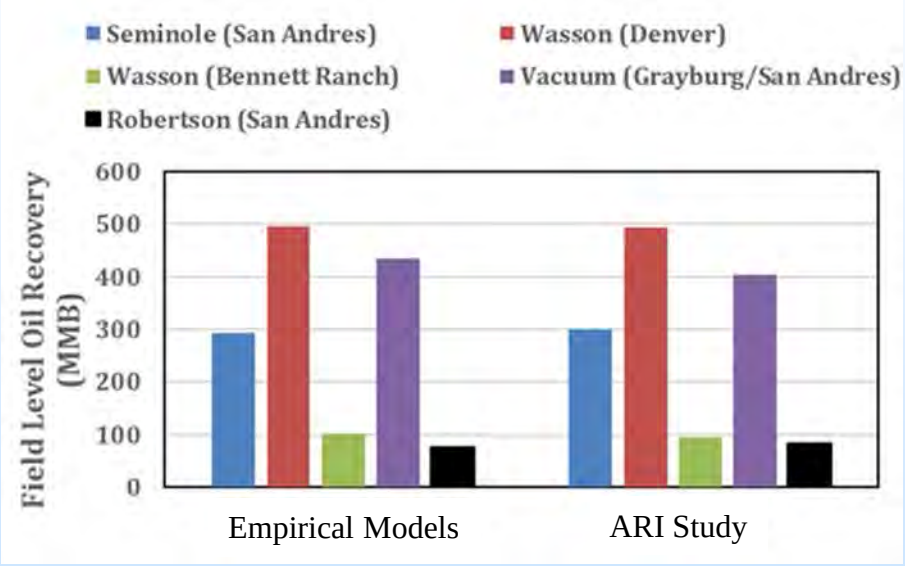
Favorable:	Production BHP > Injection Rate > Thickness	Injection Rate > Thickness > Permeability
Unfavorable:	Permeability > Depth	Sorw > Production BHP

Empirical model application to real fields

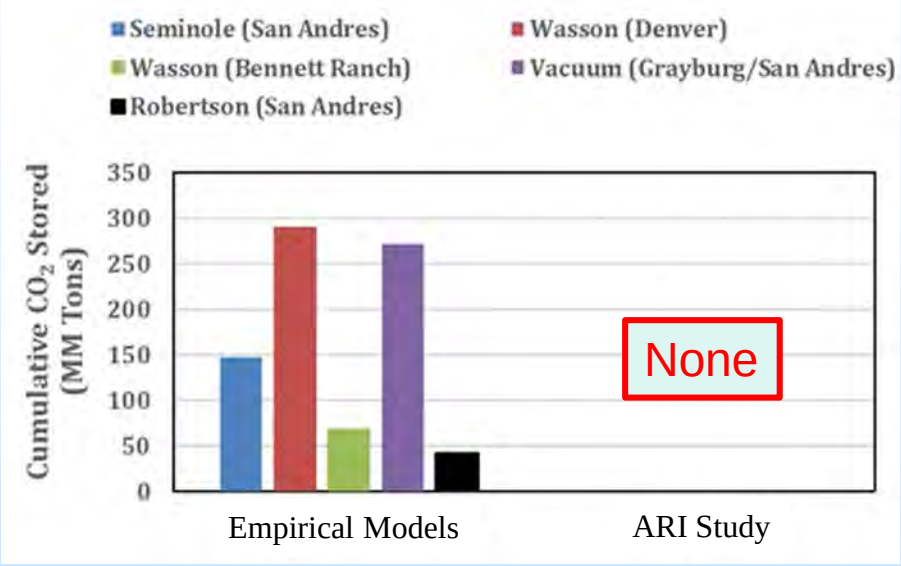
- Previous studies on Permian Basin fields (simulation based)
  - Focused on oil recovery
  - Little information on field-specific CO_2 storage capacity
- Limited data in public literature
  - Values of some critical parameters not reported: CO_2 injection rates, permeability
- ML-based empirical models applied to 5 Permian basin fields (reported in ARI study)

Empirical model application to Permian Basin fields

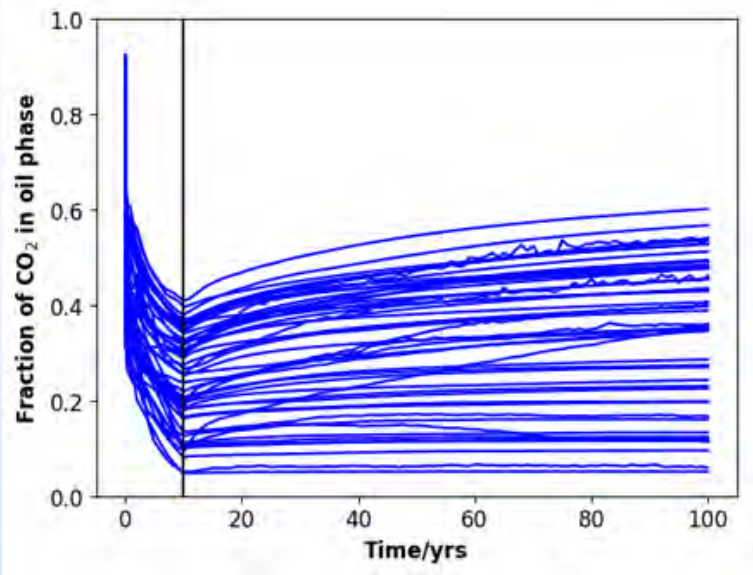
Cumulative Oil Recovery

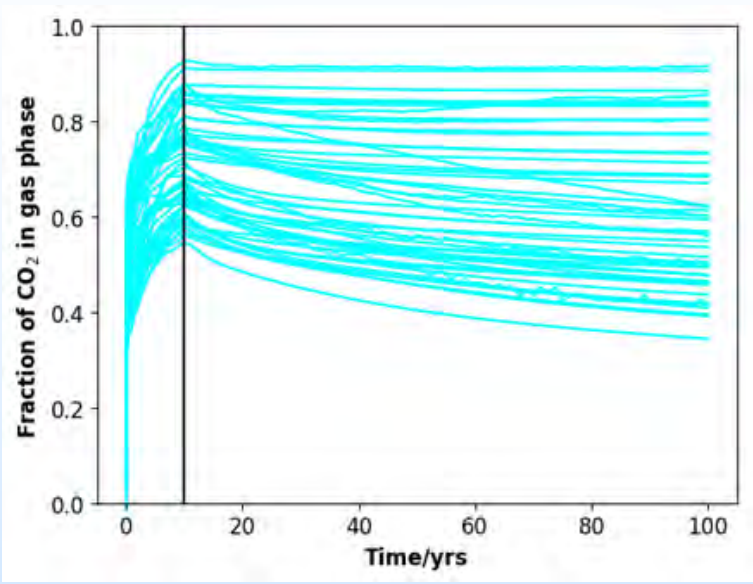


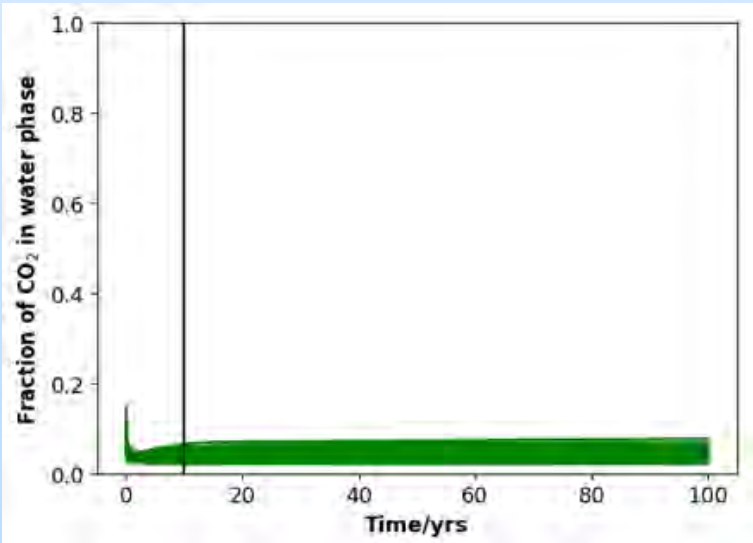
Cumulative CO_2 Storage



Long term CO_2 fate







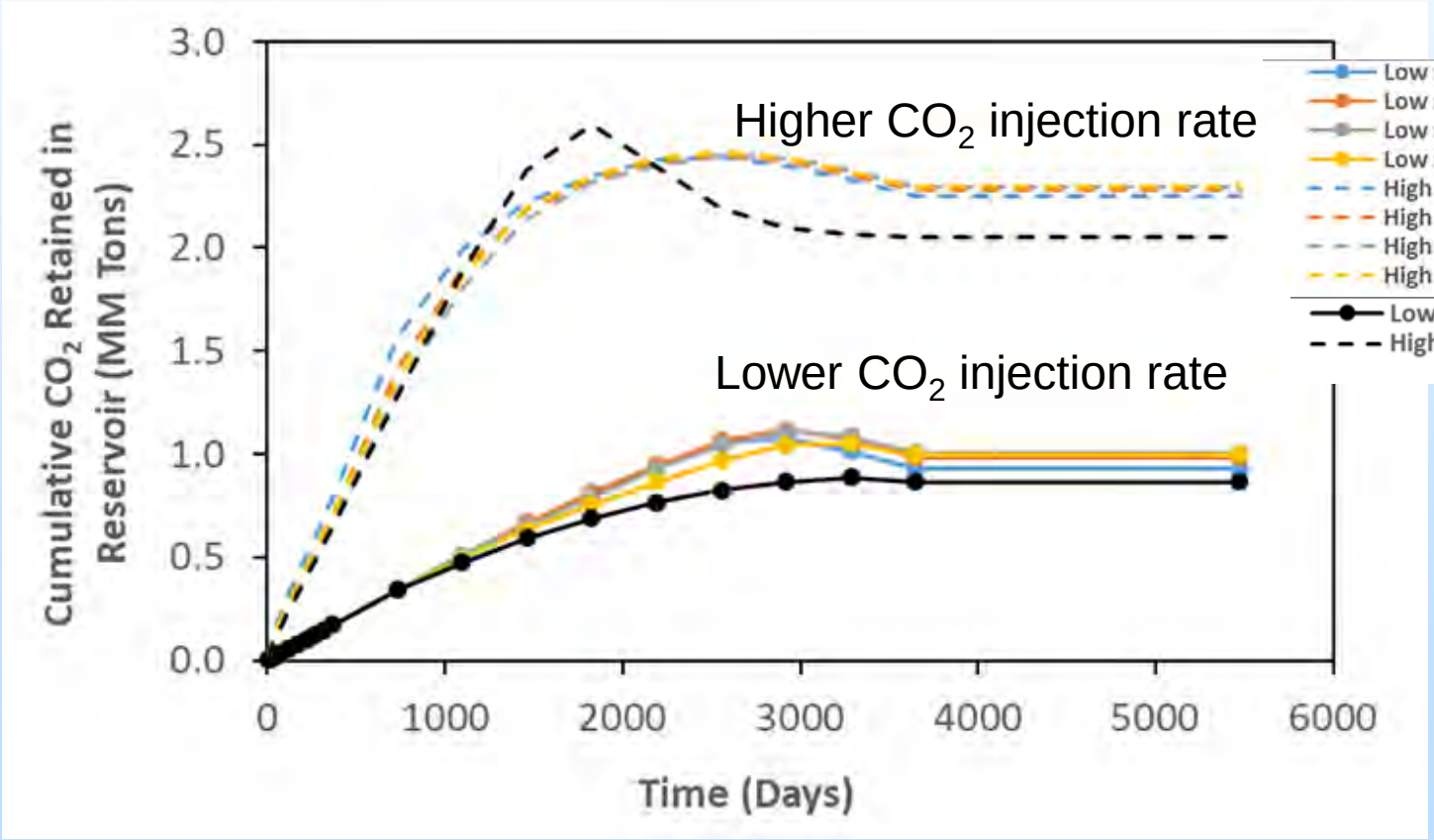
- Significant fraction of retained CO_2 exists as dissolved in oil-phase
- Comparatively, very little fraction of injected CO_2 dissolves in water

Comparing CO_2 storage in ROZ, saline aquifers and oil reservoirs

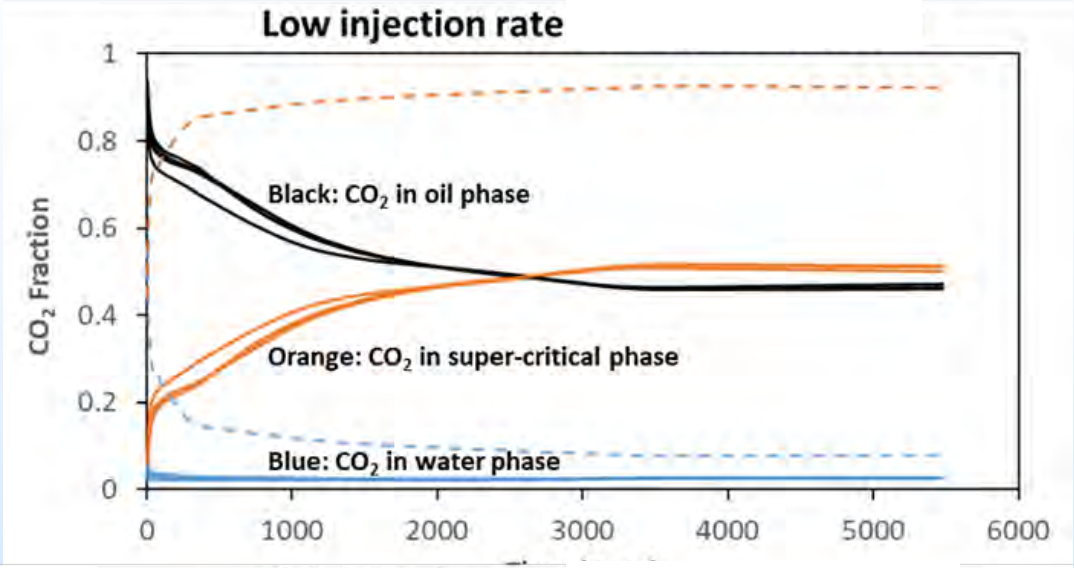
Varied initial oil saturation: 0.7, 0.6, 0.5, 0.4 (=Sor, ROZ), 0 (saline aquifer)

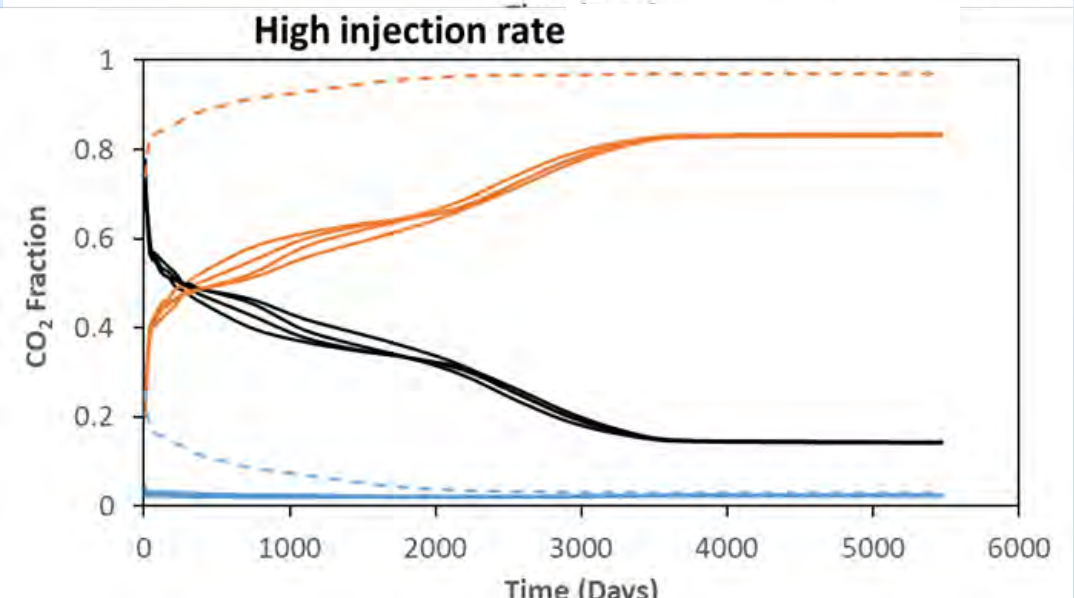
Well pattern: Single five-spot

Injection rate: 233 tons/day/well, 933 tons/day/well



Comparing CO_2 storage in ROZ, saline aquifers and oil reservoirs





Solid line - Sio=0.7, 0.6, 0.5 or 0.4

Dashed line - Sio = 0

Project Summary

- Key Findings:
  - Numerical simulations have been used to identify key characteristics as well as develop empirical models for quantifying preliminary CO_2 storage capacity, oil recovery potential in ROZs
    - ROZs potentially have significant CO_2 storage capacity
    - Field-specific studies needed to improve predictions & predictive capabilities
  - Modeling results show that CO_2 primarily resides as dissolved in oil-phase or free-phase. Only a little fraction of CO_2 is retained in in-situ water phase
  - Preliminary modeling studies have been performed to compare CO_2 storage between saline reservoirs and reservoir with hydrocarbons at or above residual oil saturations

Project Summary

- Key Findings (contd.):
  - In spite of increased commercial CO_2-EOR operations in ROZs, critical understanding needs to be developed for CO_2 storage & oil production mechanisms as well as long-term CO_2 fate and risks
    - Lack of appropriate data
    - Large uncertainty
- Next Steps:
  - Contribute to NETL initiative on developing ROZ CO_2 storage capacity estimates: Compare modeling results with other efforts
  - Apply empirical models to ROZs from other basins in US
  - Continue work on comparison between CO_2 storage in saline aquifers and reservoirs with hydrocarbons
  - Laboratory experimental characterization of parameters/processes in ROZ

Synergy Opportunities

- NETL Carbon Storage Atlas project: share empirical models for estimating storage capacity
- Other modeling efforts on ROZ storage potential: compare modeling approaches, share results, share lessons learned
- Collaborations and knowledge-sharing with NETL, Illinois Geologic Survey, UT-BEG, UND-EERC

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

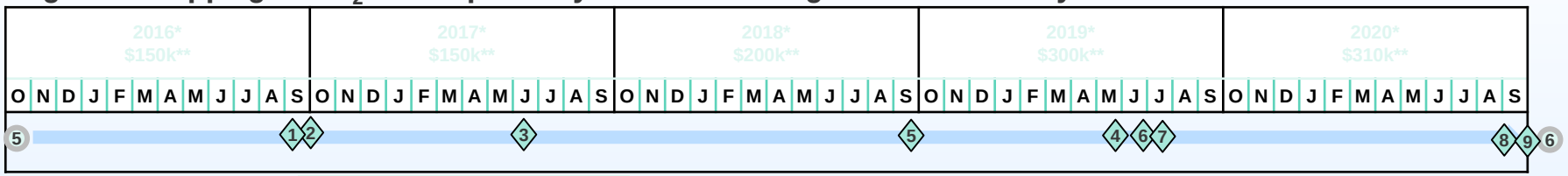
- Develop improved quantitative relationships for predicting storage and trapping efficiencies in environments where both a brine and hydrocarbon fluid are present (primarily, unconventional reservoirs such as ROZs).
  - Identify key characteristics
  - Develop empirical models for quantifying: CO_2 storage capacity, oil recovery potential, CO_2 fate
  - Assess CO_2 storage capacity and associated oil recovery for different ROZ fields

Organization Chart

- Rajesh Pawar, PI
- Bailian Chen, Post-doc
- George Guthrie, LANL Program Manager

Gantt Chart

Storage and Trapping of CO_2 in Multiphase Systems Containing both Brine and Hydrocarbon



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.

Chart Key

TRL Score

Go / No-Go Timeframe

Project Completion

Milestone

Go / No-Go

Key Accomplishments/Deliverables	Value Delivered
2016: Successfully developed empirical relationships for estimating CO_2 storage capacity, oil recovery potential in ROZs. **2017**: Quantified CO_2 storage capacity, oil recovery potential in multiple ROZ fields in the Permian Basin. Identified key uncertainties associated with CO_2-brine-hydrocarbon interactions in ROZ fields.	• Empirical models that can be used to quantify CO_2 storage capacity, oil recovery potential in ROZ fields and long-term risks in CO_2-brine-hydrocarbon systems. • Reduction in uncertainties in knowledge base related to ROZs.

*FY of Performance
**FY of funds (Note: funds normally become available mid- to late-FY)

Bibliography

- Chen, B. and Pawar, R. J., 2018, Capacity Assessment of CO_2 Storage and Enhanced Oil Recovery in Residual Oil Zones. SPE-191604-MS, 2018 SPE Annual Technical Conference and Exhibition, Dallas, TX, 24-26 Septmember.
- Chen, B. and Pawar, R. J., 2018, Capacity Assessment of CO_2 Storage and Enhanced Oil Recovery in Residual Oil Zones. 14th International Conference on Greenhouse Gas Control Technologies, Melbourne, Australia.