Characterization of CO_2 Storage in Residual Oil Zones

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

- Introduction
- Project Objective
- Technical Status
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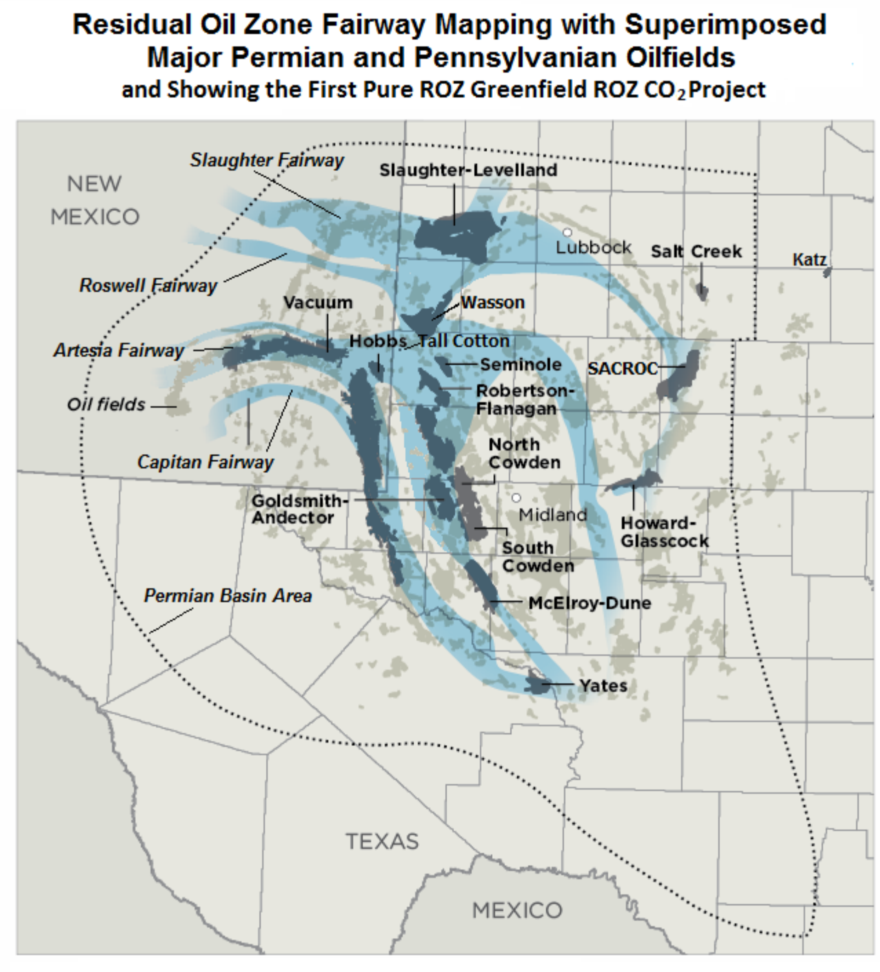
- Synergy Opportunities
- Project Summary

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



Map source: http://melzerconsulting.com/maps/

CO_2 Storage in Residual Oil Zones

- Preliminary studies estimate potentially high CO_2 storage capacity in ROZs
  - Primarily focused on the Permian Basin ROZs
  - Preliminary evidence indicate ROZs' presence in other major basins including, Williston, Big Horn, etc.
- Characterization data for ROZs are extremely limited
  - Mainly Permian Basin based
  - Not much information in public domain
  - Large uncertainties
- Further refinement of estimates with focused studies is needed
  - Improving understanding of CO_2 storage processes
  - Development of consistent methodology

Project Objective

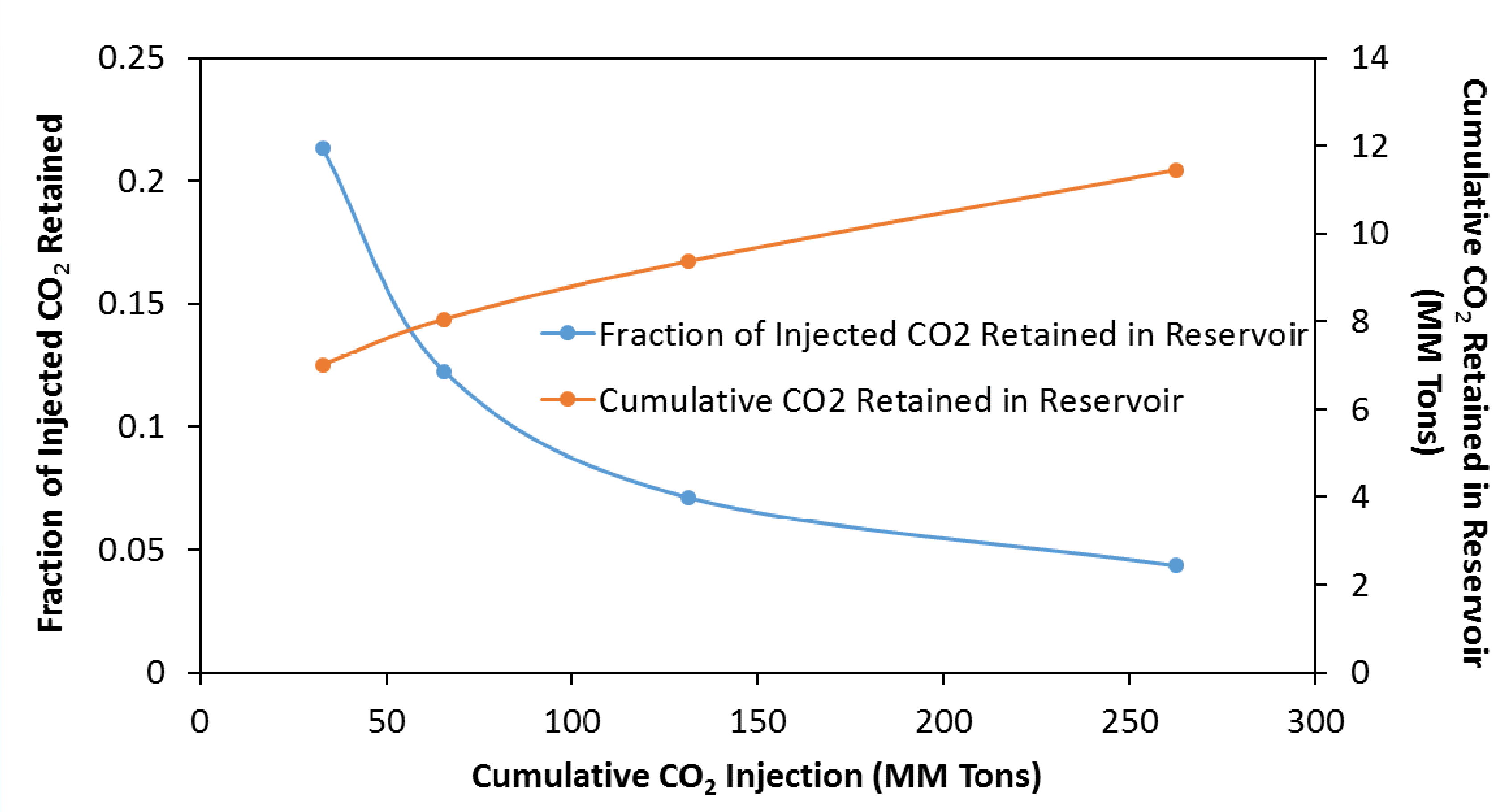
- Characterize CO_2 storage potential in ROZs:
  - Primarily Greenfield
  - Oil recovery potential
  - Long-term CO_2 fate
  - Assess key uncertainties and data needs
  - Develop general relationships to assess CO_2 storage and oil recovery potential applicable to wide range of geologic characteristics

TECHNICAL STATUS

Approach

- Literature search on data:
  - Limited public domain information
  - Main source: UT-PB, Melzer Consulting, ARI report on Goldsmith-Landreth San Andres Unit (GLSAU) in the Permian Basin: CO_2 flooding in ROZ and MPZ since 2010
- Our approach is based on numerical simulations:
  - Numerical model for GLSAU based on public domain data
  - Focused only on Greenfield portion (ignored MPZ)
  - Simulations of CO_2 injection and oil production: Eclipse, compositional simulations with aqueous CO_2 dissolution
  - Multiple scenarios:
    - Varied injection rate, well patterns, injection patterns, reservoir permeability, residual oil saturation, etc.

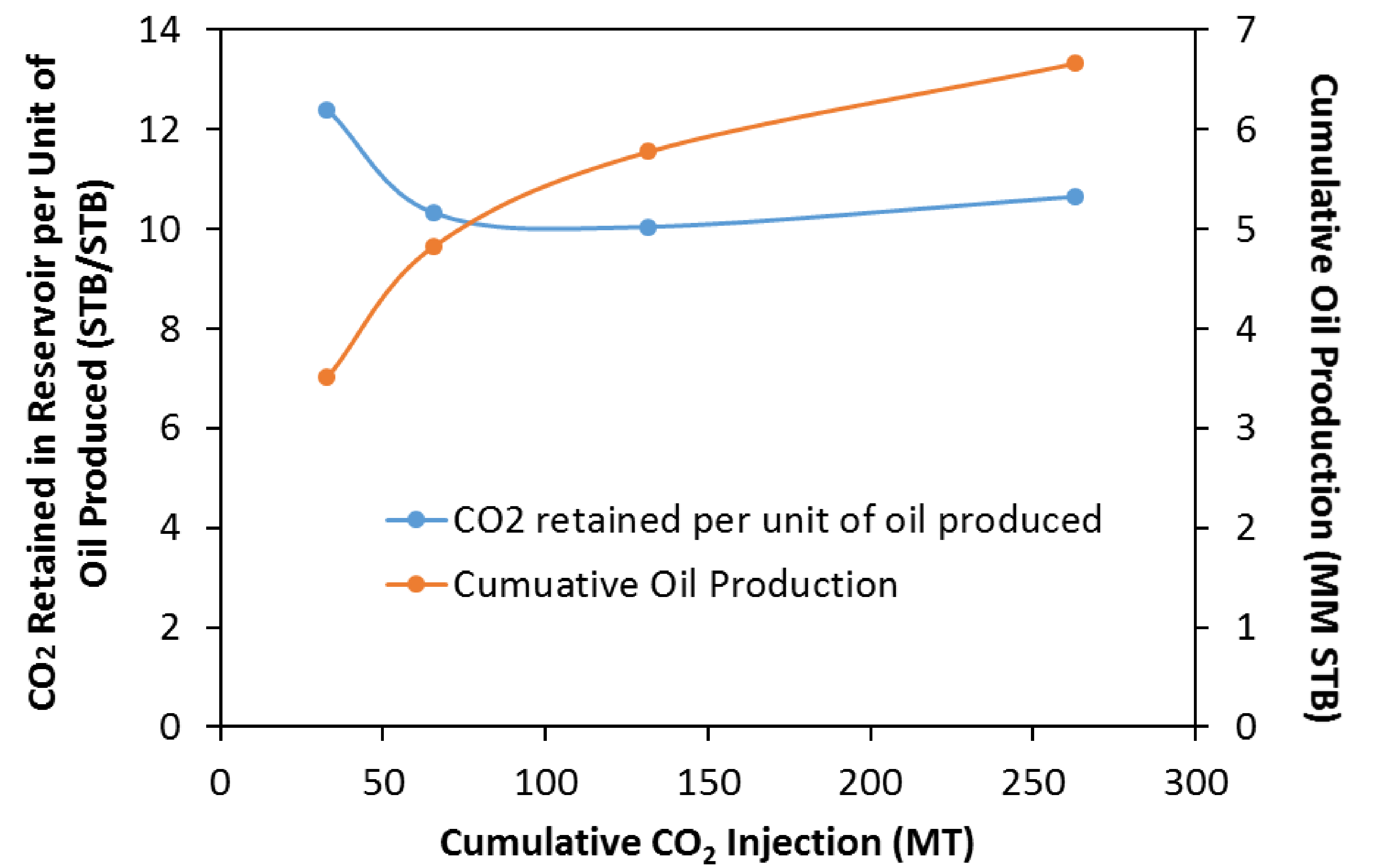
CO_2 storage capacity



Base Case:

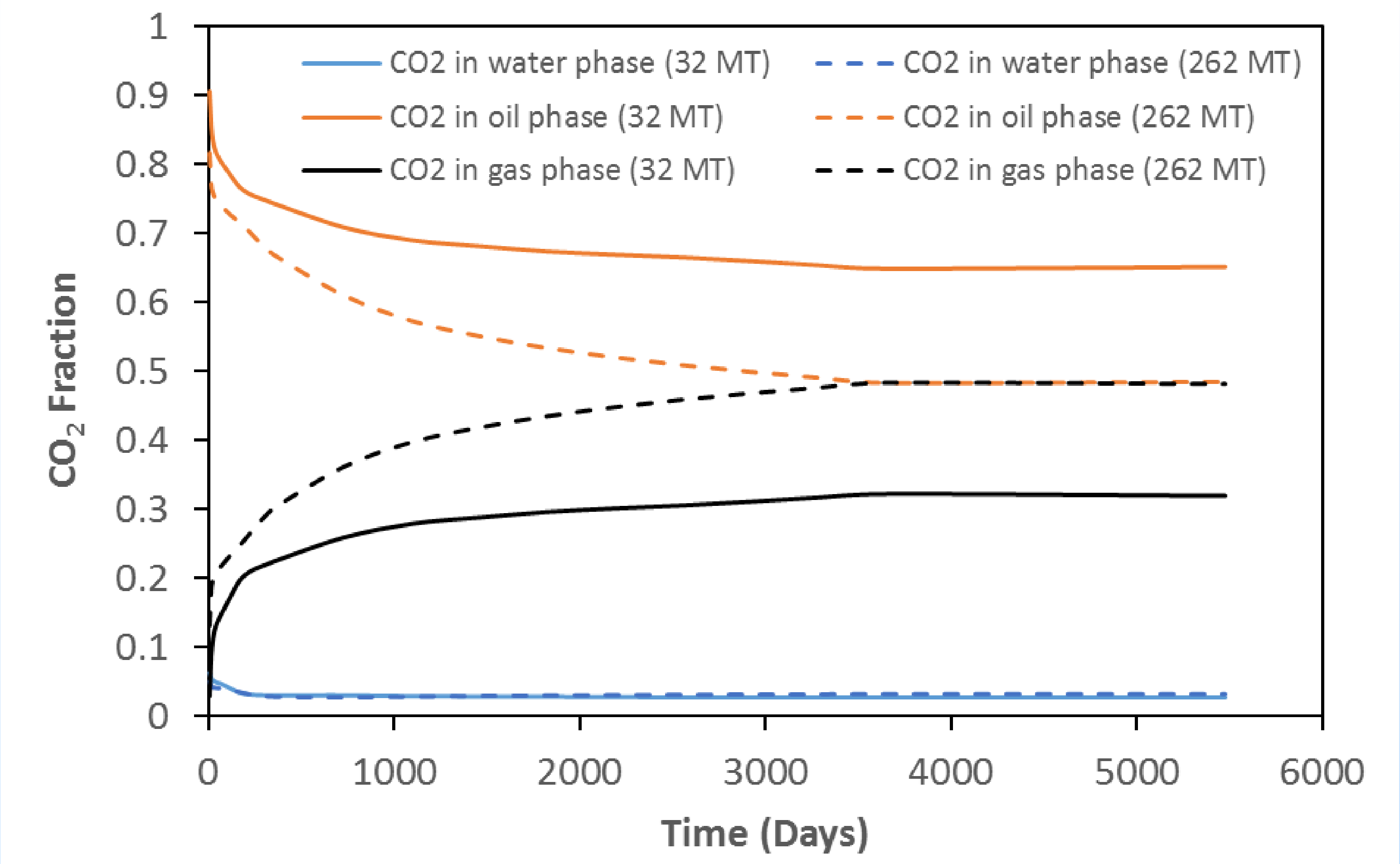
- Five spot pattern: 16 injectors & 9 producers, 40 acre well spacing
- 10 years continuous CO_2 injection with simultaneous production followed by 5 years of no injection and production: constant rate injection with BHP control (4000 psi)

Oil Recovery Potential



Oil recovery and CO_2 retention efficiency vary non-linearly with amount injected

Reservoir CO_2 Distribution

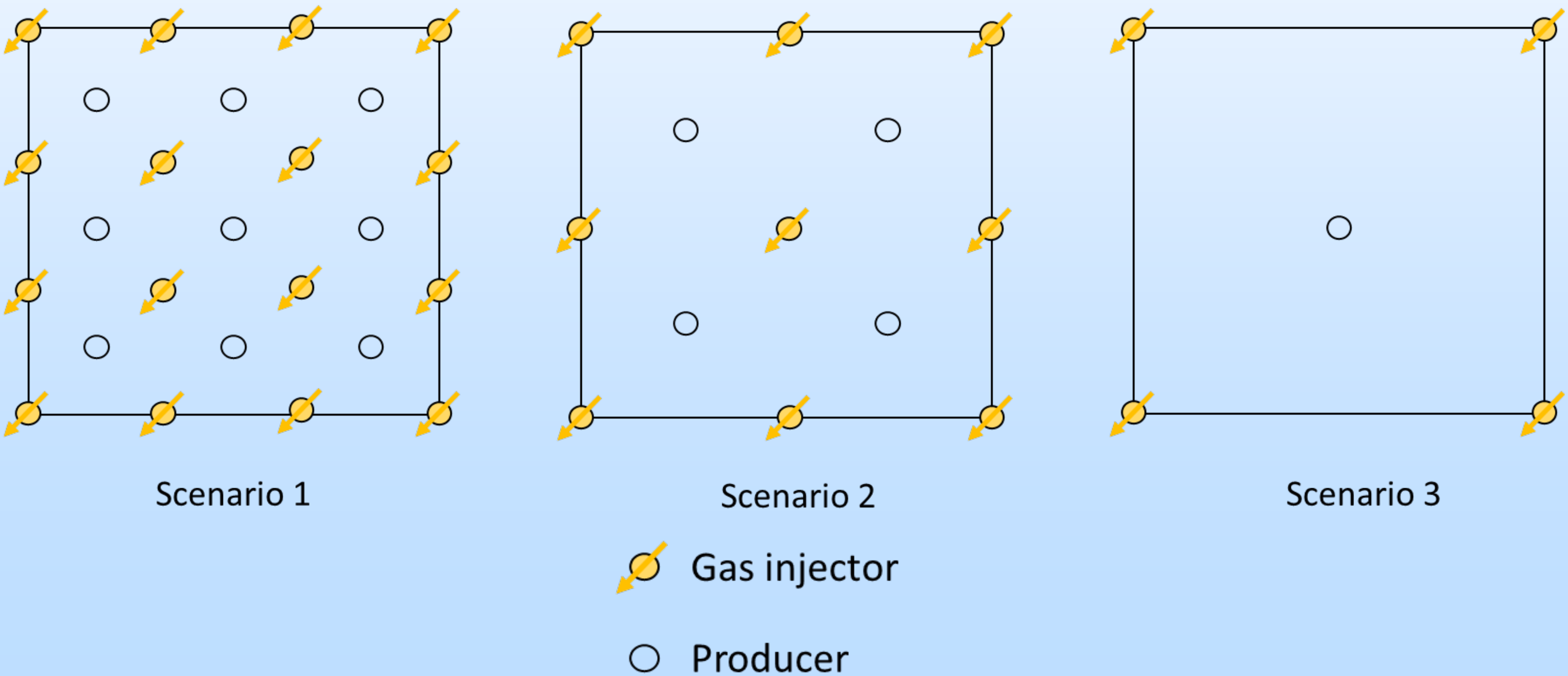


- Long-term CO_2 inter-phase distribution is a function of CO_2 injection amount
- Significant fraction of reservoir CO_2 resides in hydrocarbon phase

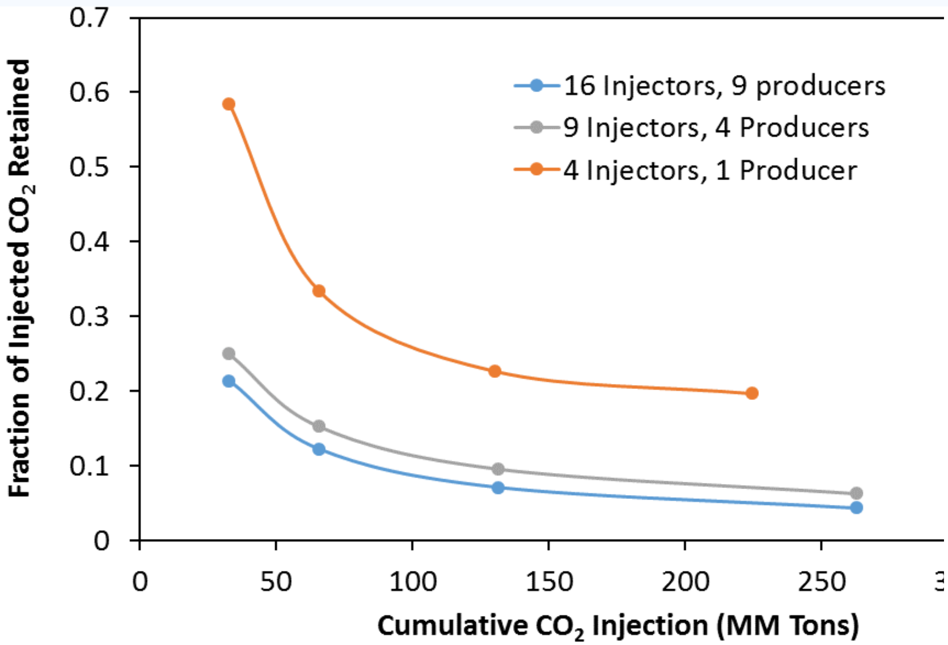
Effect of Well Spacing

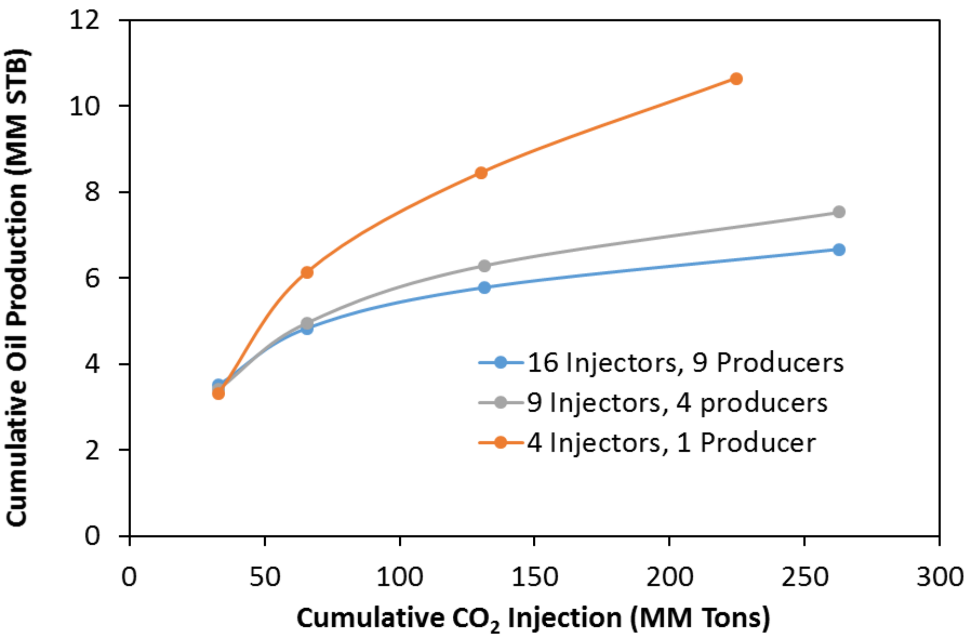
Compare performance among three scenarios:

1. Multiple five-spot patterns (16 Injectors, 9 Producers)
2. Multiple five-spot patterns (9 Injectors, 4 Producers)
3. Single five-spot pattern (4 Injectors, 1 Producer)



Effect of Well Spacing





- Less number of wells actually results in higher CO_2 retention and oil recovery: better reservoir sweep
- Less number of wells ⇨ Decreased potential for wellbore leakage

Continuous injection versus WAG

	Cont. CO_2 (BHP)	Cont. CO_2 (Rate)	WAG 3m-3m	WAG 1m-5m	WAG 2m-4m
Cumulative CO_2 injected (MM Tons)	294	225	133	248	194
Cumulative CO_2 retained (MM Tons)	58.8	44.2	43.5	55.4	50.4
Fraction of CO_2 retained	20.0%	19.7%	32.8%	22.3%	26.0%
Cumulative Oil Production (MM STB)	11.9	10.6	10.1	11.3	10.8

- Continuous CO_2: BHP control results in much higher cumulative CO_2 retained and 1.3 MM STB more oil produced.
- WAG injection has lower cumulative CO_2 retention but higher fractional retention and higher CO_2 retention efficiency.

Accomplishments to Date

- Successfully developed a numerical model for a Greenfield ROZ site
  - Model based on public domain data for an operational field with CO_2-EOR in ROZ
- Performed multiple compositional simulations to estimate CO_2 storage and associated oil recovery potential in the Residual Oil Zone
  - Gained key insights in variability of CO_2 storage capacity and oil recovery due to variability in operational parameters and geologic parameters

Lessons Learned

- Research gaps/challenges:
  - Significant lack of appropriate characterization data
  - Large uncertainties

Synergy Opportunities

- NETL modeling efforts on ROZ storage potential: compare modeling approaches, share results, share lessons learned
- UT-BEG experimental efforts: characterization data
- NETL Carbon Storage Atlas project: approaches for estimating storage capacity

Project Summary

- Key Findings:
  - CO_2 storage in ROZ does not scale with injected CO_2 amount
  - CO_2 storage fraction decreases non-linearly with increasing CO_2 injection
  - Oil recovery and CO_2 retention efficiency vary non-linearly with CO_2 injection
  - Majority of CO_2 resides in hydro-carbon phase
  - Larger well spacing (than traditional 40 acre) improves CO_2 retention and oil recovery: reduced potential for leakage
  - Variability in reservoir vertical permeability and residual oil saturation does not have any significant effect of CO_2 storage capacity or oil recovery
- Next Steps:
  - Extend model application to ROZs from other basins in US
  - Develop relationships to estimate CO_2 storage capacity and oil recovery potential in ROZ applicable over wide range of geologic conditions

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 CO2 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
  - Oil recovery potential
  - Long-term CO_2 fate
  - Assess key uncertainties and data needs
  - Develop general 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
- George Guthrie, LANL Program Manager

Gantt Chart

	0-6 months	6-12 months
Task 3.1 Project Management & Planning	←	→
Task 3.2 Refine estimates of ROZ CO_2 utilization potential for US	←	→
Task 3.3 Develop reduced order models for ROZ CO_2 storage potential assessment		↔

Bibliography

– List peer reviewed publications generated from the project per the format of the examples below.

- Journal, one author:
  - Gaus, I., 2010, Role and impact of CO2-rock interactions during CO2 storage in sedimentary rocks: International Journal of Greenhouse Gas Control, v. 4, p. 73-89, available at: XXXXXXX.com.
- Journal, multiple authors:
  - MacQuarrie, K., and Mayer, K.U., 2005, Reactive transport modeling in fractured rock: A state-of-the-science review. Earth Science Reviews, v. 72, p. 189-227, available at: XXXXXXX.com.
- Publication:
  - Bethke, C.M., 1996, Geochemical reaction modeling, concepts and applications: New York, Oxford University Press, 397 p.