

# **Carbon Life Cycle Analysis of CO<sub>2</sub>- EOR for Net Carbon Negative Oil (NCNO) Classification**

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Vanessa Nuñez-Lopez  
Bureau of Economic Geology  
The University of Texas

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National Energy Technology Laboratory  
Carbon Storage R&D Project Review Meeting  
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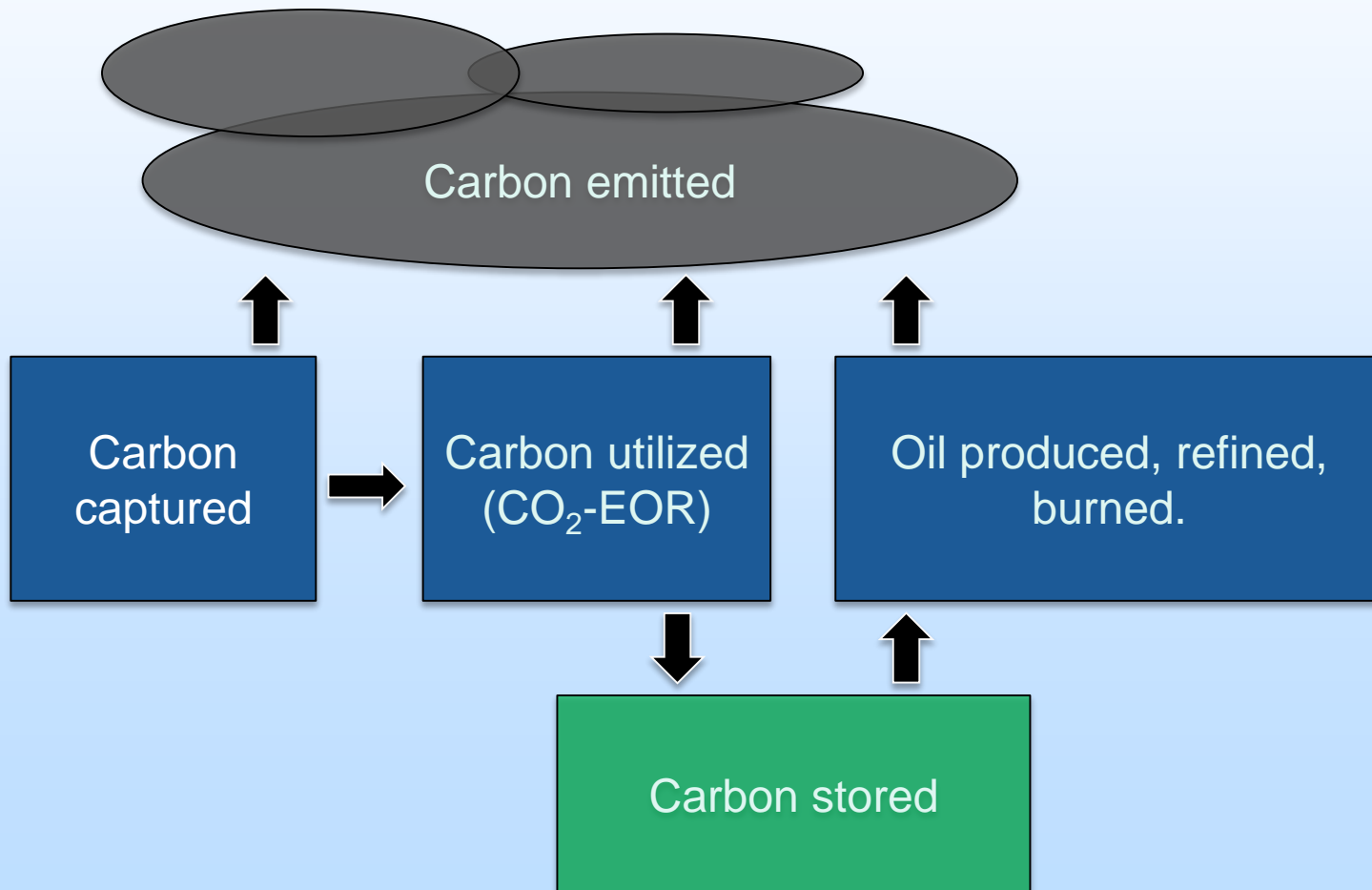
# Presentation Outline

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- Project overview
  - Goals and objectives
  - Methodology
- Accomplishments to date
- Expected Outcomes
- Summary

# Problem Statement

- Is CO<sub>2</sub>-EOR a valid option for greenhouse gas emission reduction? Are geologically stored carbon volumes larger than direct/indirect emissions resulting from CO<sub>2</sub>-EOR operations?

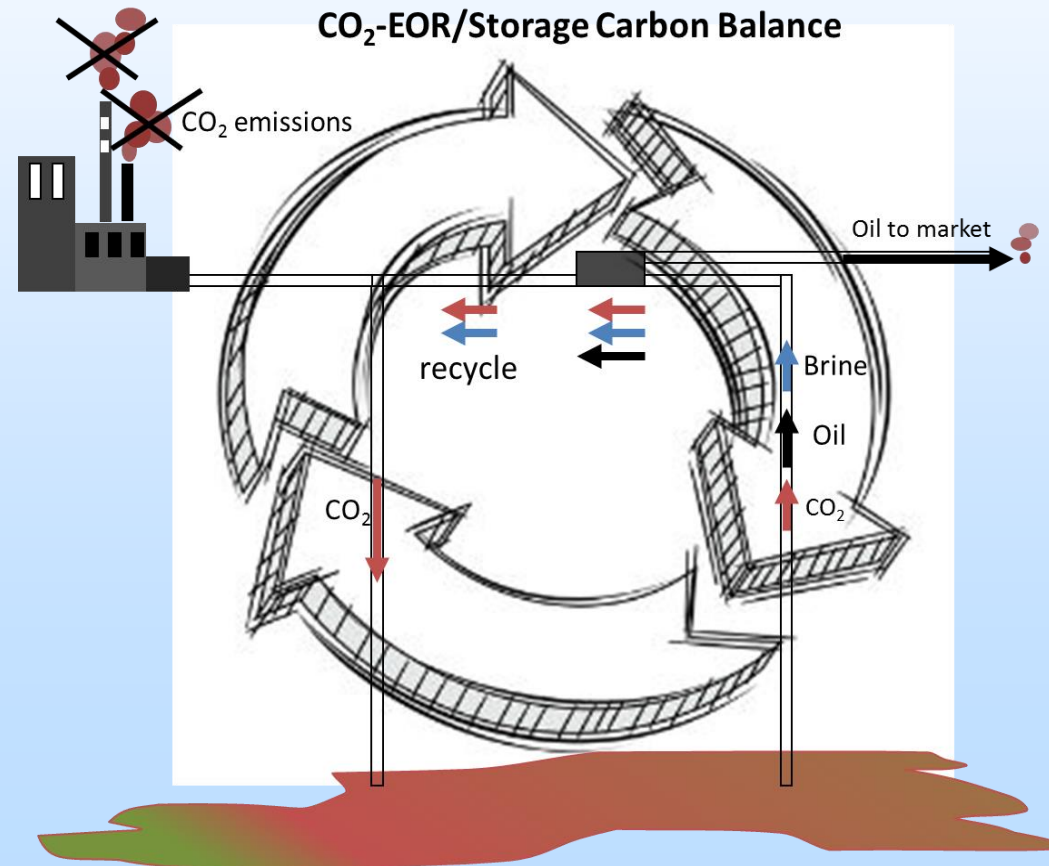


# Project Overview: Goals and Objectives

**Goal:** To develop a clear, universal, repeatable methodology for making the determination of whether a CO<sub>2</sub>-EOR operation can be classified as Net carbon Negative Oil (NCNO)

## Objectives:

- Identify and frame critical carbon balance components for the accurate mass accounting of a CO<sub>2</sub>-EOR operation.
- Develop strategies that are conducive to achieving a NCNO classification.
- Develop a comprehensive, yet commercially applicable, monitoring, verification, and accounting (MVA) methodology.



# Related Literature

## Life Cycle Inventory of CO<sub>2</sub> in an Enhanced Oil Recovery System

Environ. Sci. Technol. 2009, 43, 8027-8032

PAULINA JARAMILLO,\*†  
W. MICHAEL GRIFFIN,†,§ AND  
SEAN T. MCCOY§  
Civil and Environmental Engineering Department, Tepper  
School of Business, and Department of Engineering and  
Public Policy, Carnegie Mellon University, 5000 Forbes  
Avenue, Pittsburgh, Pennsylvania 15213-3890

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27, 2009. Accepted September 14, 2009.

Enhanced oil recovery (EOR) has been identified as a meth  
of sequestering CO<sub>2</sub> recovered from power plants. In CO<sub>2</sub>-  
flood EOR, CO<sub>2</sub> is injected into an oil reservoir to reduce v  
viscosity, reduce interfacial tension, and cause oil swelling v  
recovery. Previous studies suggest that substa  
amounts of CO<sub>2</sub> from power plants could be sequestered  
EOR projects, thus reducing the amount of CO<sub>2</sub> emitted in  
atmosphere. This claim, however, ignores the fact that  
carbon rich fuel, is produced and 93% of the carbon in pet  
is refined into combustible products ultimately emitted i  
the atmosphere. In this study we analyze the net life c  
CO<sub>2</sub> emissions in an EOR system. This study assesses th  
life cycle emissions associated with sequestration via  
flood EOR under a number of different scenarios and  
the impact of various methods for allocating CO<sub>2</sub> syst  
emissions and the benefits of sequestration.

### Introduction

Injection of CO<sub>2</sub> to increase oil recovery from ma  
known as CO<sub>2</sub>-flood enhanced oil recovery (CO<sub>2</sub>-  
been practiced commercially for nearly 40 years in  
States (7). As of 2008, there were approximately 10  
projects operating in the U.S. producing clos  
barrels of oil per day (BOPD), slightly less than  
U.S. domestic oil production (2, 3). Recent as  
the U.S. potential for CO<sub>2</sub>-EOR vary some  
assumptions and final estimates (4-6), bu  
conclude that if crude oil prices are between \$  
barrel incremental production from CO<sub>2</sub>-EO  
the order of tens of billions of barrels of oil. As  
of metric tons of CO<sub>2</sub> will be consumed and,  
anthropogenic sources and properly manag  
in permanent sequestration of this CO<sub>2</sub> in  
EOR is primarily motivated by the ecor  
However, as concer

approximately 5130 million metric tons of CO<sub>2</sub> and there  
remains large amounts of CO<sub>2</sub> available from these and other  
accumulations (9). Although these natural sources of CO<sub>2</sub>-EOR, climate  
could provide the anticipated needs for CO<sub>2</sub>-EOR, climate  
change could motivate the use of captured CO<sub>2</sub> from  
industrial facilities, such as power plants. It is likely that,  
industrial facilities or oil producers  
can-and-trade system, such as those being considered

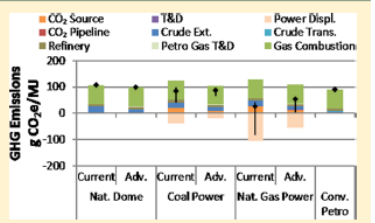


## Evaluating the Climate Benefits of CO<sub>2</sub>-Enhanced Oil Recovery Using Life Cycle Analysis

Gregory Cooney\*  
Associate, Booz Allen Hamilton, 651 Holiday Drive, Foster Plaza 5, Suite 300, Pittsburgh, Pennsylvania 15220, United States  
James Littlefield  
Associate, Booz Allen Hamilton, 651 Holiday Drive, Foster Plaza 5, Suite 300, Pittsburgh, Pennsylvania 15220, United States  
Joe Marriott  
Lead Associate, Booz Allen Hamilton, 651 Holiday Drive, Foster Plaza 5, Suite 300, Pittsburgh, Pennsylvania 15220, United States  
Timothy J. Skone  
Senior Environmental Engineer, National Energy Technology Laboratory, 626 Cochran's Mill Road, P.O. Box 10940, Pittsburgh, Pennsylvania 15236, United States

Supporting Information

**ABSTRACT:** This study uses life cycle analysis (LCA) to evaluate the greenhouse gas (GHG) performance of carbon dioxide (CO<sub>2</sub>) enhanced oil recovery (EOR) systems. A detailed gate-to-gate LCA model of EOR was developed and incorporated into a cradle-to-grave boundary with a functional unit of 1 MJ of combusted gasoline. The cradle-to-grave model includes two sources of CO<sub>2</sub>: natural domes and anthropogenic (fossil power equipped with carbon capture). A critical parameter is the crude recovery ratio, which describes how much crude is recovered for a fixed amount of purchased CO<sub>2</sub>. When CO<sub>2</sub> is sourced from a natural dome, increasing the crude recovery ratio decreases emissions, the opposite is true for anthropogenic CO<sub>2</sub>. When the CO<sub>2</sub> is sourced from a power plant, the electricity coproduct is assumed to displace existing power. With anthropogenic CO<sub>2</sub> required, thereby reducing the amount of power displaced and the corresponding credit. Only the anthropogenic EOR cases result in emissions lower than conventionally produced crude. This is not specific to EOR, rather the fact that carbon-intensive electricity is being displaced with captured electricity, and the fuel produced from that system receives a credit for this displacement.



## Reducing Carbon Dioxide Emissions with Enhanced Oil Recovery Projects: A Life Cycle Assessment Approach

Energy & Fuels 2001, 15, 303-308

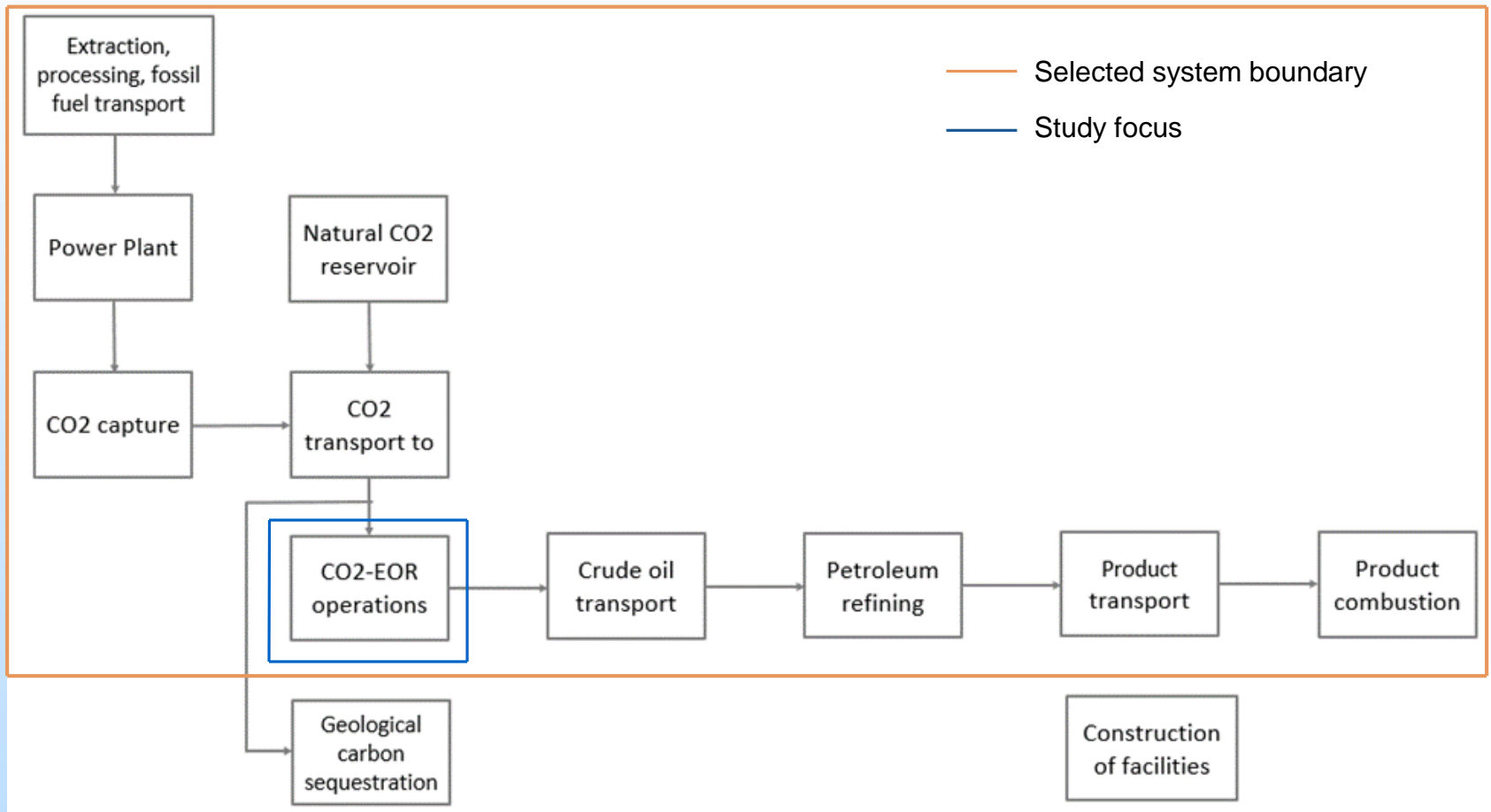
Anne-Christine Aycaguer,\*†,‡ Miriam Lev-On,† and Arthur M. Winer†  
BP Health, Safety, and Environment, 333 S. Hope Street, Los Angeles, California 90071, and  
Environmental Engineering Program, UCLA School of Public Health,  
Los Angeles, California 90095-1772

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Investigating methods of reducing their emissions of greenhouse  
gas, methane (CH<sub>4</sub>), and nitrous oxide (N<sub>2</sub>O). Several options  
though greenhouse gases are not yet regulated, the power  
are already considering greenhouse gas capture and storage  
the atmosphere. Preferred options are the ones utilizing  
an additional economic benefit to the oil and gas  
widerly used for enhanced oil recovery (EOR) projects to  
Thus, storage of CO<sub>2</sub> in active reservoirs does not require  
advantage of reducing greenhouse gas emissions to the  
a life cycle assessment to determine the benefits  
while enhancing the extraction of oil and the impacts  
time. The potential for CO<sub>2</sub> storage in a specific oil  
well as the mass balance of greenhouse gas emissions  
issues. Our findings suggest that the storage capacity of  
is minimal in comparison, and the EOR activity is  
storage potential and gasoline emissions from the

Reducing greenhouse gas emissions to the atmosphere  
can be accomplished by improving the efficiency of  
equipment and processes to reduce energy consumption,  
by developing renewable energy sources, by shifting to  
lower carbon content fuels, or by implementing storage  
projects in geologic formations where CO<sub>2</sub> may poten-  
tially remain for many decades. While each approach  
has benefits and drawbacks, the present study focused  
on geologic storage of CO<sub>2</sub>.  
Both depleted and active fossil fuel reservoirs are  
used for storage of CO<sub>2</sub> in underground  
is estimated that the  
formations

# Selection of system boundaries for NCNO classification: Cradle-to-Grave



# Methodology: Select Field Setting

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- (Cranfield, Mississippi)
  - It provides the optimal mass accounting data set as it was required by its comprehensive SECARB MVA program
  - It is a desirable direct injection (no WAG), which is favorable for achieving NCNO
  - Pattern geometry and operations repeated systematically around field development
  - Provides a simpler environment than many CO<sub>2</sub>-EOR floods

# Methodology: Numerical Simulation

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- Utilize Cranfield pattern calibrated models to:
  - Run numerical simulations for different novel and standard CO<sub>2</sub> injection scenarios (WAG, direct CO<sub>2</sub> injection)
  - Evaluate how the variability of CO<sub>2</sub> utilization ratios for the different injection scenarios affects the identified system components.
  - Understand the carbon balance evolution from start of injection to completion.



# Methodology: Develop MVA Plan

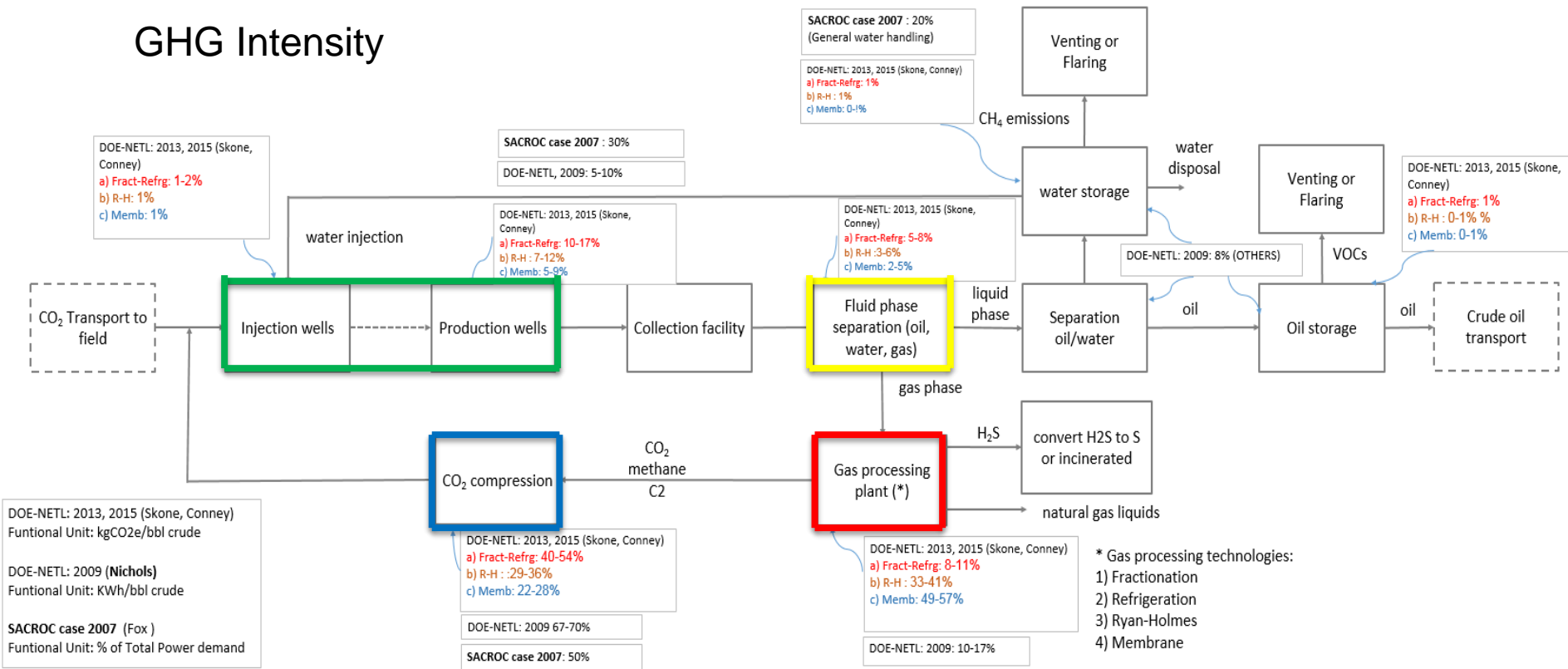
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- Use predictive flow and pressure elevation results to develop a generic but comprehensive MVA plan that is based on:
  - existing regulatory monitoring requirements
  - existing best practices
  - a number of proposed and suggested processes that are currently being considered for possible future regulatory or credit trading conditions

# Accomplishments to Date

## Identification of critical CO<sub>2</sub> emission components within the EOR site

### GHG Intensity



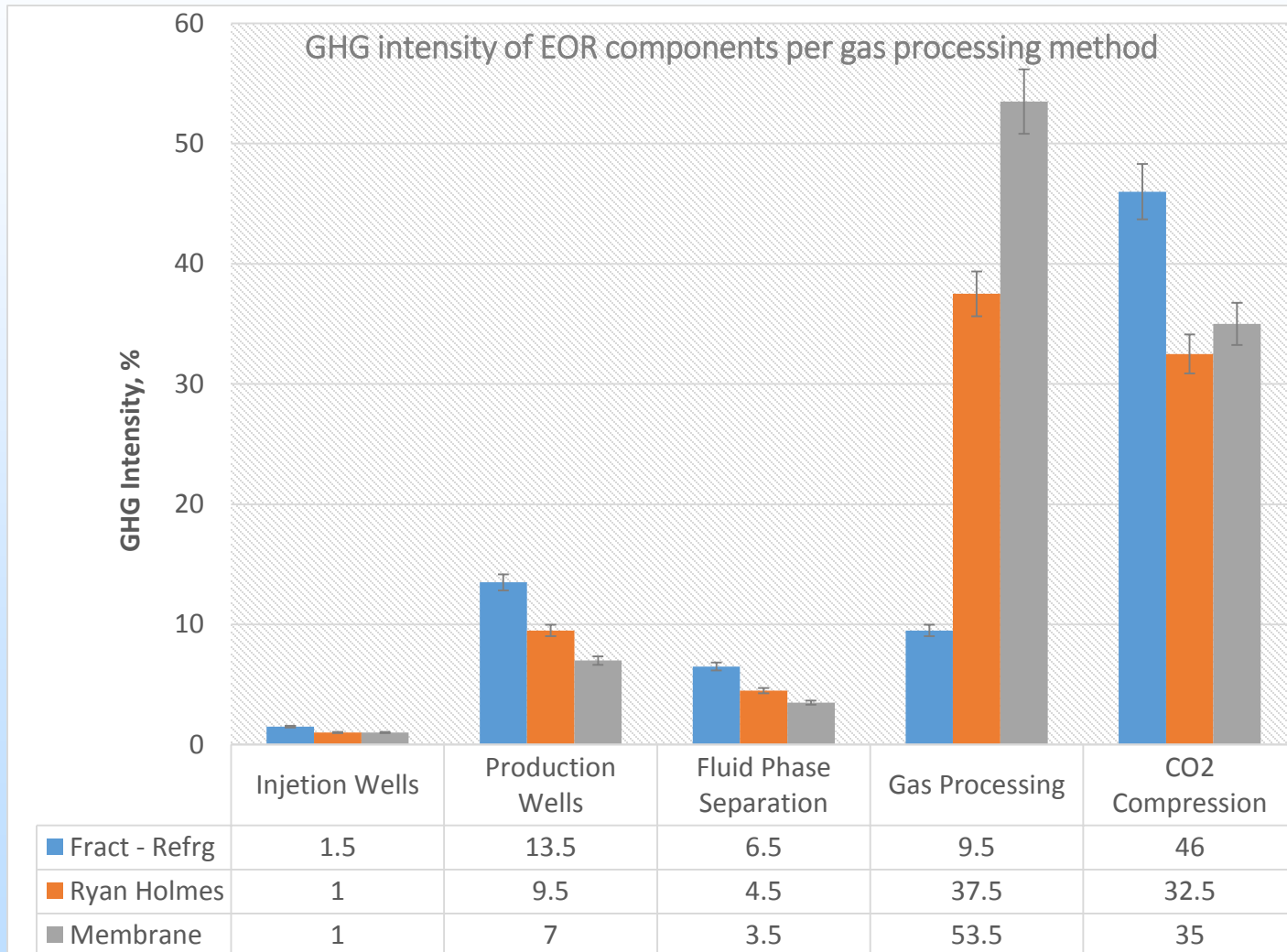
Injection/production wells

Production separation

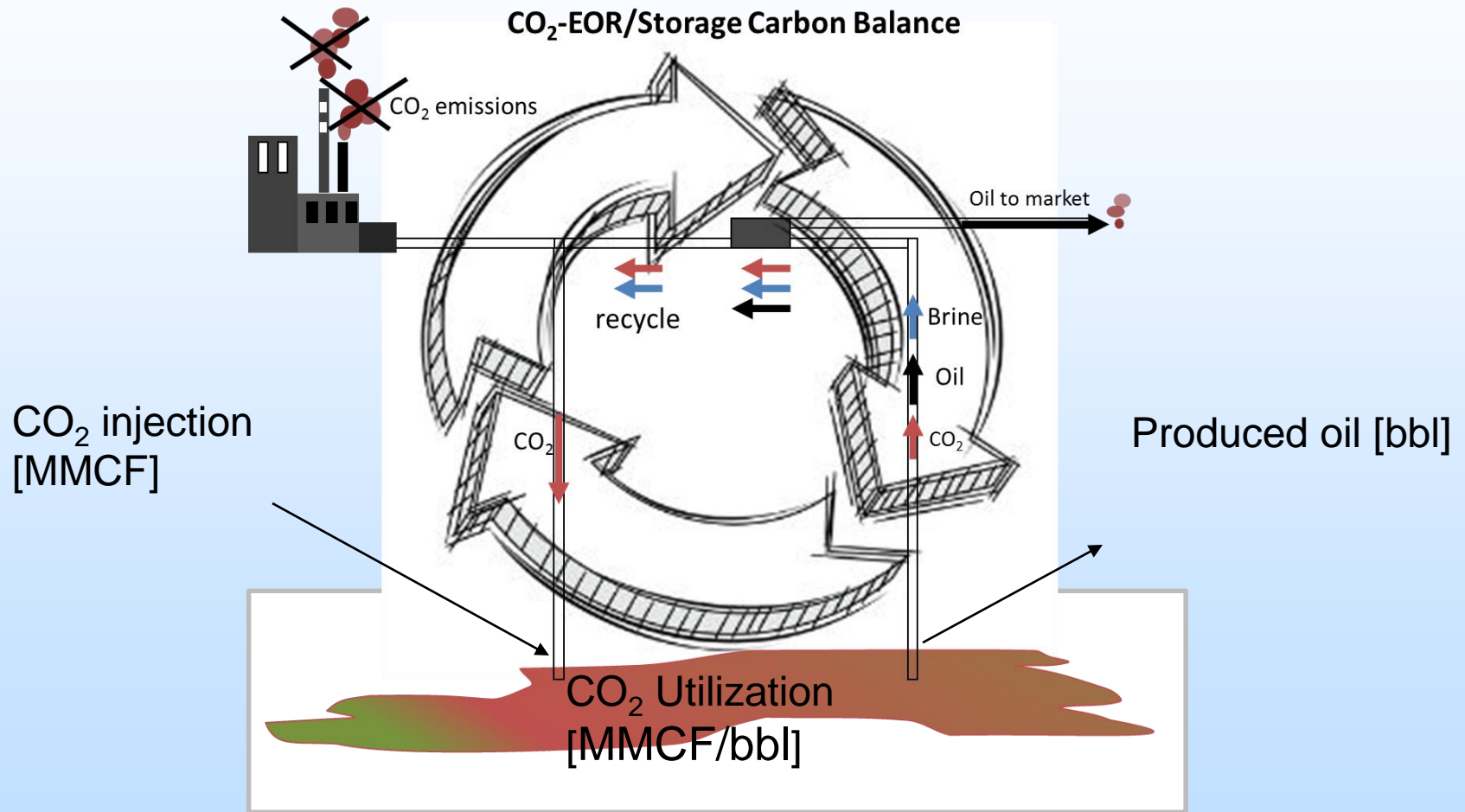
CO<sub>2</sub> separation

CO<sub>2</sub> compression

# GHG Intensity per EOR Component



# Study focus: CO<sub>2</sub> utilization ratios

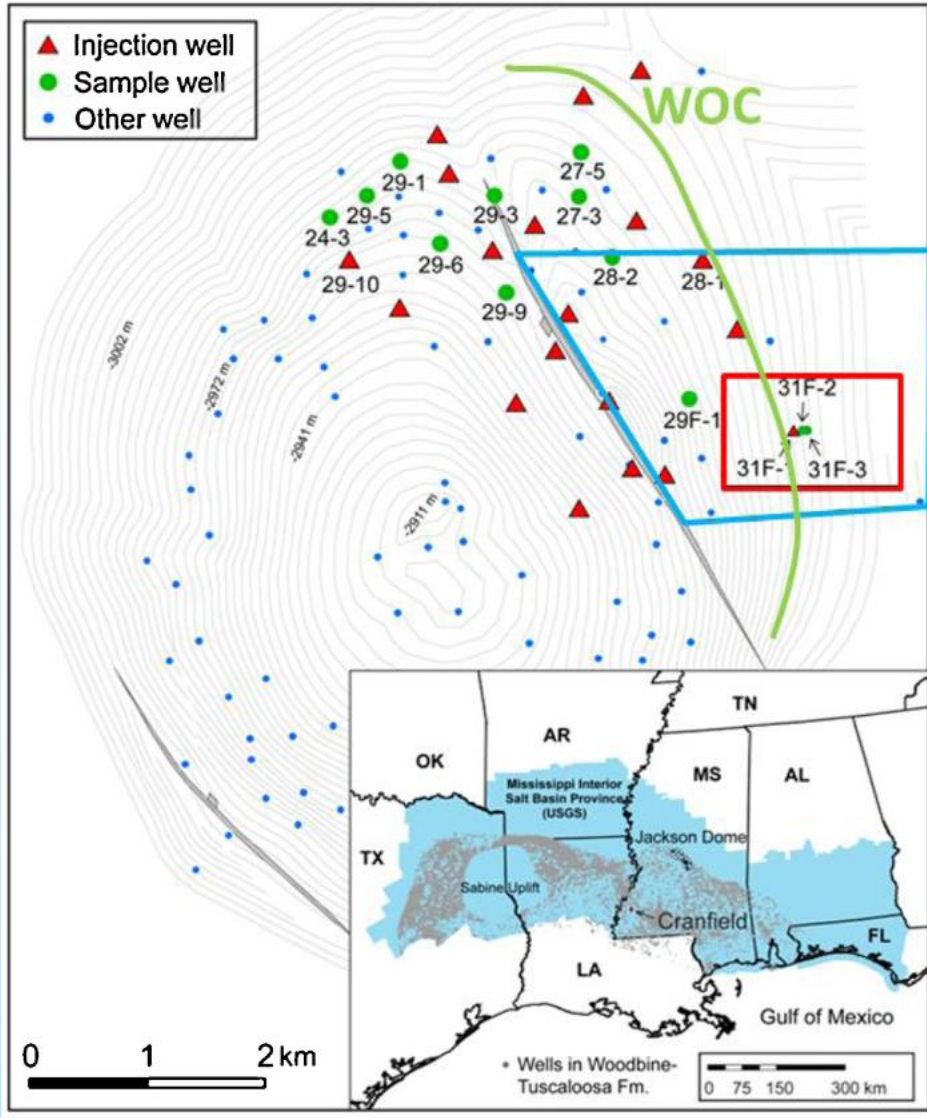


# Field Study

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- (Cranfield, Mississippi)
  - It provides the optimal mass accounting data set as it was required by its comprehensive SECARB MVA program
  - It is a desirable direct injection (no WAG), which is favorable for achieving NCNO
  - Pattern geometry and operations repeated systematically around field development
  - Provides a simpler environment than many CO<sub>2</sub>-EOR floods

# Field Setting



## Cranfield overview:

- Clastic Mississippi field
- Apex of 4-way closed anticline
- Main pay is ~10,000 ft deep
- $P_i = 4,600$  psi,  $T_i = 150^\circ\text{F}$
- Original gas cap
- Productive during 1940s and 50s
- $\text{CO}_2$  injection started in 2007
- Available mass accounting data as required by SECARB's monitoring program.

# Methodology: Numerical Simulation

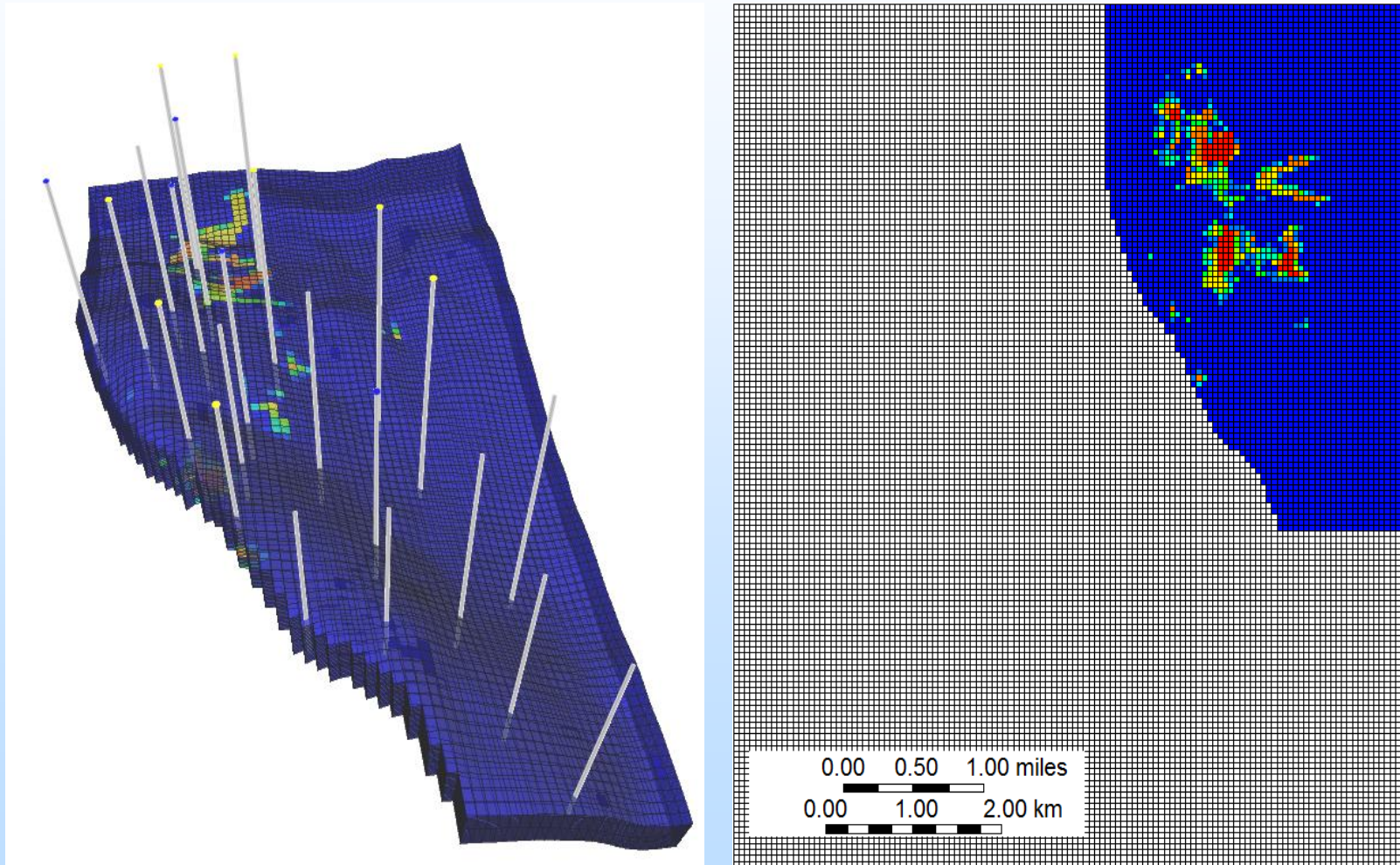
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- Utilize Cranfield pattern calibrated models to:
  - Run numerical simulations for different novel and standard CO<sub>2</sub> injection scenarios (WAG, direct CO<sub>2</sub> injection)
  - Evaluate how the variability of CO<sub>2</sub> utilization ratios for the different injection scenarios affects the GHG intensity of the system components (New contribution)
  - Understand the carbon balance evolution from start of injection to completion (New contribution)
- Current activities:
  - ✓ Updated existing Cranfield models: added physics
  - ✓ Relative permeability laboratory experiments
  - ✓ History matching for historic Cranfield production (1944-1972)



# Methodology: Numerical Simulation

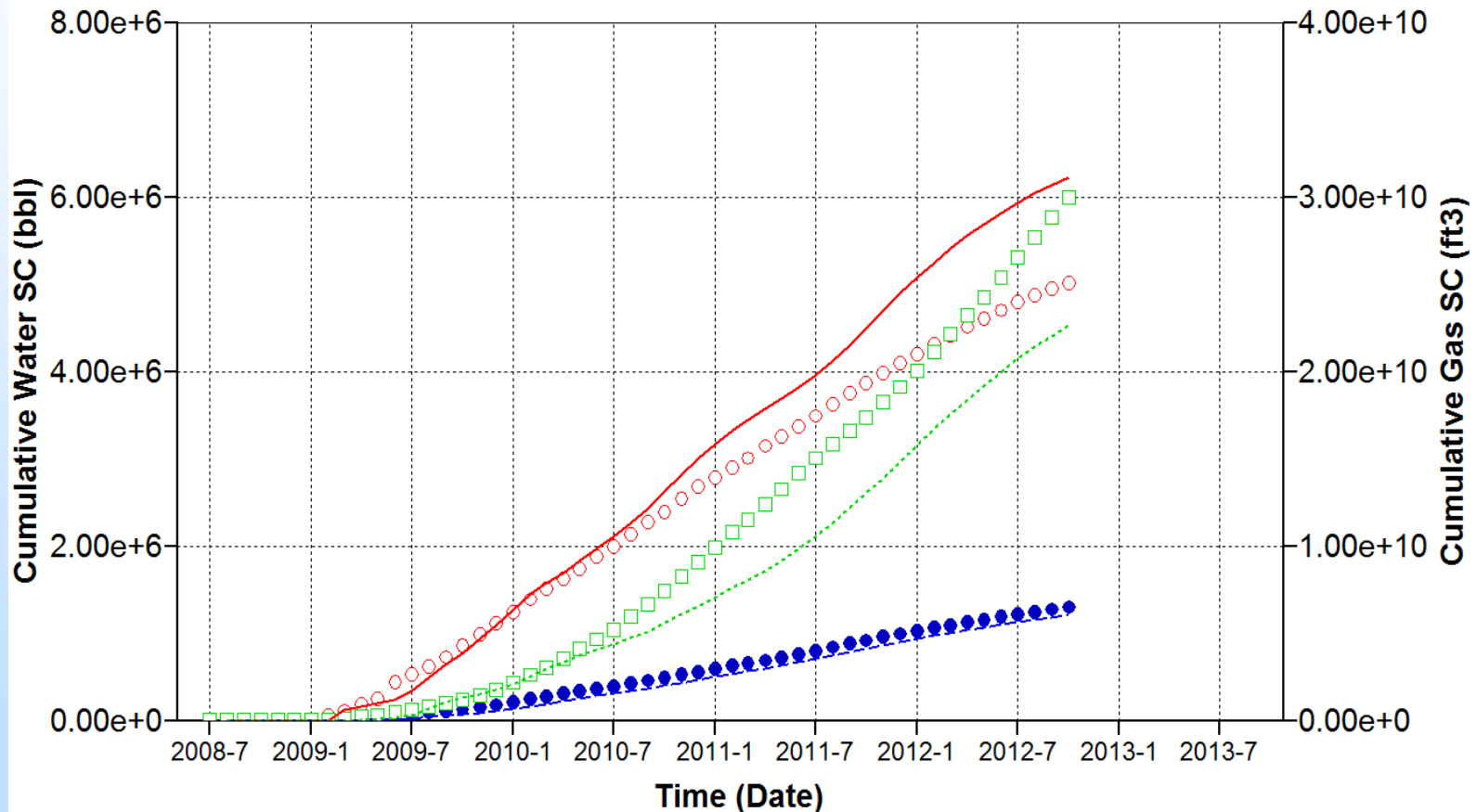
Compositional model simulates CO<sub>2</sub> injection





# Methodology: Numerical Simulation

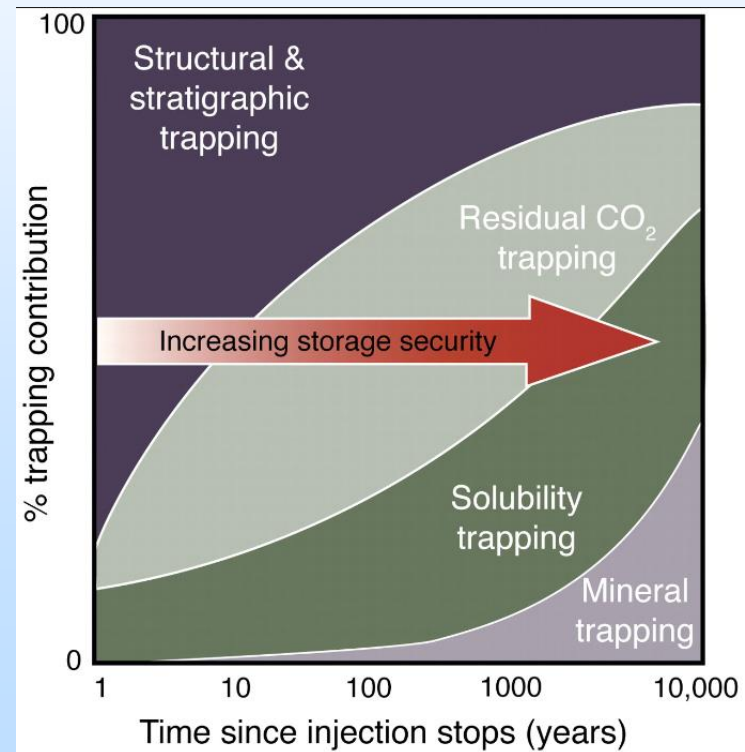
## Preliminary History Matching of Primary Production



# Trapping Mechanisms

- Additional funds allowed us to add valuable work to the modeling tasks by studying the trapping mechanisms that contribute to the geological permanence of the stored CO<sub>2</sub>

1. Residual/capillary trapping
2. CO<sub>2</sub> dissolution into brine
3. CO<sub>2</sub> dissolution into oil
4. Mineral trapping

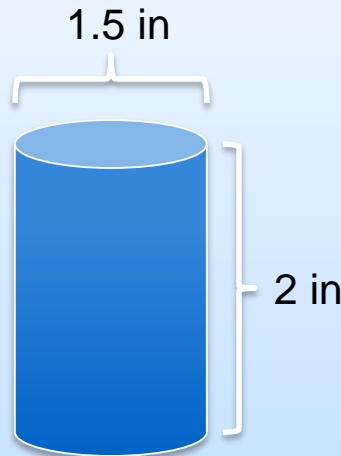


Benson, 2003

# New CO<sub>2</sub>-brine Relative Permeability

12 Cranfield core plugs were sent to a commercial laboratory

Relative permeability experiments will be run in in 2 composite samples consisting of 6 aligned core plugs



Weatherford LABORATORIES		SUMMARY OF ROUTINE CORE ANALYSES RESULTS				
Bureau of Economic Geology Undisclosed Project		Vacuum Dried at 140°F	Net Confining Stress: 3400 psi			USA File: HH-79894 Date: 2-5-16
Sample Number	Sample Type	Sample Depth, feet	Permeability, millidarcys		NCS Porosity, percent	Grain Density, gm/cc
			to Air	Klinkenberg		
22	Horizontal	10462.66	312.	288.	27.7	2.68
23	Horizontal	10462.83	483.	452.	28.3	2.69
24	Horizontal	10463.00	278.	256.	27.8	2.69
26	Horizontal	10463.45	107.	95.2	25.9	2.69
29	Horizontal	10464.04	207.	189.	28.3	2.69
30	Horizontal	10464.20	286.	264.	28.9	2.69
31	Horizontal	10464.45	237.	217.	28.2	2.69
3	Vertical	10461.80 - 10462.30	6.79	5.61	28.3	2.69
1A	Vertical	10463.60 - 10464.10	10.3	8.05	28.7	2.69
1B	Vertical	10463.60 - 10464.10	11.2	9.17	28.9	2.70
2A	Vertical	10465.30 - 10465.80	3.71	2.97	28.2	2.70
2B	Vertical	10465.30 - 10465.80	9.40	7.39	28.2	2.69
Average values:			160.	150.	28.1	2.69

# Expected Outcomes

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- A comprehensive carbon balance analysis of a CO<sub>2</sub>-EOR operation with an accurate mass accounting methodology for determining whether the operation can be classified as NCNO.
- A recommendation of CO<sub>2</sub> surface operation and injection strategies that are conducive to achieving a NCNO classification.
- A universal MVA methodology encompassing the entire CO<sub>2</sub>-EOR operation and inclusive of pre CO<sub>2</sub> injection, injection, and stabilization periods.

# Summary

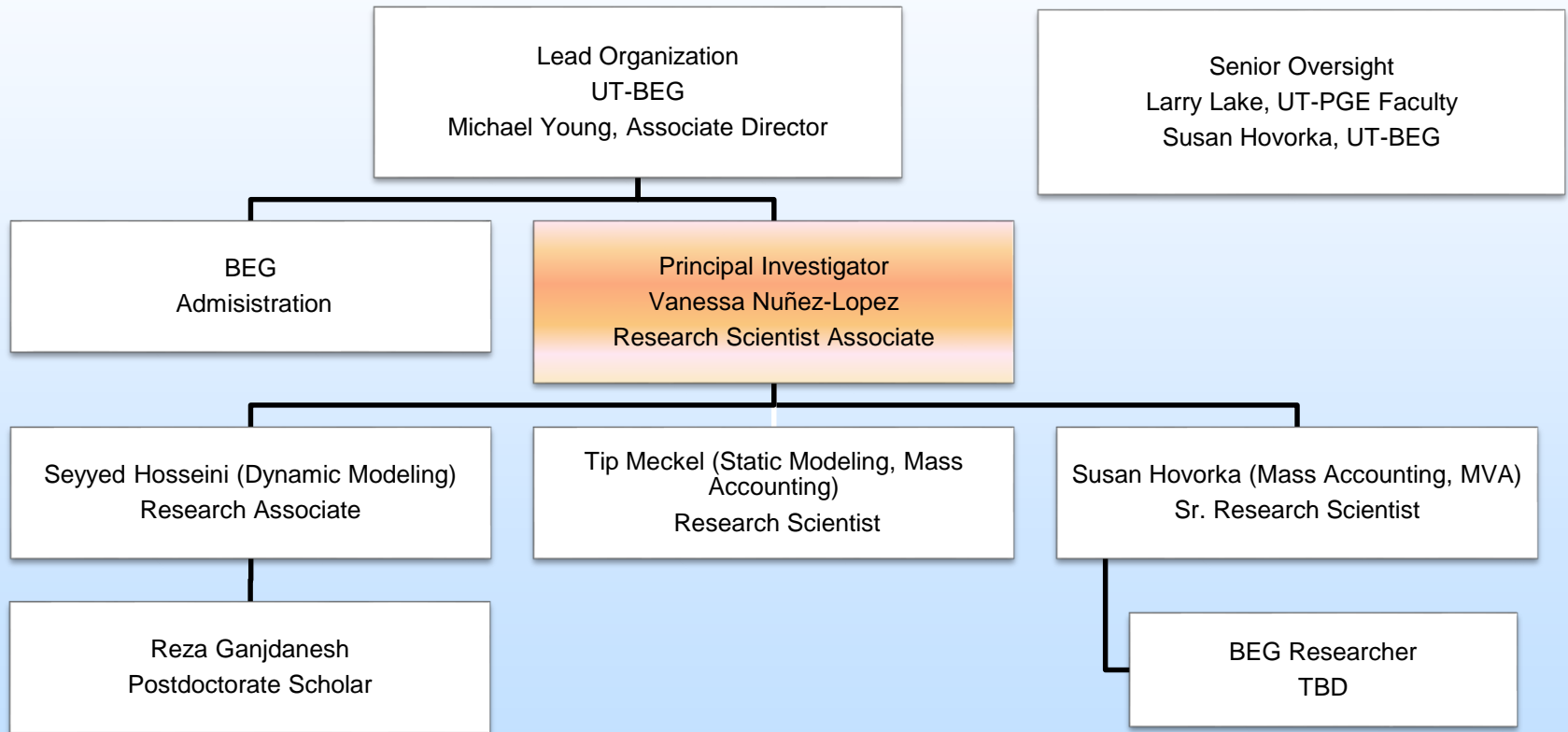
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- Accomplishments:
  - ✓ Selection of system boundaries relevant to NCNO classification: gate-to-grave
  - ✓ Identification of critical CO<sub>2</sub> emission components within the EOR site
  - ✓ Gathered and classifying Cranfield mass accounting data
  - ✓ Built Cranfield static model
  - ✓ Completed historic and EOR history matching
  - ✓ Started numerical simulation tasks
  - ✓ Build a model for energy consumption of the CO<sub>2</sub>-EOR operation
- Future Plans:
  - Start scenario analysis
  - Link results from numerical simulations with energy consumption model
  - Develop an MVA plan

# Appendix

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# Organization Chart



# Gantt Chart

		BUDGET PERIOD 1				BUDGET PERIOD 2				BUDGET PERIOD 3			
		Year 1: FY 2015				Year 2: FY 2016				Year 3: FY 2017			
		qtr1	qtr2	qtr3	qtr4	qtr1	qtr2	qtr3	qtr4	qtr1	qtr2	qtr3	qtr4
Task	Tasks												
	<b>Carbon Life Cycle Analysis of CO<sub>2</sub>-EOR for Net Carbon Negative Oil (NCNO) Classification</b>												
1	Project Management, Planning, and Reporting												
1.1	Revision and Maintenance of Project Management Plan	D 1.1											
1.2	Management and Reporting	Q	Q	Q	Q	Q	A	Q	Q	Q	Q	Q	F
2	Project Framework and Data Gathering												
3	Reservoir Mass Accounting Methodology												
			I, 2					D, 3.1					
4	Static and Dynamic Modeling												
4.1	Static Model												
4.2	EOR-storage performance model development									D, 4.2			
5	Monitoring, Verification, and Accounting (MVA) methodology												
													D, 5.0
	Q = Quarterly Report; A = Annual Report; F = Final Report												
	D = Deliverable												



# Bibliography

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None yet