Optimizing CO_2 Sweep based on Geochemical and Reservoir Characterization of the Residual Oil Zone of Hess's Seminole Unit

Project Number: **DE-FE0024375**

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U.S. Department of Energy

National Energy Technology Laboratory

Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting

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Presentation Outline

Technical Status

- Advanced Reservoir Characterization
- Use Foam to Increase Sweep in ROZ

Accomplishments to Date

Lessons Learned

Synergy Opportunities

Project Summary

Technical Status

Advanced Reservoir Characterization

- Carbon and oxygen stable isotopes
  - 5 continuous cores
  - entire ROZ (2,400 feet core)
- Machine learning
  - model petro-physical properties and wireline logs
  - calibrated against measurement on continuous cores
  - extend to
    - » measurement of P_c and water saturation
    - » Uses 130 core plugs, 500 NMR measurements

Technical Status

Use Foam to Increase Sweep in ROZ

- Oil recovery and CO_2 storage
  - foam injection (surfactant alternating gas)
  - water alternating gas (WAG)
  - continuous CO_2 injection
- Influencing factors
  - injector bottom hole pressure target
  - reservoir heterogeneity

Improving Sweep by Foam Flooding

Foam Flooding

- Foam: aggregated bubbles
- Increase the apparent viscosity of CO_2
- Block high-perm pathways temporarily
- Increases CO_2 sweep

There is an expectation that foam will increase both oil production and CO_2 storage because of the above.

Water Alternating Gas (WAG)
Surfactant Alternating Gas (SAG)

Continuous CO_2 injection

WAG Ratio =0

CO_2	CO_2	CO_2

WAG injection

one cycle ⟷

WAG Ratio =1

CO_2	Water	CO_2	Water	CO_2	Water	CO_2	Water

WAG Ratio =2

CO_2	Water	CO_2	Water	CO_2	Water

Foam (surfactant (S) alternating gas) injection

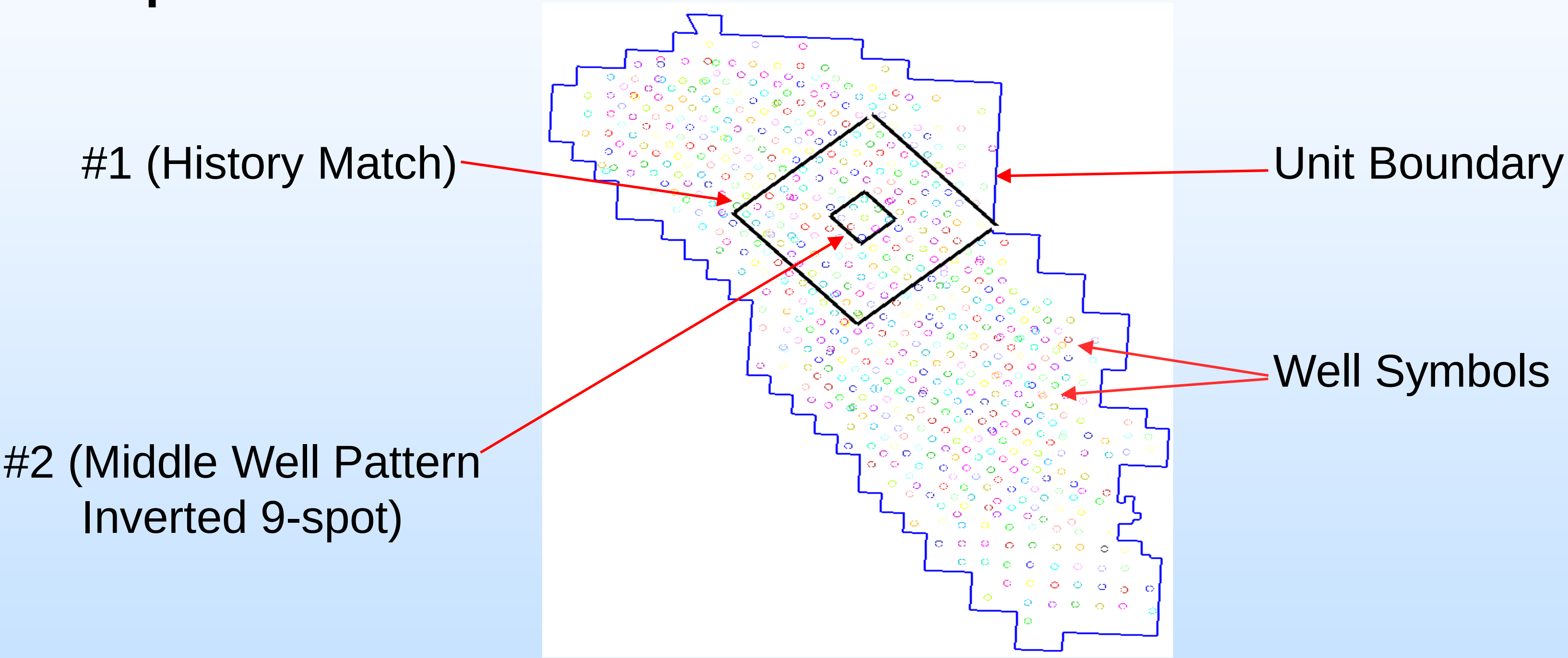
SAG Ratio =1

CO_2	S	CO_2	S	S	Water	S	Water

$$\textbf{WAG Ratio} = \frac{\text{Injected water reservoir volume in each cycle}}{\text{injected } CO_2 \text{ reservoir volume in each cycle}}$$

Reservoir Flow Simulation Workflow

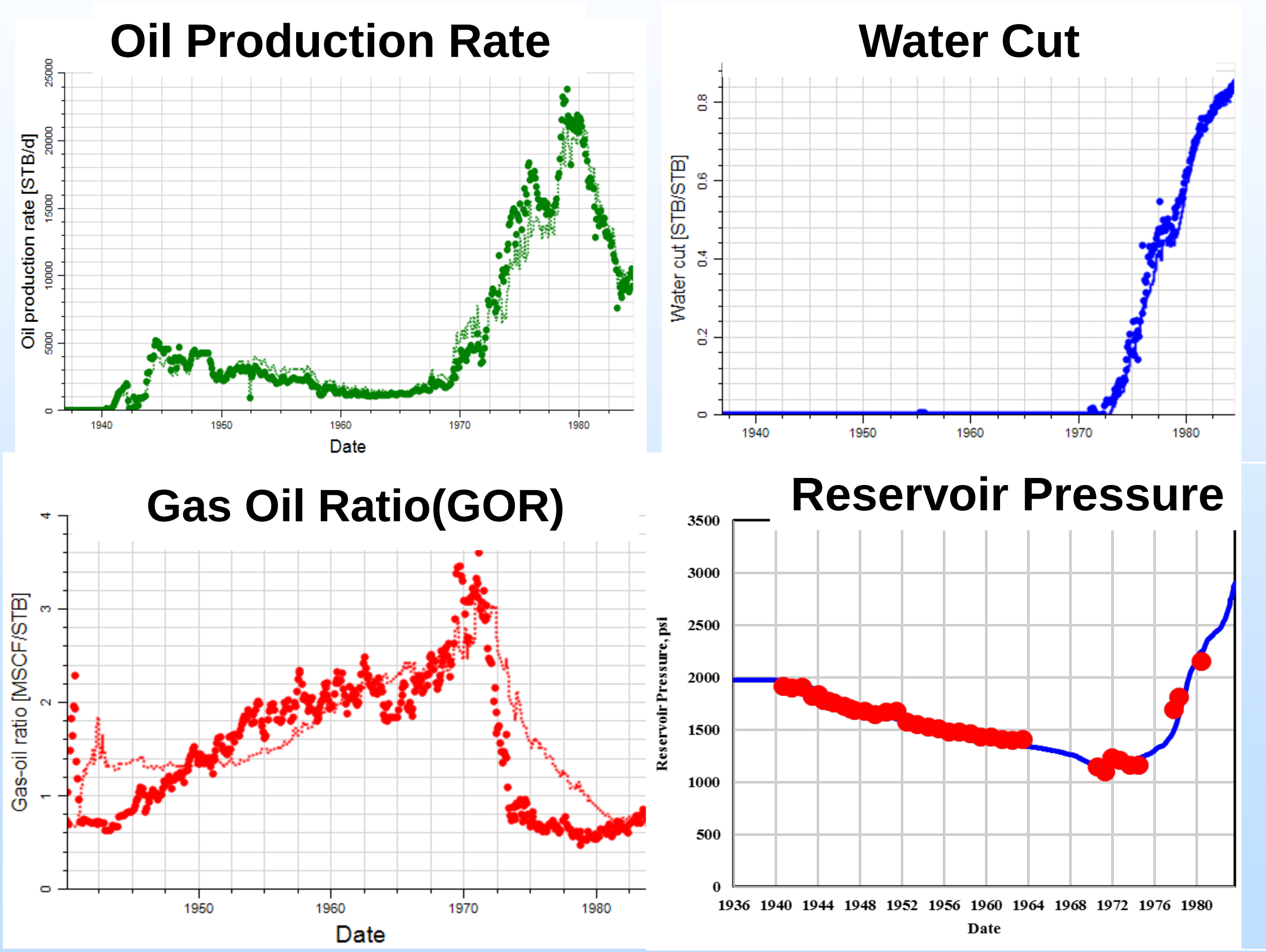
Step1: Cut a sector model from the full-field Seminole



Step2: History matching (oil rate, water cut, GOR, and pressure)

Step3: Prediction - water alternating gas (WAG) and foam injection

History Matching

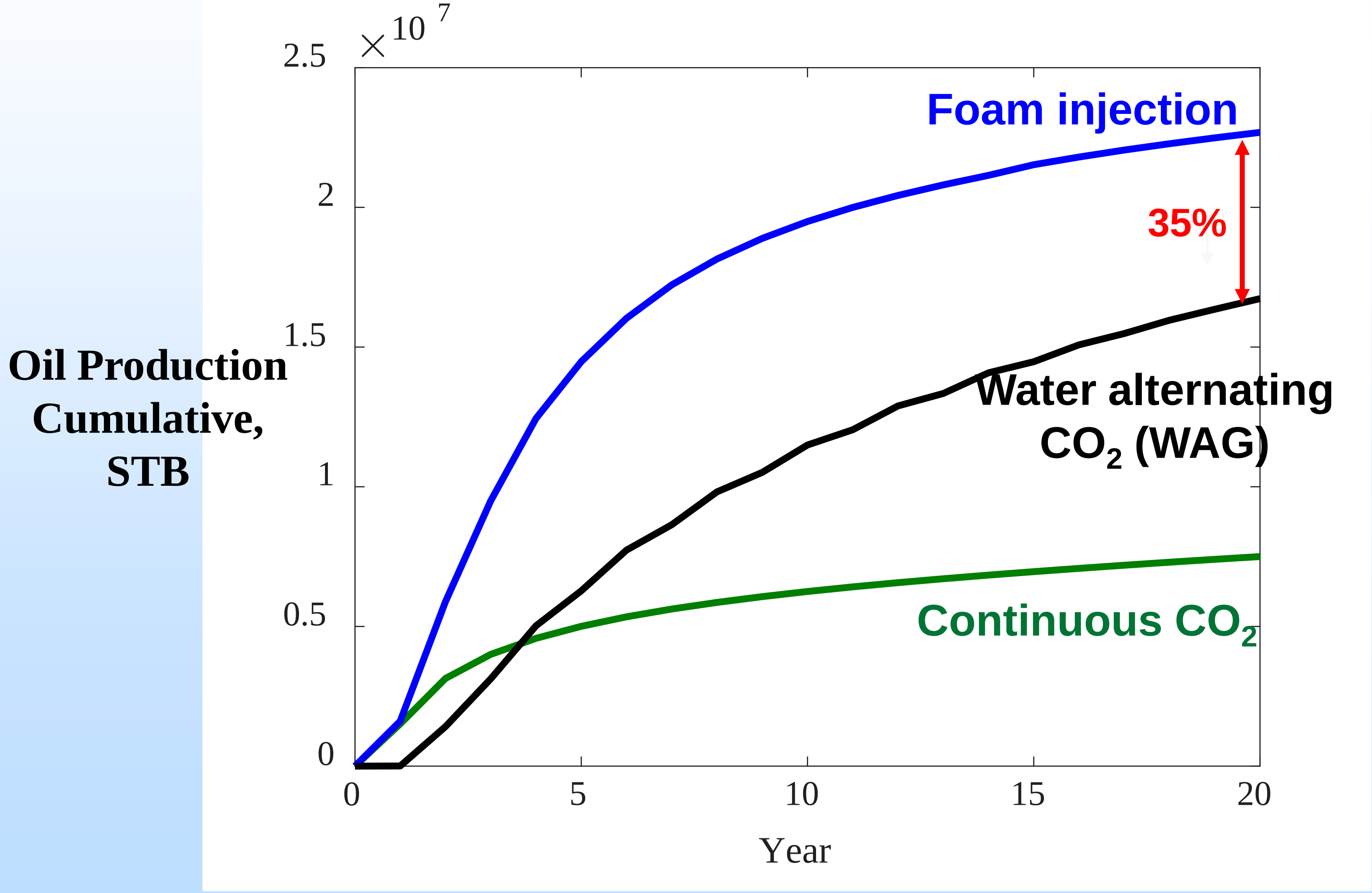


Foam Model

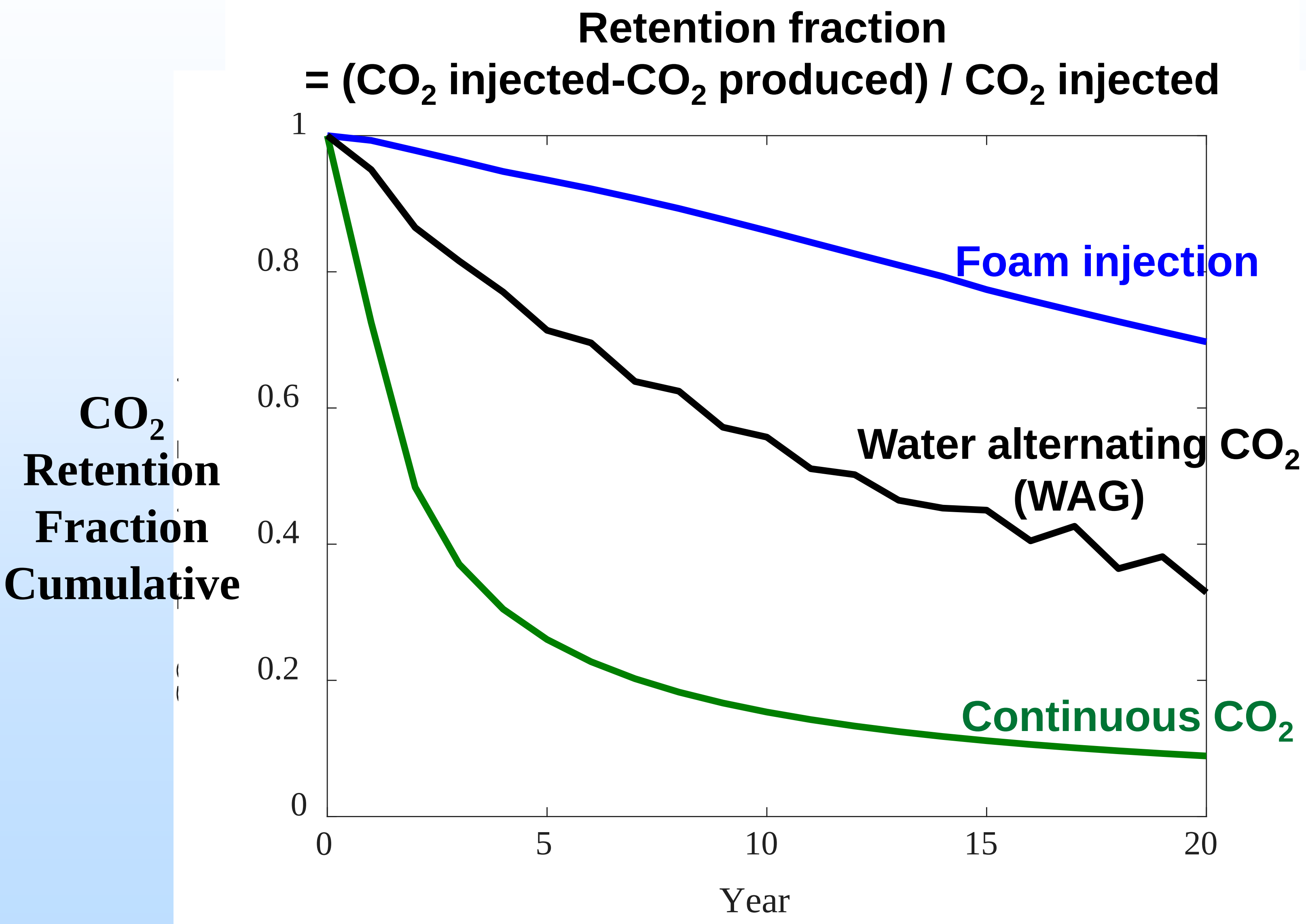
Foam model	Texture-implicit local-equilibrium
$k_{rg.foam} = k_{rg} \times M_{rf}$ $M_{rf} = 1/ [1 + (M_r \cdot F_s \cdot F_w \cdot F_o \cdot F_c)]$	
M_r	Reference mobility reduction factor
F_s	Surfactant concentration related
F_w	Water saturation related
F_o	Oil saturation related
F_c	Capillary number related
Parameter settings	Kristiansen, 2018

Results for the Middle Well Pattern

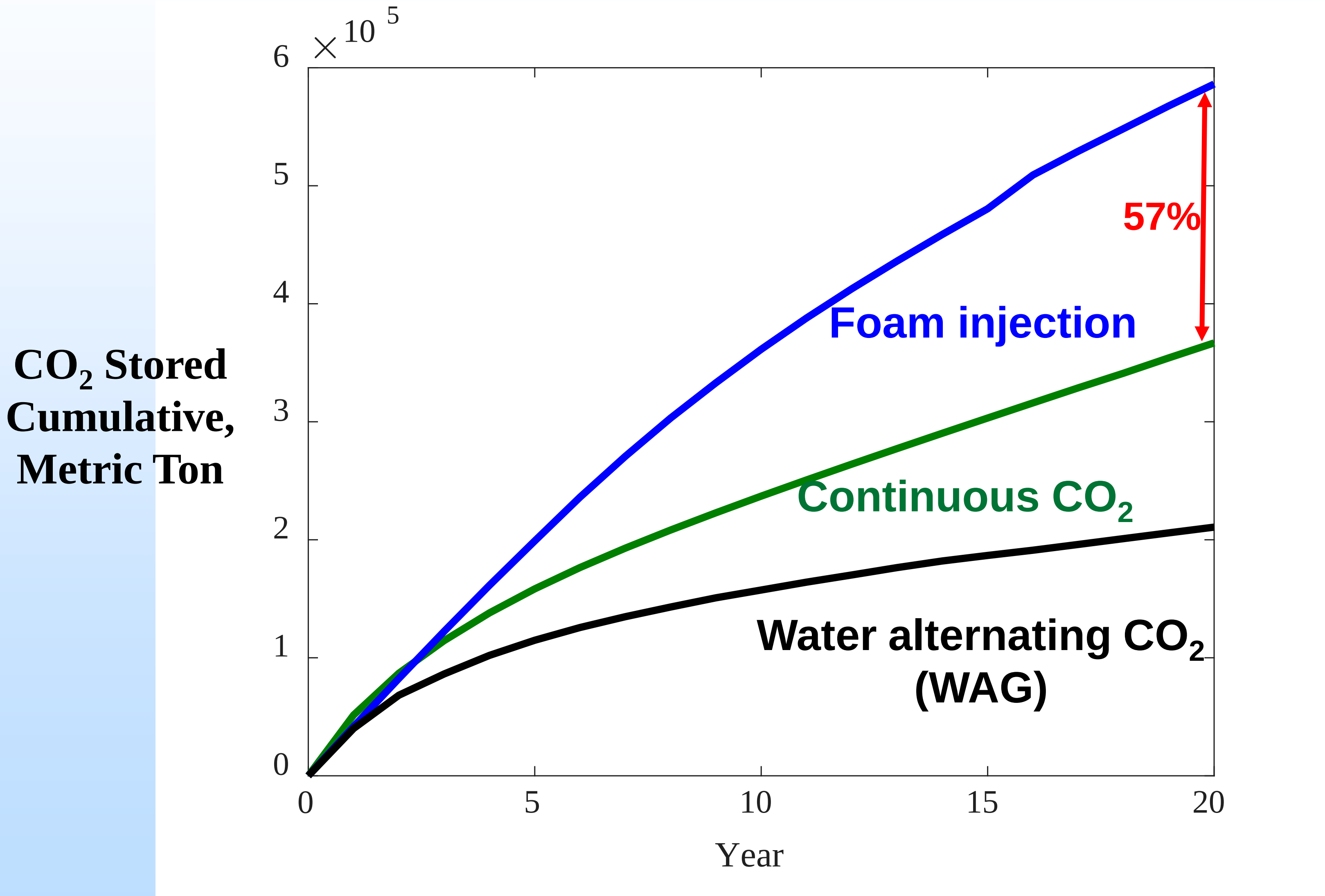
Foam Can Recover Oil from the ROZ More Effectively than WAG



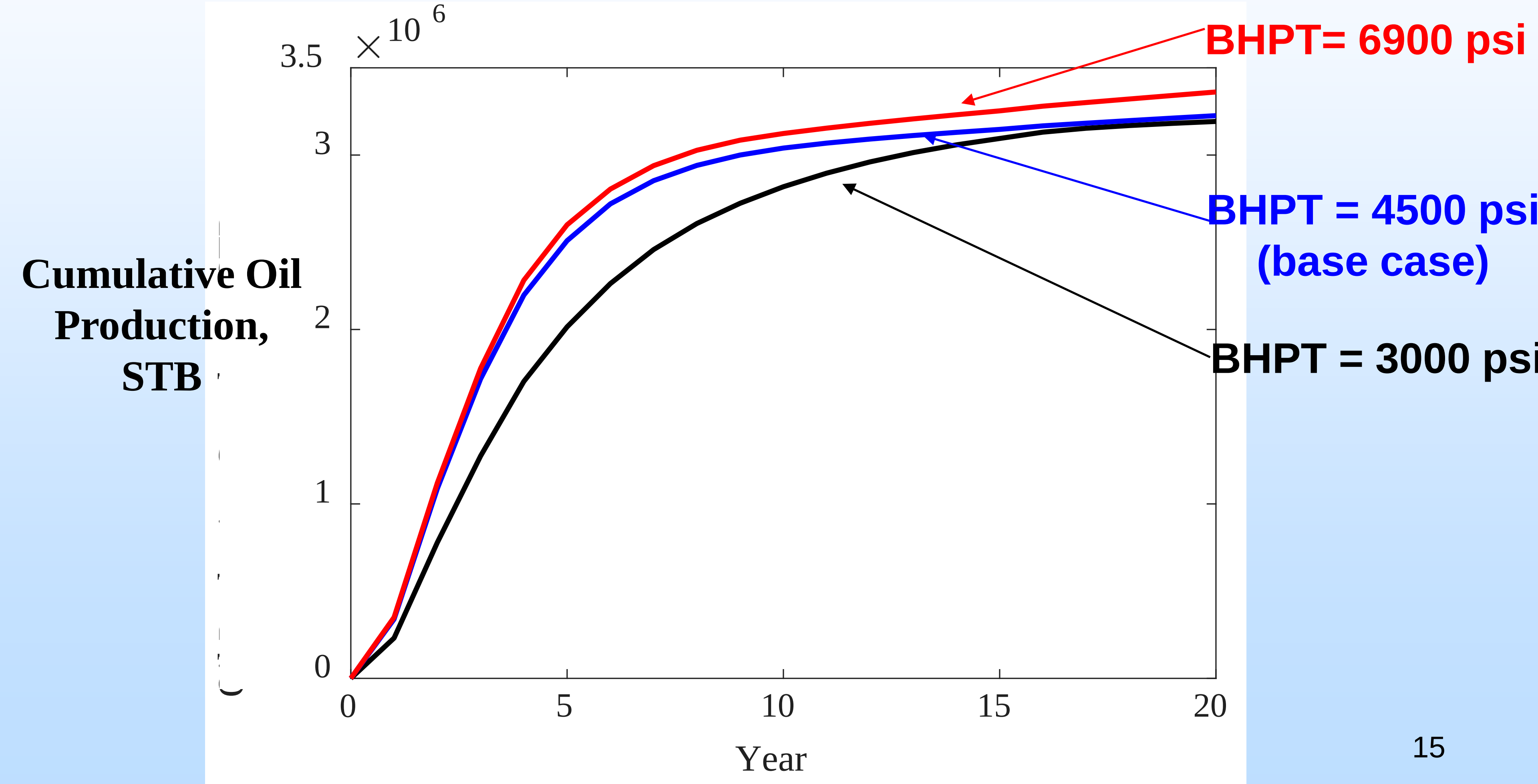
Foam Enhances CO_2 Retention in ROZ



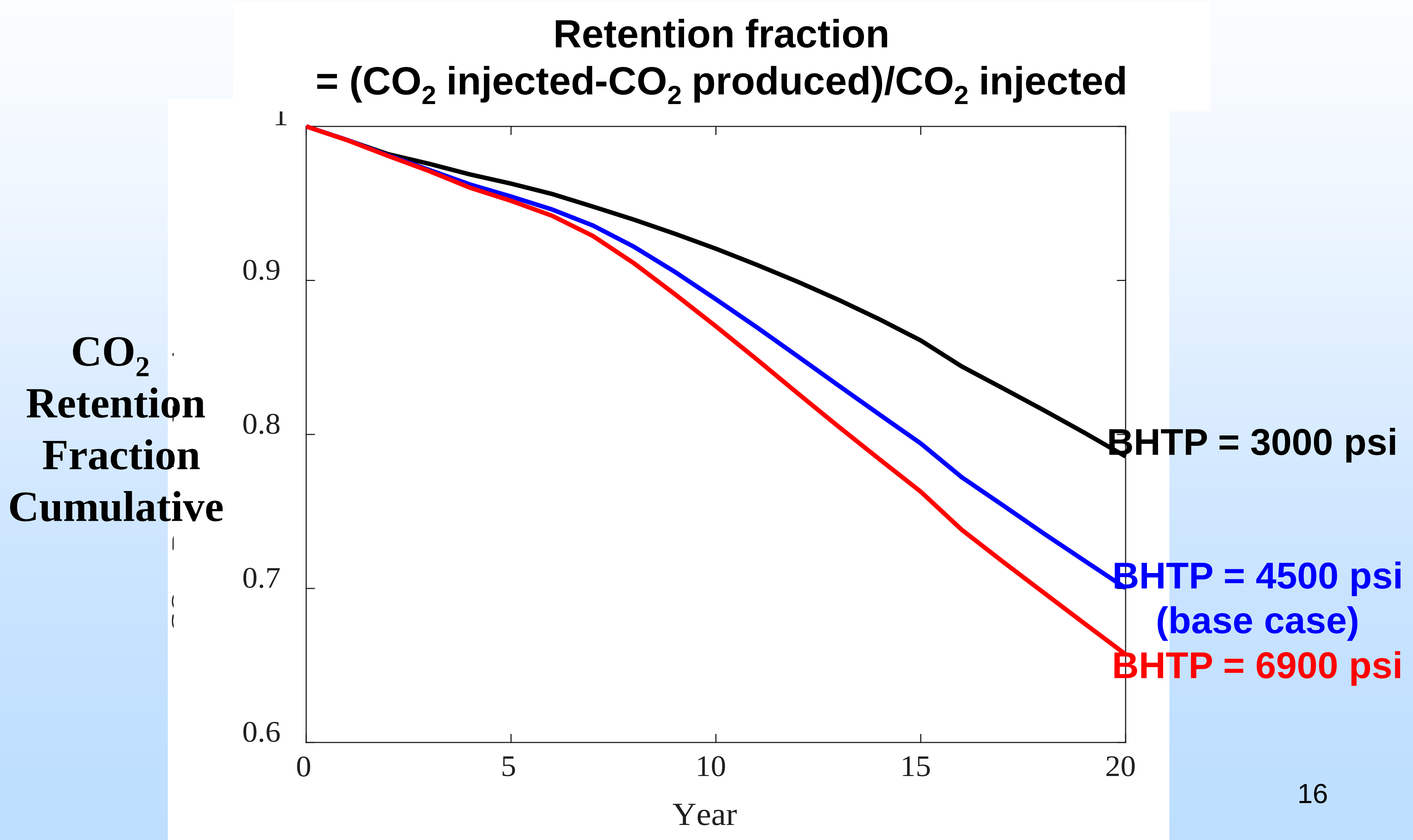
Foam Injection Can Improve CO_2 Storage in the ROZ



Deceasing Injection Bottomhole Pressure Target (BHPT) Decreases Oil Production from Foam Flooding

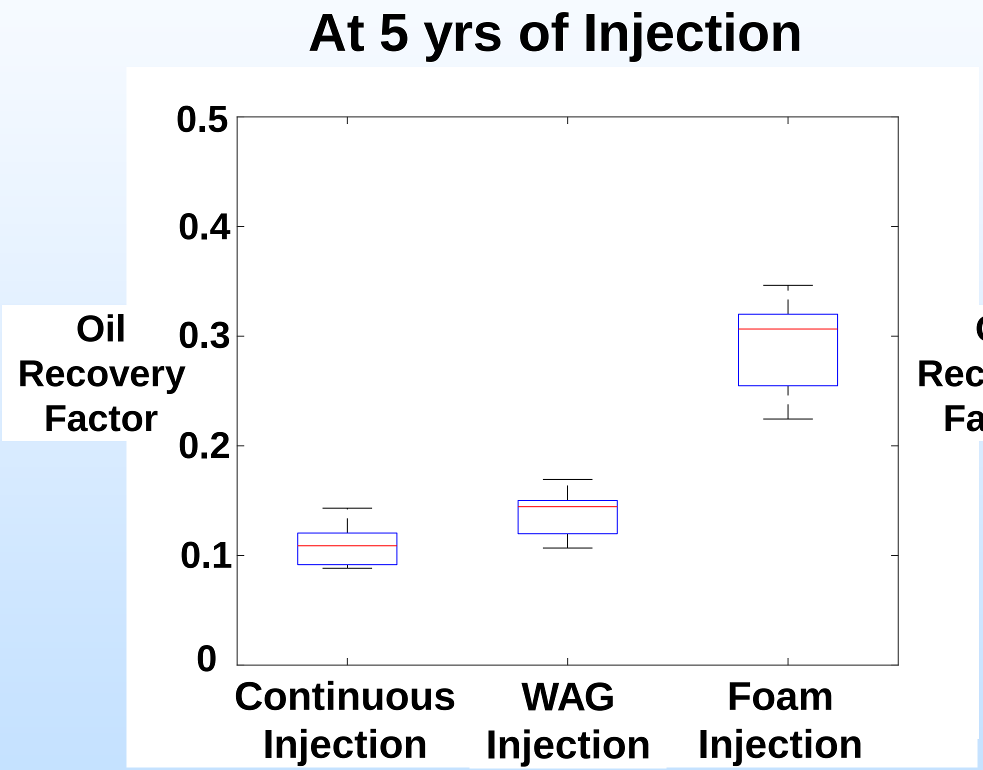


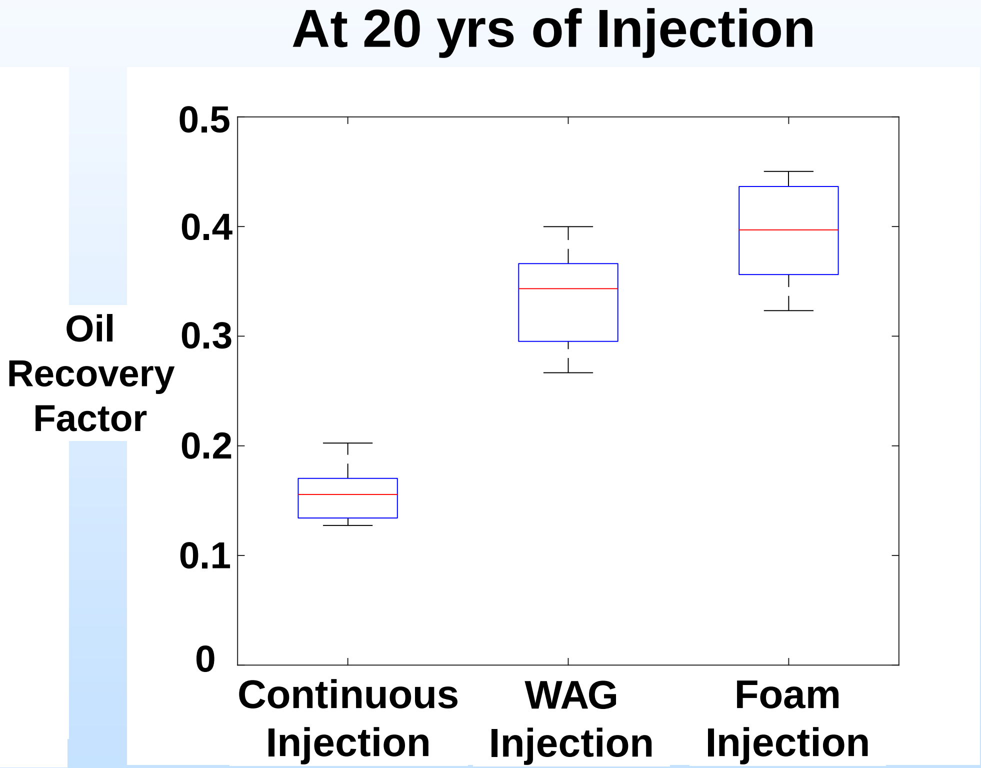
Decreasing Injection Bottomhole Pressure Target (BHPT) Favors CO_2 Retention from Foam Flooding



Results from
Other Well Patterns

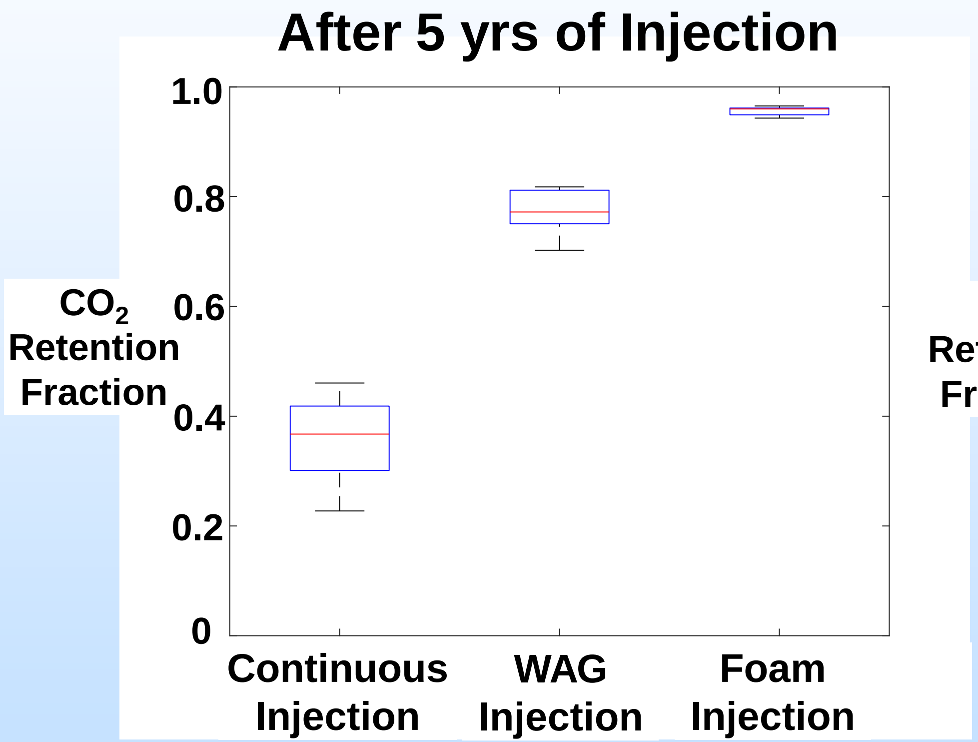
Oil Recovery from Foam Flooding is Faster and More Effective than WAG

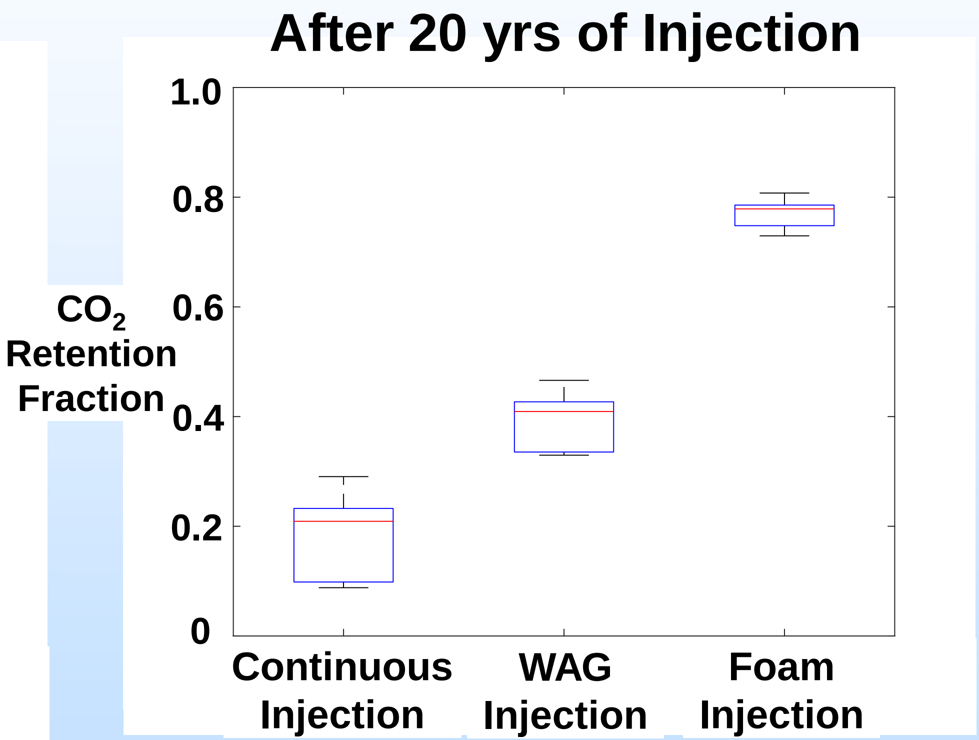




Oil Recovery Factor: the percentage of the ROZ remaining oil in place recovered

Foam is More Robust than WAG in Retaining CO_2 in the ROZ

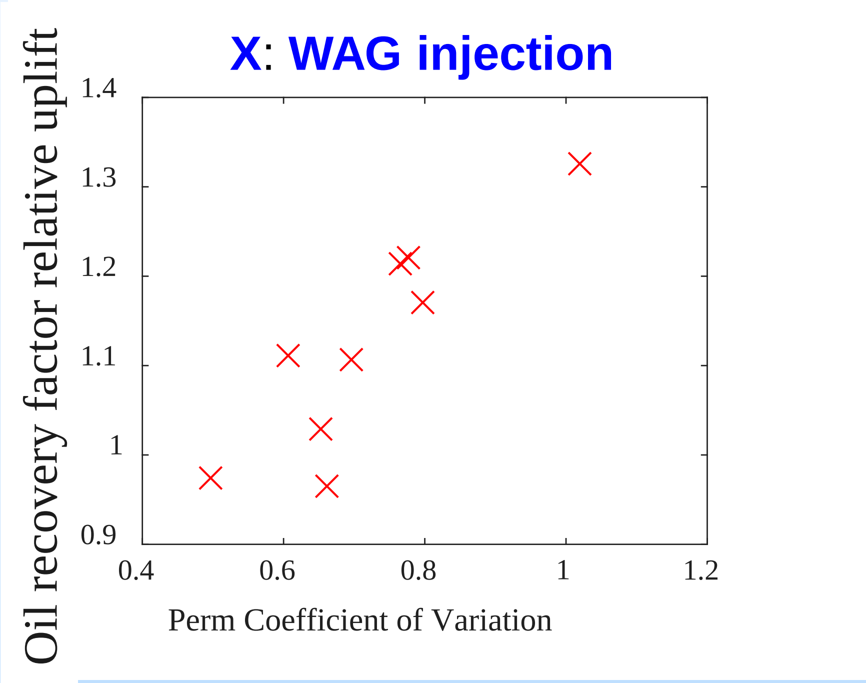


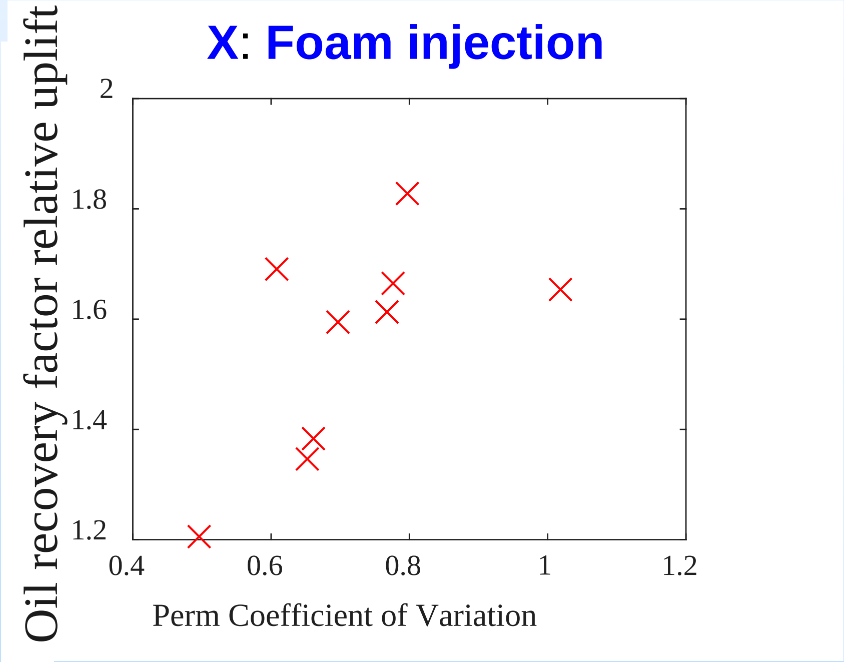


CO_2 Retention Fraction
= (CO_2 injected-CO_2 produced) / CO_2 injected

Increased Oil Recovery By Foam and WAG as Heterogeneity Increases

Oil recovery factor relative uplift =
(recovery factor by X - recovery factor by continuous CO_2) / recovery factor by continuous CO_2





Conclusions on Foam Flooding

Foam flooding

- can increase oil production by ~15% compared to WAG
- can increase CO_2 retention fraction by ~80% compared to continuous injection
- affected by injection pressure targets and reservoir heterogeneity

Accomplishments to Date

- Second Generation Static Reservoir Model completed
- Data base of geologic logging, digital core scans, petro-physical measurements, wireline logs assembled in TechLog
- Machine learning analysis of porosity- permeability-micro-facies relationships in paper to be submitted in September
- Machine learning used to model wireline logs and conditioned using petro-physical core data
- Eclipse simulation of formation of ROZ and of optimizing WAG injections into ROZ using full static reservoir model
- Used echelon accelerator to achieve high resolution simulations that avoids artificial numerical dispersion, provides significantly higher accuracy

Lessons Learned

Research gaps and challenges

1. What factors control distribution of ROZ oil? We are exploring a new model for the origin of ROZ as the residuum from oil migration
2. It has been a challenge to incorporate measured capillary pressures etc. into simulations without causing convergence problems

Lessons Learned

Solving unanticipated research difficulties:

1. Convergence issues in foam simulations have been solved by eliminating core-based scaling metric.
2. We have overcome the need for more computer power to carry out the high resolution simulations required by using Echelon accelerator for Eclipse on a high performance computer and on the TACC supercomputer at UT-Austin.

Synergy Opportunities

Our study will provide the first detailed publically available study of a ROZ….. We are interested in collaborating with other projects.

Project Summary

- Provided the first fact-based model for a ROZ reservoir
- Provided a detailed and rich set of petro-physical measurements of the ROZ reservoir based on an extensive set of complete cores through the ROZ
- Achieved a high accuracy history match
- Published the first high-resolution simulation of the "Natural Waterflood" model for the origin of ROZs
- Published detailed study of the effect of WAG ratio on sweep as well as oil production and CO_2 storage in the MPZ compared to the ROZ reservoirs
- Made the first simulations of Foam injections into ROZ, providing interesting results on the large impact on CO_2 storage

Thanks and Questions!

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Appendix

Benefit to the Program

- Supports DOE's Programmatic goal No. 2, to "Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness".

Project Overview

Goals and Objectives

Project objective: “To improve the understanding of how much CO_2 can be stored in residual oil zones (ROZ) given current practice and how much this could be increased, by using strategies to increase sweep efficiency”.

These same strategies will increase the efficiency of oil production.

Organization Chart

Project Director Ian Duncan	
Task 1 Management	**Task 2 through 6**
Task Leader/Back-up Duncan/Ambrose	**Task Leader/Back-up** Duncan/Ambrose

Gantt Chart

	Yr1 Q1	Yr1 Q2	Yr1 Q3	Yr1 Q4	Yr2 Q1	Yr2 Q2	Yr2 Q3	Yr2 Q4	Yr3 Q1	Yr3 Q2	Yr3 Q3	Yr3 Q4
2	X	X	X	X	X	X	X	X	X	x D7	X	
2.1	x	x	x D3	x	x	x	x	x				
2.2		x	x	x	x	x D11	x	x				
2.3			x	x	x	x	x	x	x			
2.4				x	x	x	x	x D8				
2.5				x	x	x	x	x	x	x D9		
3		X	X	X	x D4							
4		X	X	X	X	X	x D5	X	x D6	X	X	
4.1				x	x	x						
4.2			x	x	x	x	x					
5		X	X	X	X	X	X	X	X	X	X D10	
6						X	X	X D12	X	X	X	X D13

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