Carbon Life Cycle Analysis of CO_2-EOR for Net Carbon Negative Oil (NCNO) Classification

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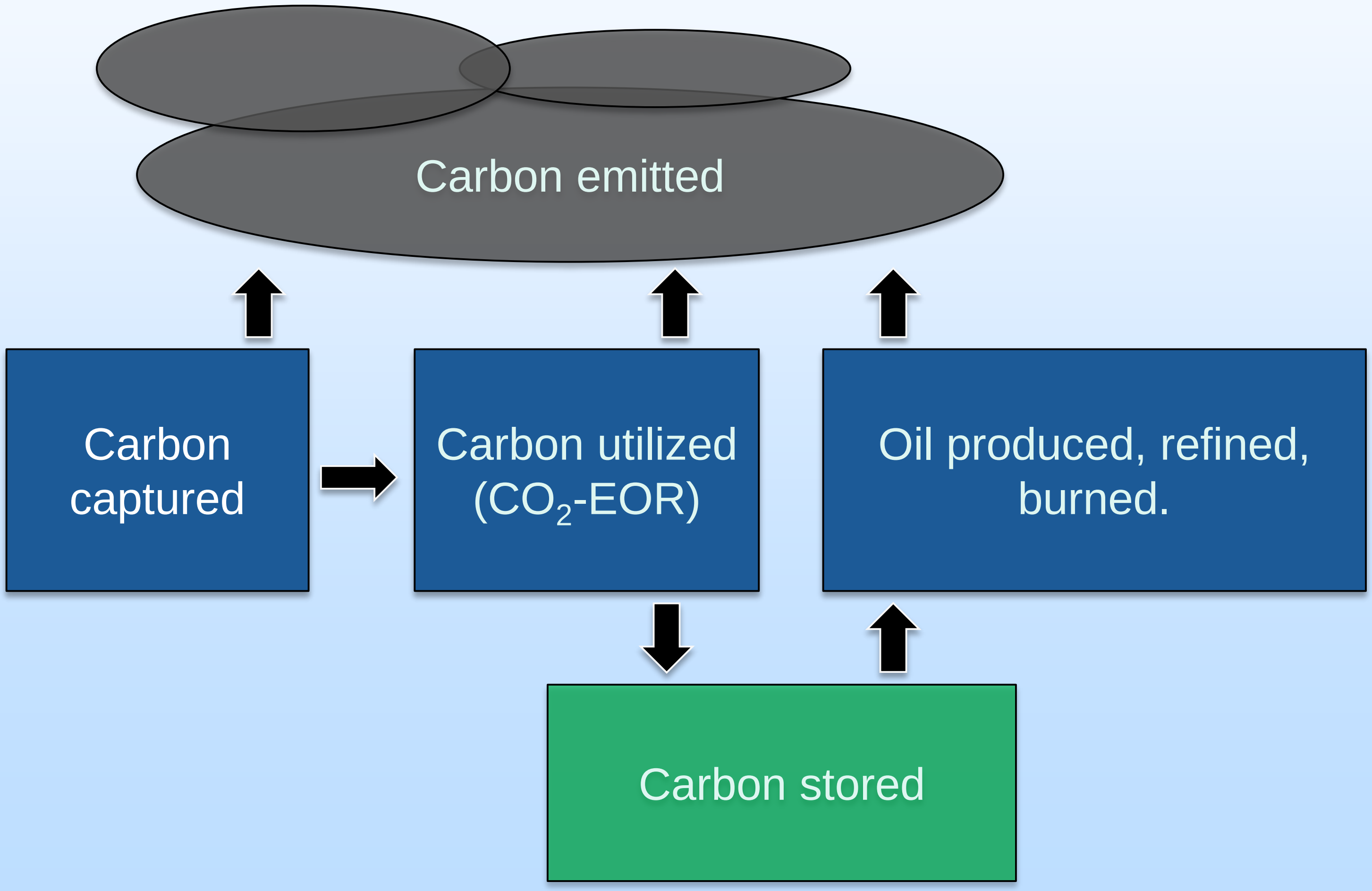
Presentation Outline

- Project Overview: Goals and Objectives
- Technical Status
- Accomplishments to Date
- Lessons Learned
- Synergy Opportunities
- Project Summary

Technical Status: Problem Statement

- Is CO_2-EOR a valid option for greenhouse gas emission reduction? Are geologically stored carbon volumes larger that direct/indirect emissions resulting from CO_2-EOR operations?



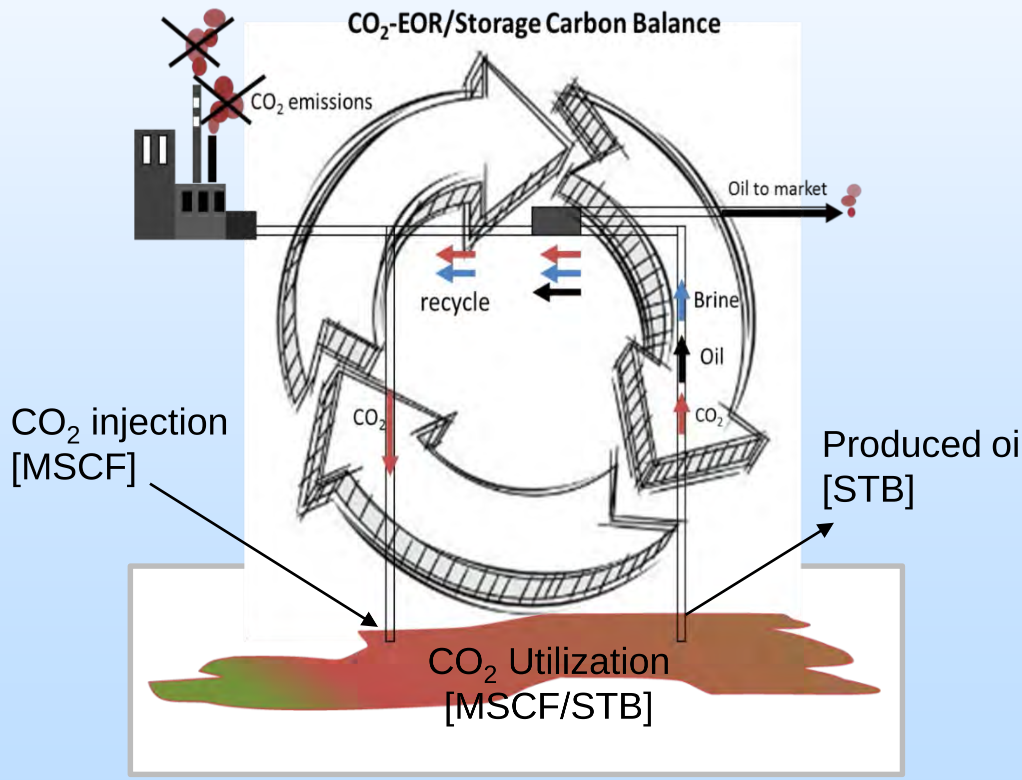
Technical Status:

Goals and Objectives

Goal: To develop a clear, universal, repeatable methodology for making the determination of whether a CO_2-EOR operation can be classified as Net carbon Negative Oil (NCNO)

Objectives:

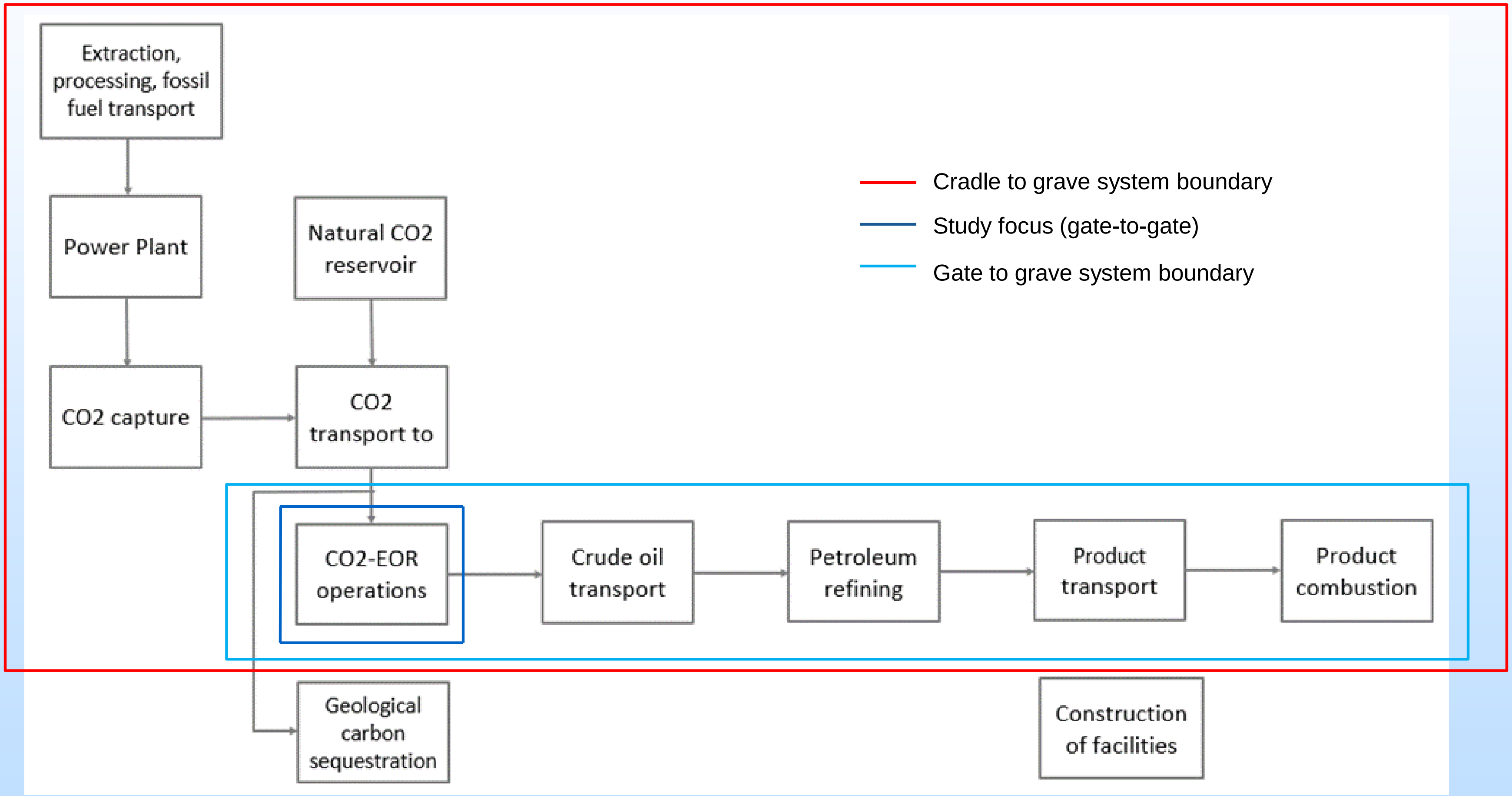
- Identify and frame critical carbon balance components for the accurate mass accounting of a CO_2-EOR operation.
- Develop strategies that are conducive to achieving a NCNO classification.
- Develop a comprehensive, yet commercially applicable, monitoring, verification, and accounting (MVA) methodology.



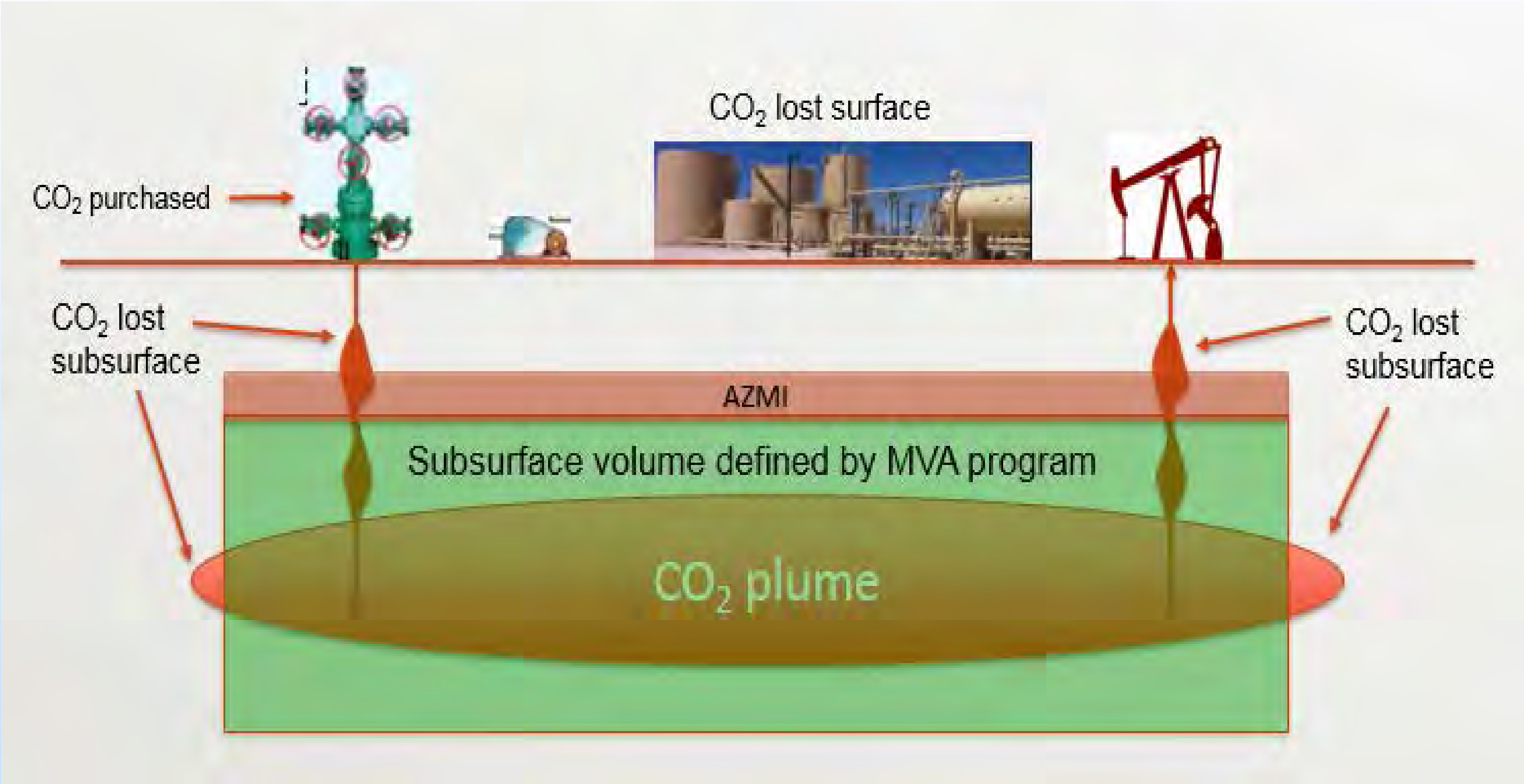
Technical Status:

(Project Background/Methodology)

LCA System boundaries for NCNO classification



Technical Status: Carbon Mass Accounting Methodology at the EOR Site



$$M_{stored} = M_{purchased} - M_{lost\ subsurface} - M_{lost\ surface}$$

$$M_{stored} = M_{total\ injected} - M_{recycle} - M_{lost\ subsurface} - M_{lost\ surface}$$

Technical Status: EOR Modeling Scenarios

EOR: Injection Scenarios & Gas Separation Process

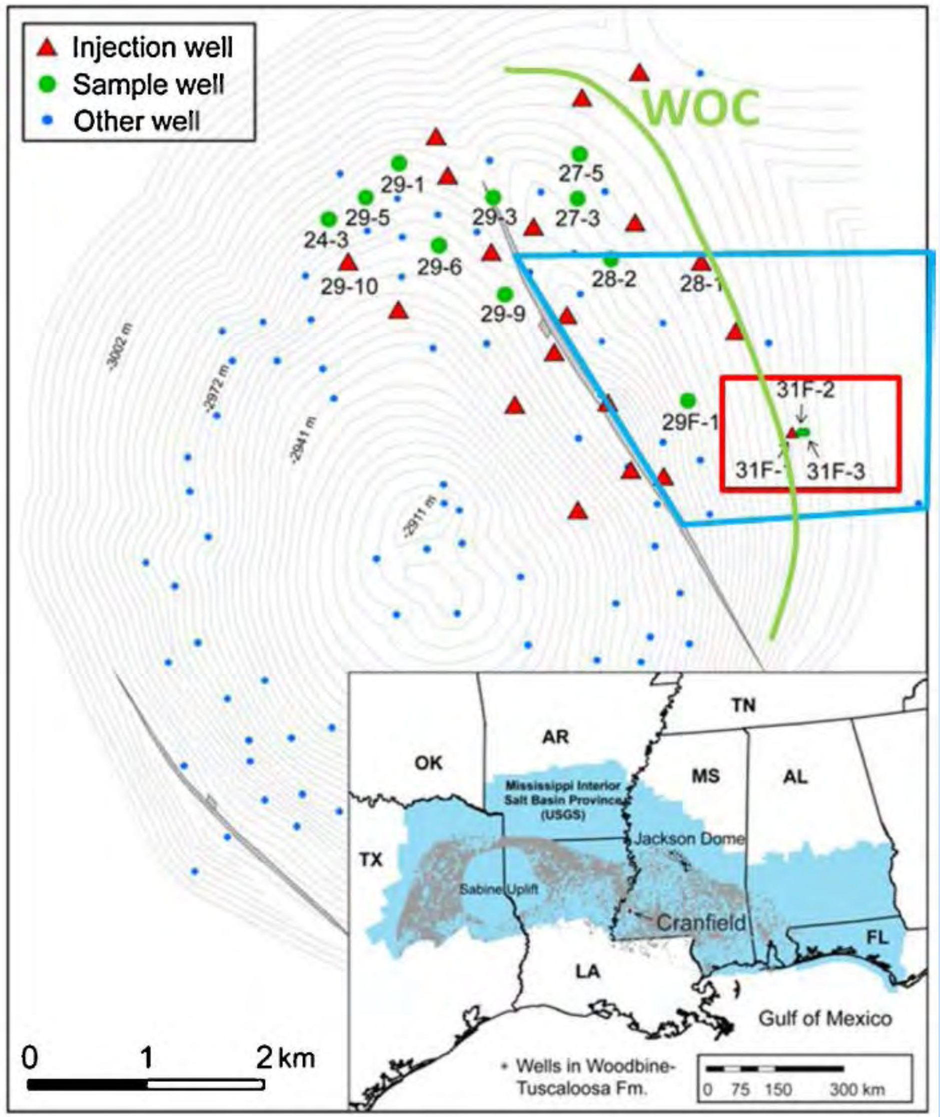
Four Injection Strategies

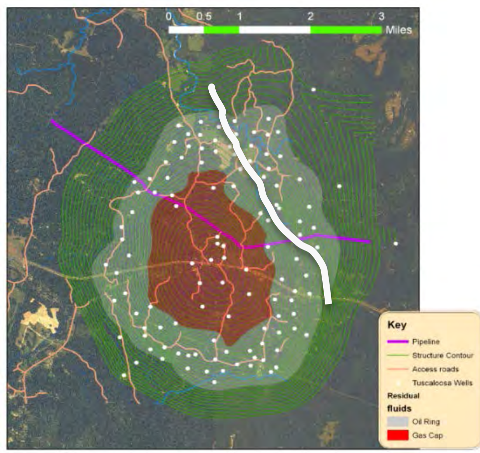
- Continuous CO_2 injection (CGI)
- Water Alternating GAS (WAG)
- Water Curtain Injection (WCI)
- Hybrid Strategy (WAG+WCI)

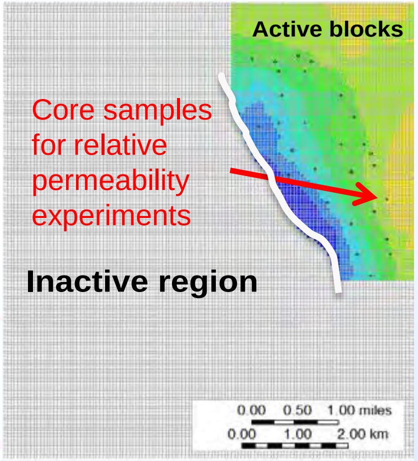
Four Gas Separation Process

- Without Gas Separation
- Fractionation/Refrigeration
- Membrane
- Ryan-Holmes

Technical Status: Cranfield Static Model (Site Characterization)





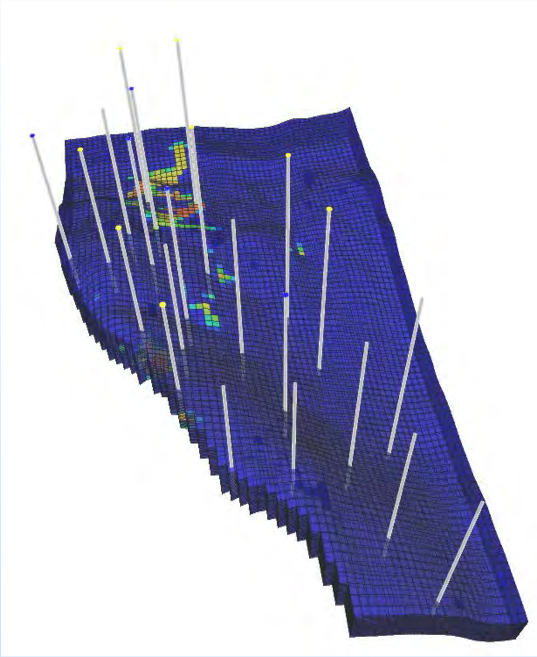


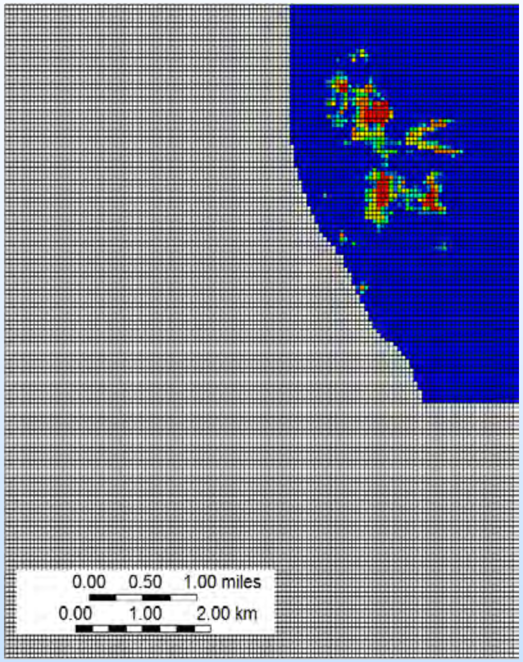
Cranfield overview:

- Clastic Mississippi field
- Apex of 4-way closed anticline
- Main pay is ~10,000 ft deep
- Pi = 4,600 psi, Ti = 150°F
- Original gas cap
- Productive during 1940s and 50s
- CO_2 injection started in 2007
- Available mass accounting data as required by SECARB's monitoring program.

Technical Status: Dynamic Model (Numerical Simulation)

Compositional model simulates CO_2 injection





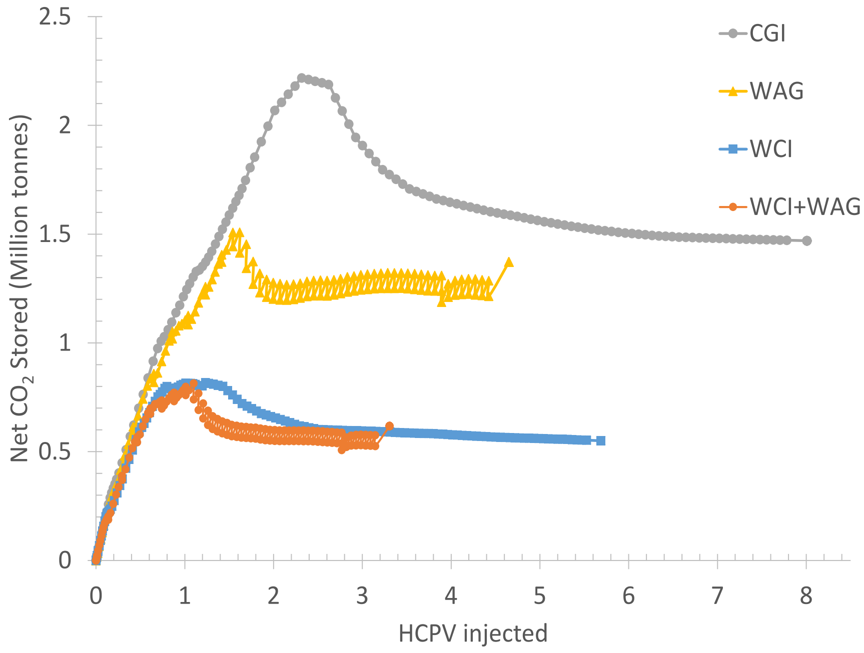
- CMG-GEM compositional package
- Solubility modeled with Henry's law
- Oil and gas PVT tuned
- History matching of historic production data (1944-1964)
- Oil, water, gas production data is available
- Shut-in period (1964-2008)

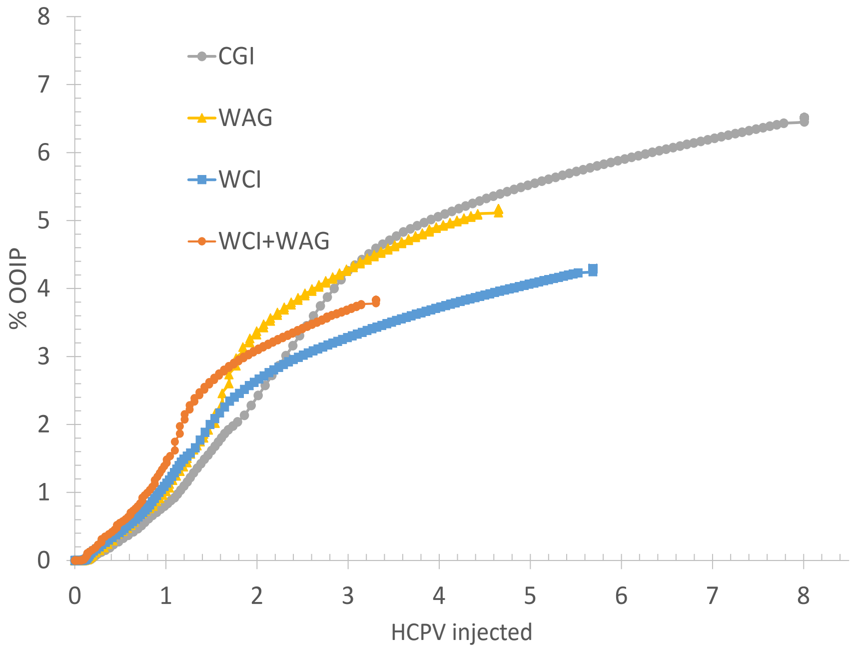
- **Compositional simulation**
- **Total number of block = 82,500**
- **25 yrs injection +75 yrs of post injection**

Technical Status:
Subsurface Results

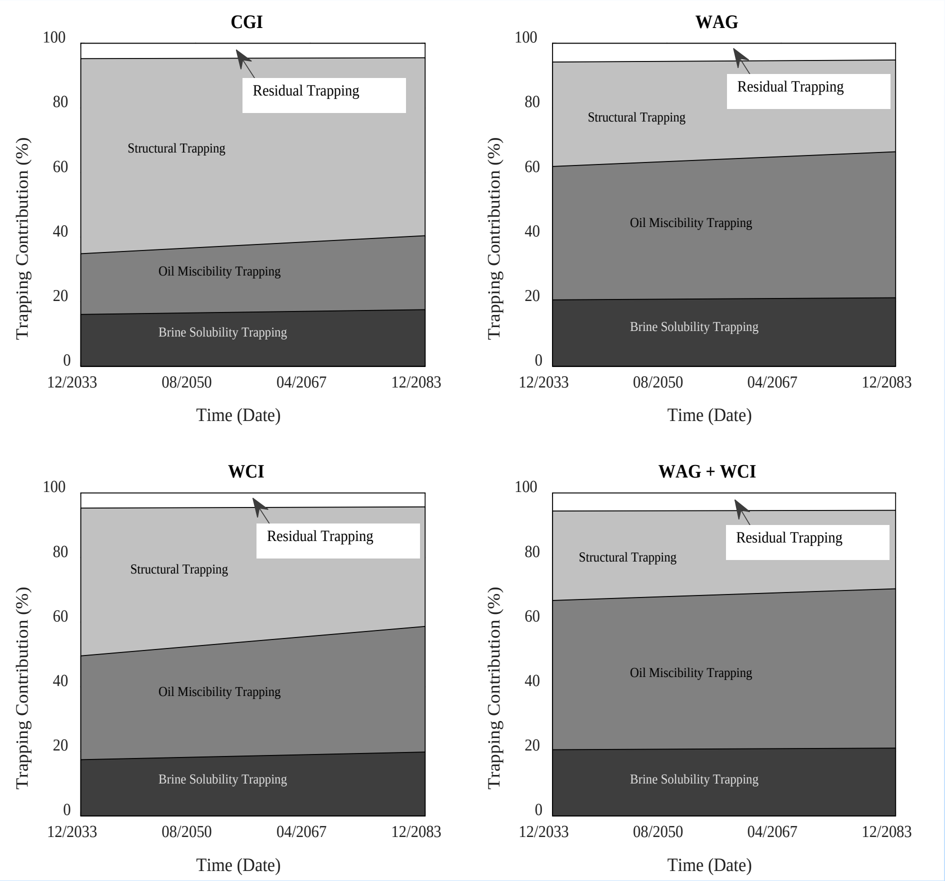
Mass of CO_2 Stored

Oil Recovery Factor

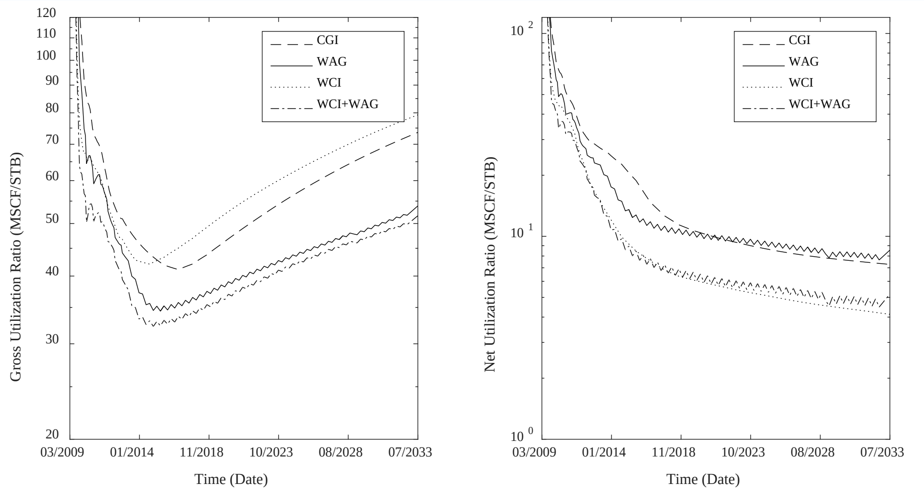




Technical Status:
Subsurface Results



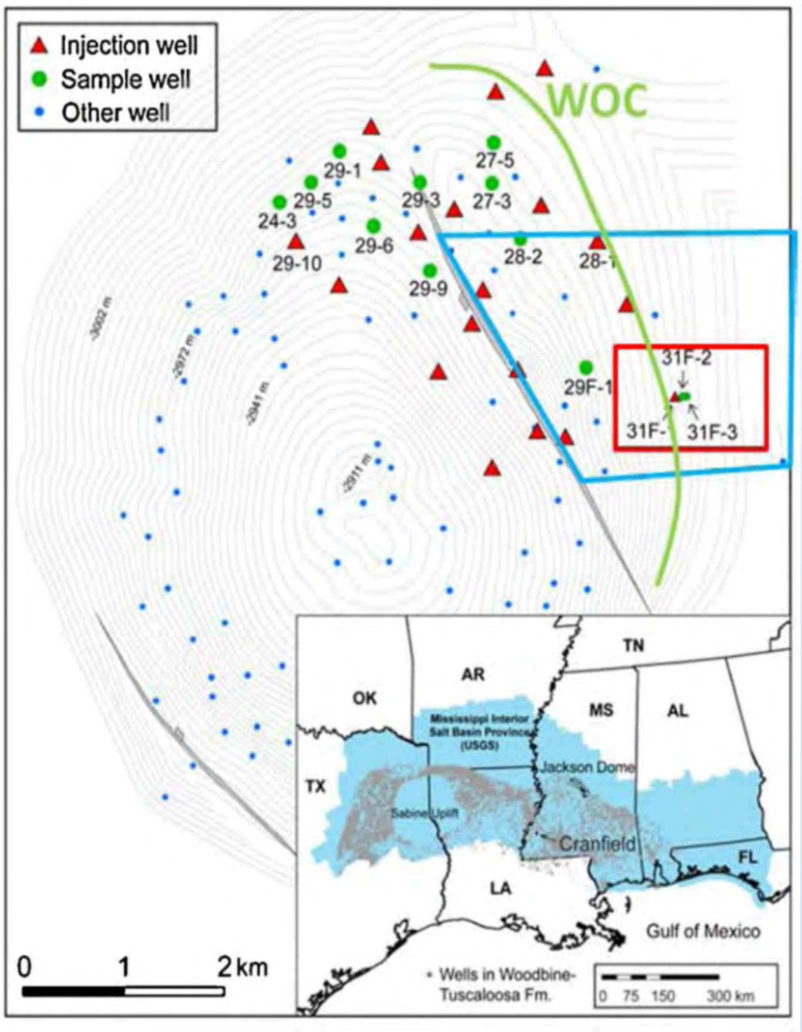
Gross Utilization Rate | **Net Utilization Rate**



1. WAG improves storage security by decreasing the amount of mobile CO_2 in the reservoir

2. CO_2 injection strategies that alternate with water have lower gross utilization ratios. However WAG's net utilization compares to that of CG.

Technical Status:
CO_2-EOR GHG Accounting



Gate to Gate (EOR Site) boundary:

Indirect Emissions (Energy Use):

- Artificial Lift (Gas Lifting)
- Gas Injection Compression
- Pumping for injection and fluid handling
- Gas Separation Process

Power source from SRMV Grid (468 KgCO2e/MWh)

Direct Emission:

- Bulk Separation (VOC)
- Fugitive/venting CO_2 released to atmosphere

Gate to Grave boundary:

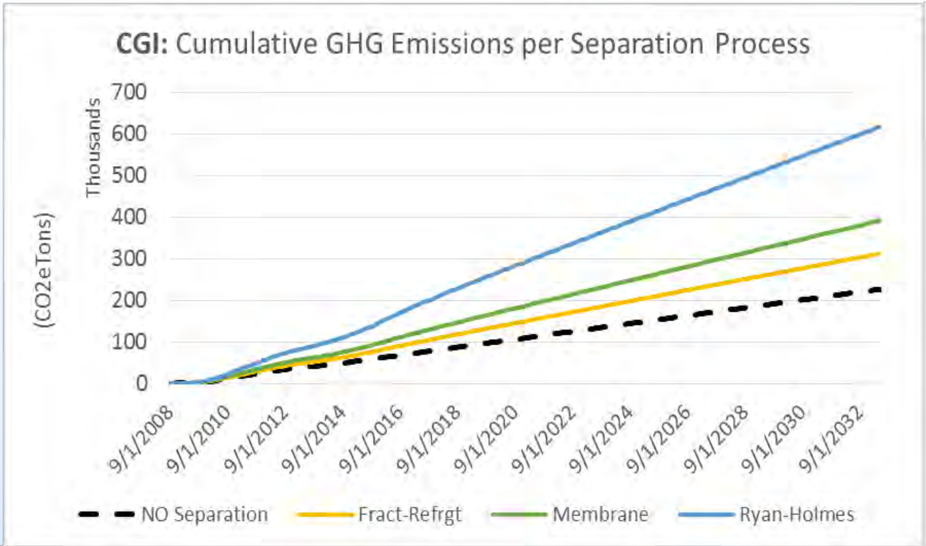
EOR Site + Downstream:

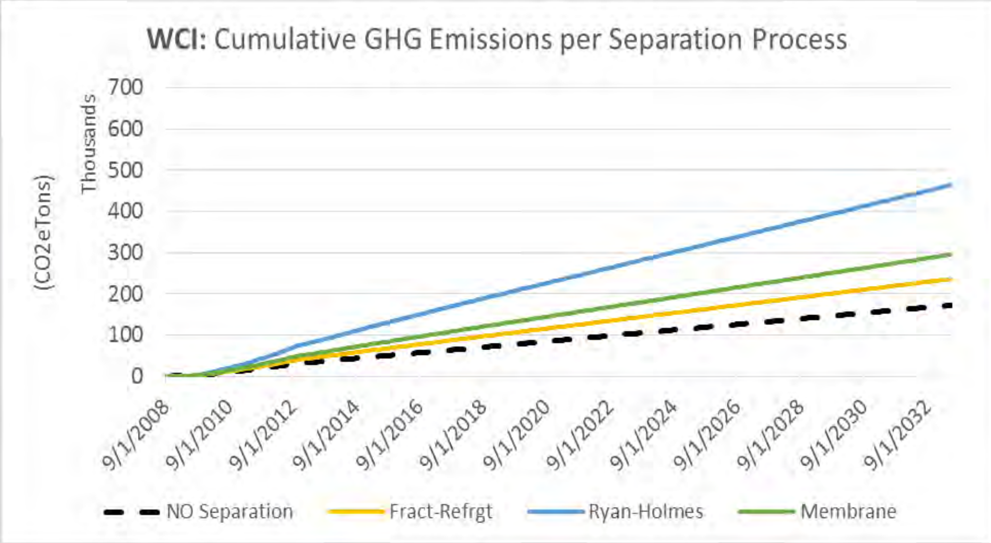
+ Crude transportation
+ Refinery
+ Product combustion

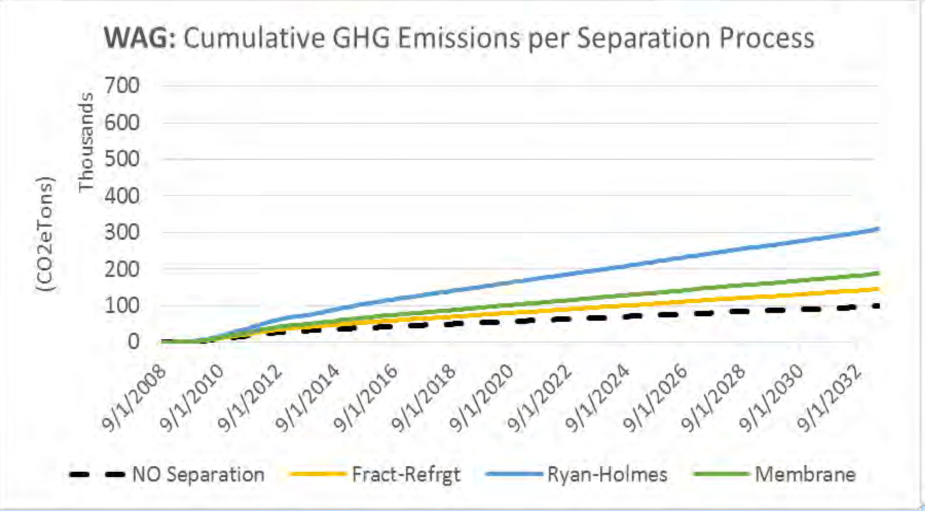
EIA (U.S. Energy Information Administration) average of carbon content and heat content of crude oil going into U.S. refineries

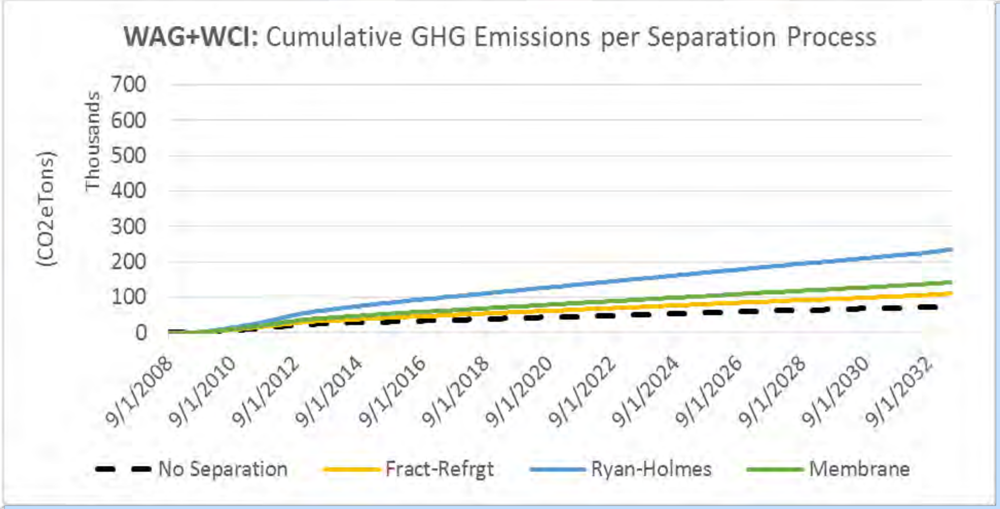
Technical Status:

GHG Emissions Evolution: **Gate to Gate**



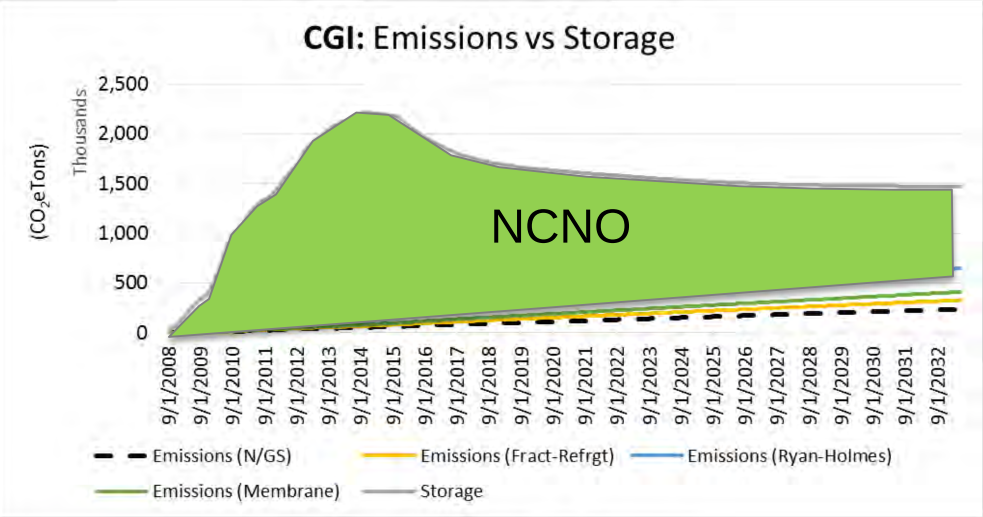


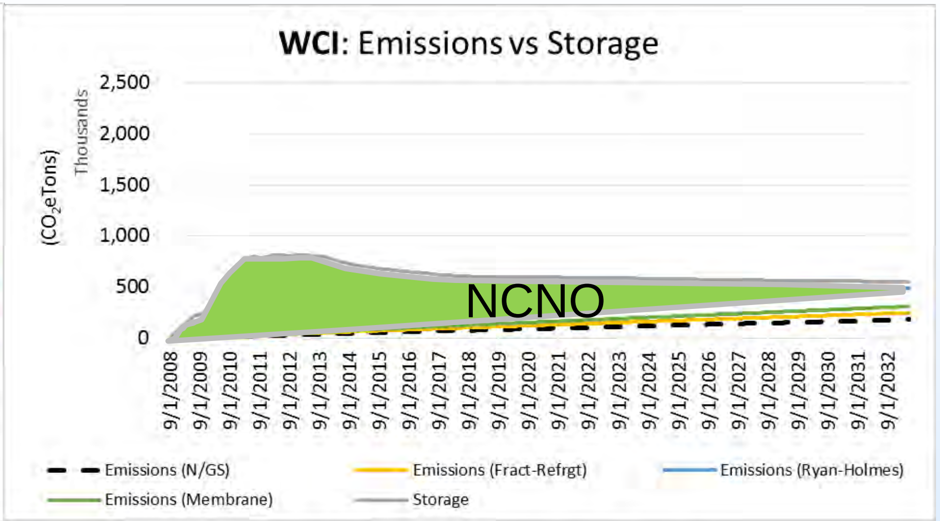


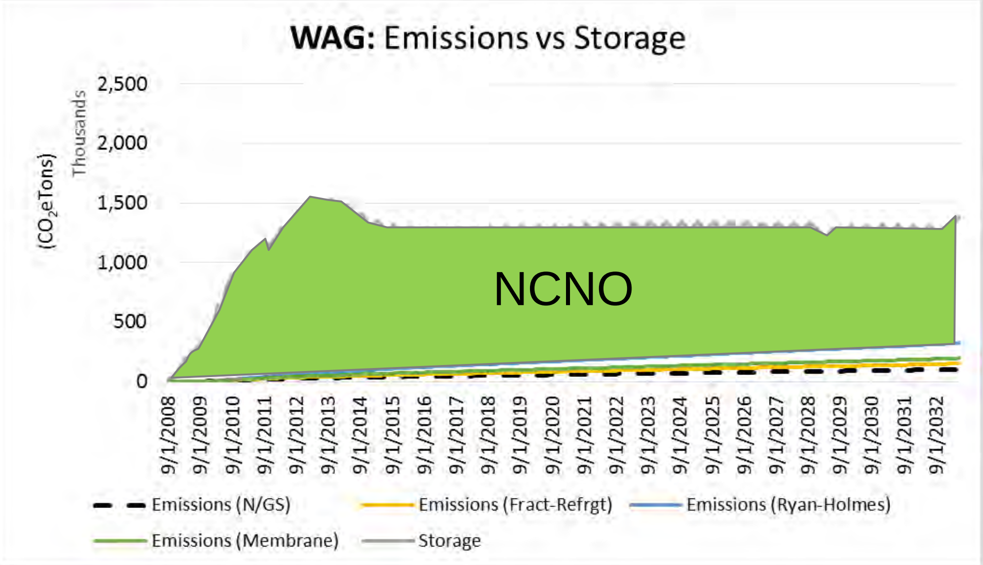


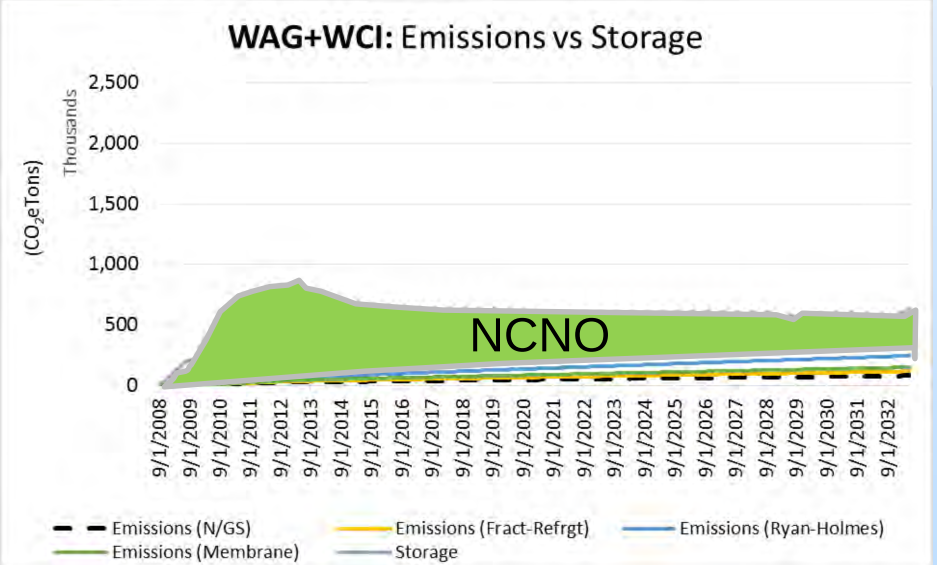
Technical Status:

Carbon Balance Evolution: **Gate to Gate**



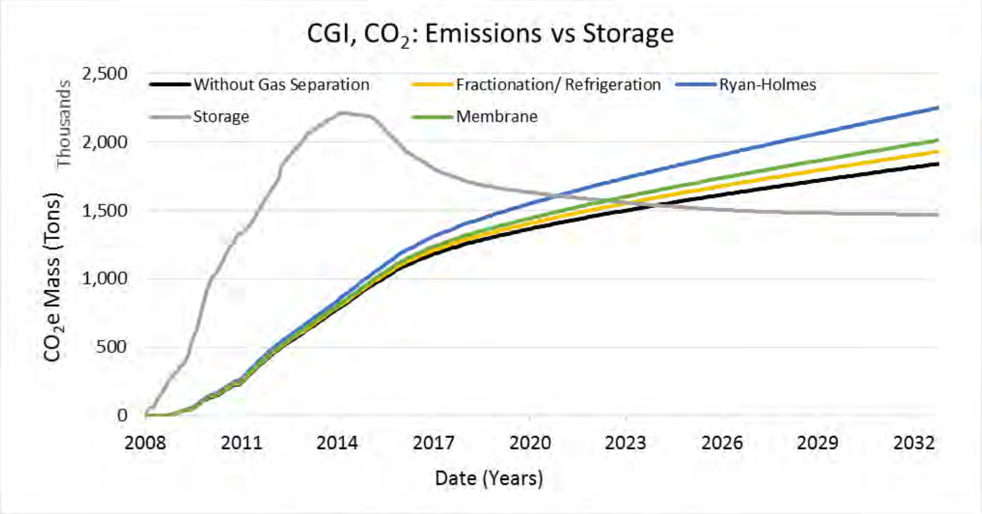


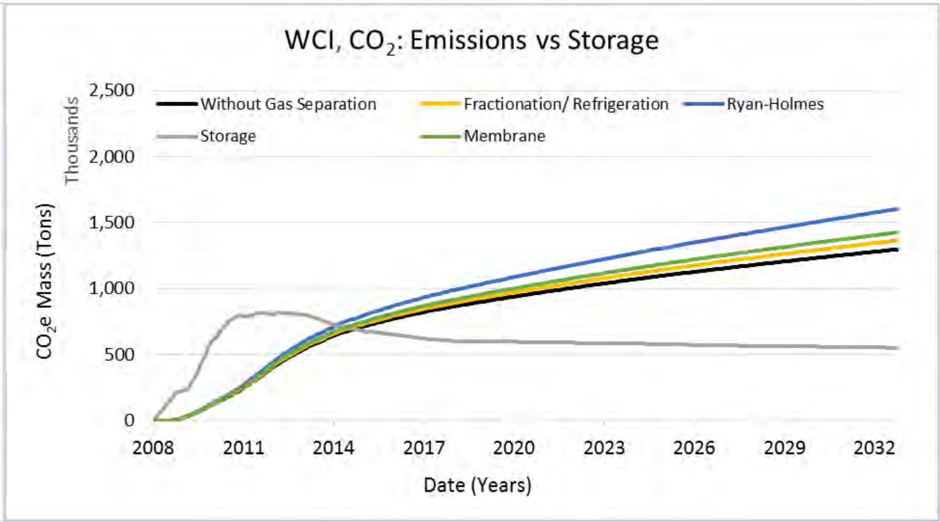


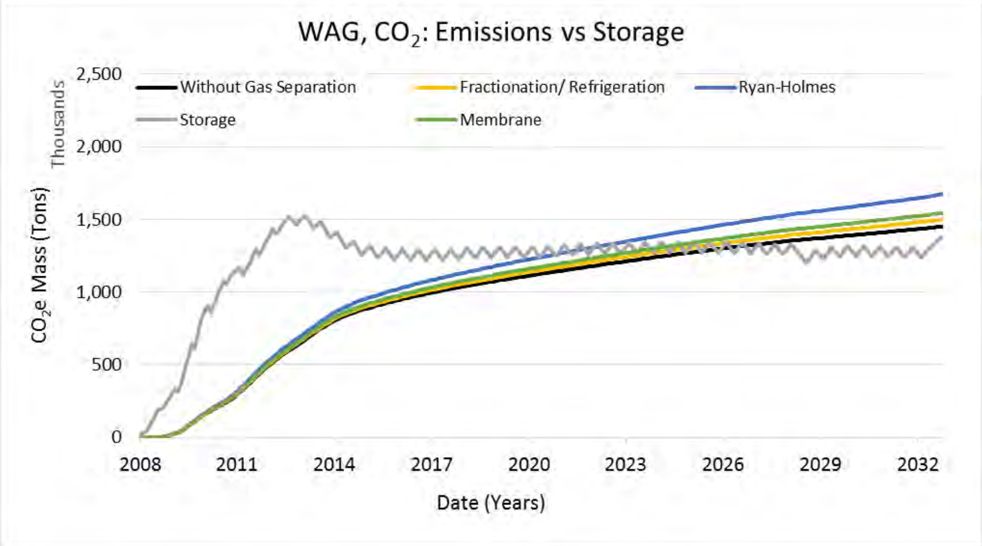


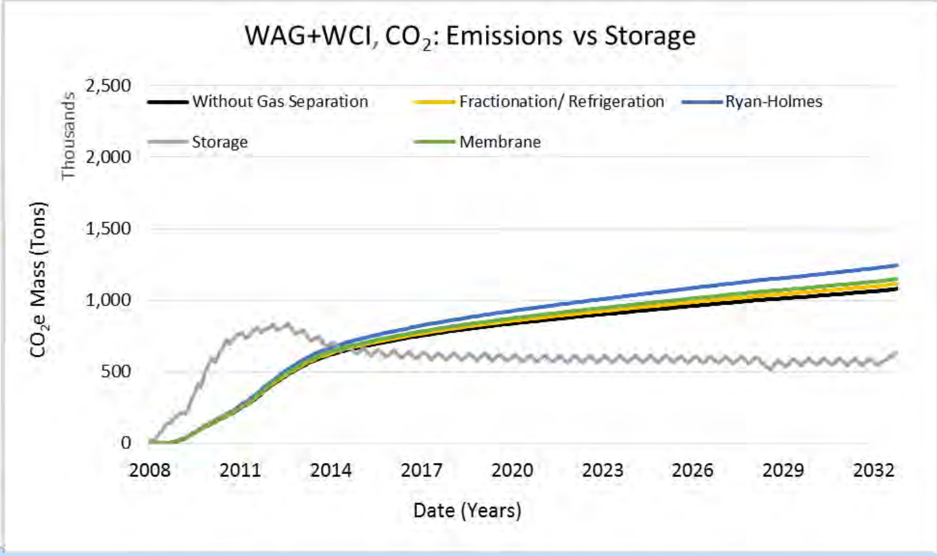
Technical Status:

Carbon Balance Evolution: **Gate to Grave**

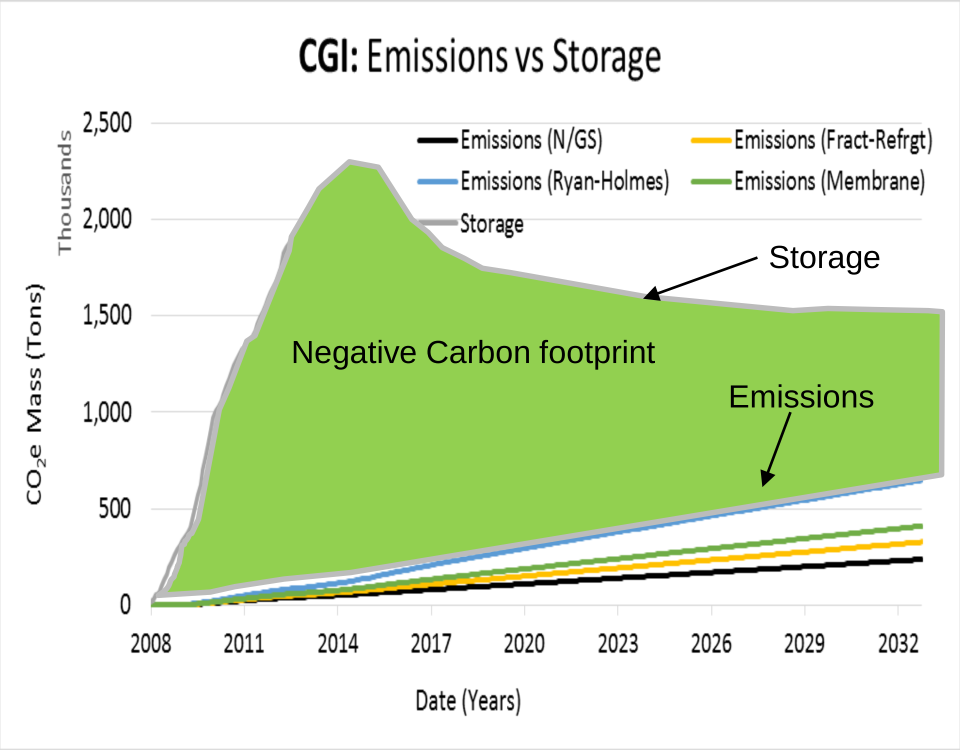


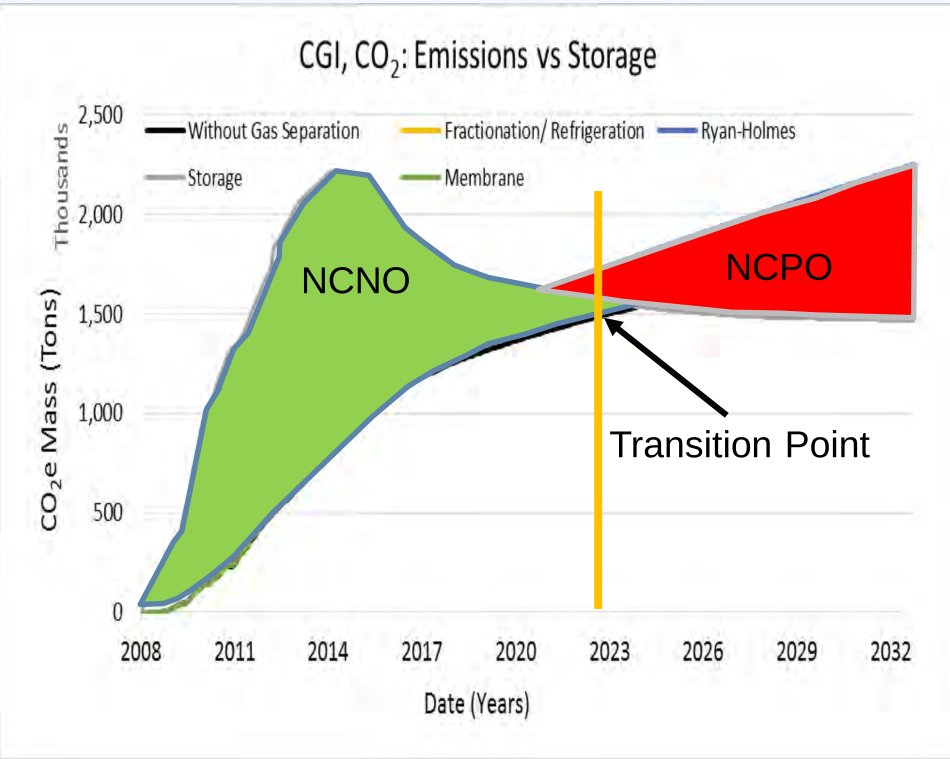






Technical Status,
Transition Point **Gate to Grave**





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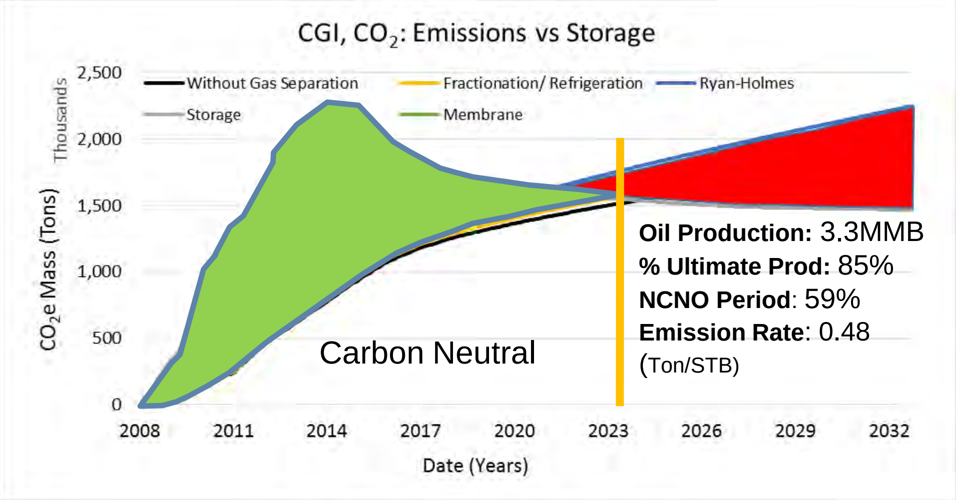
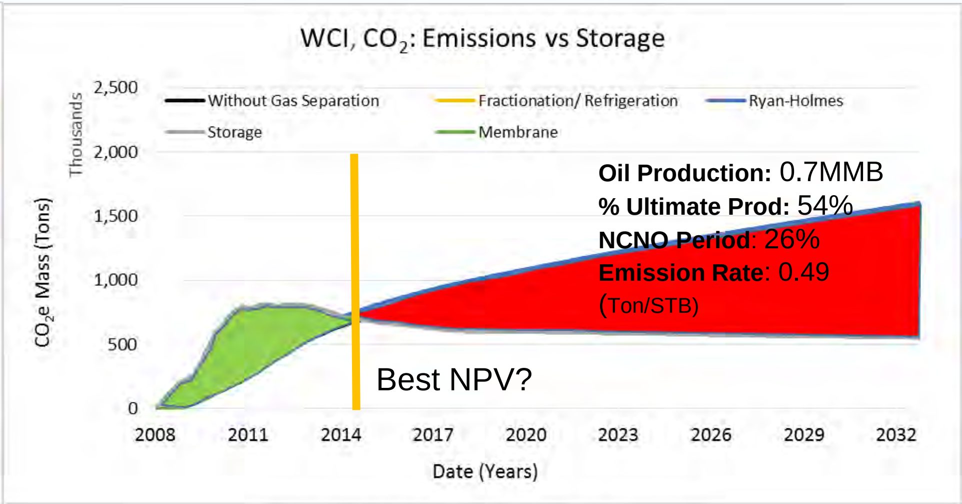
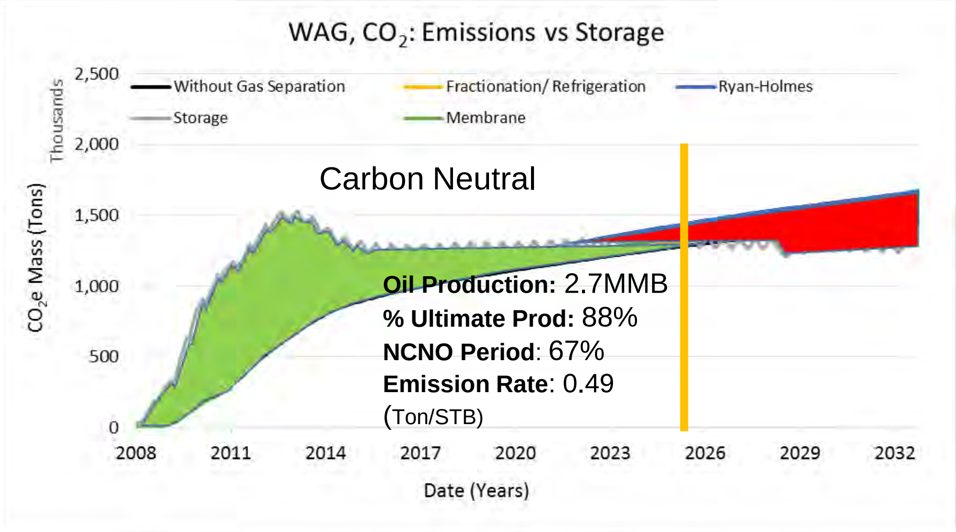
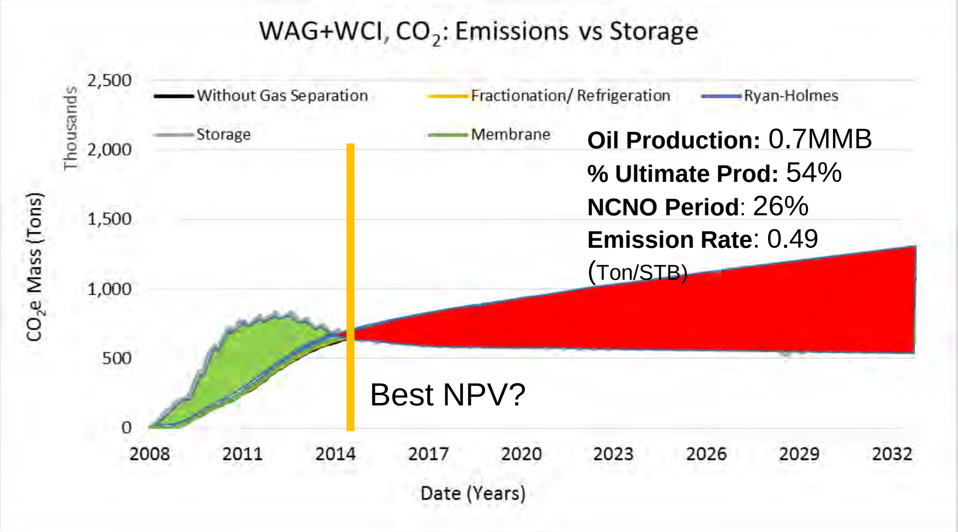
Transition Point **Gate to Grave**









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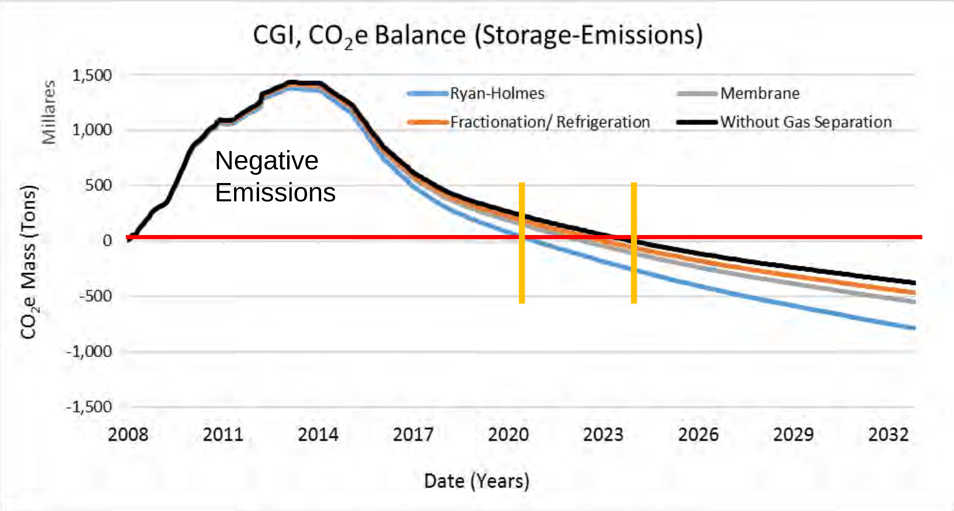
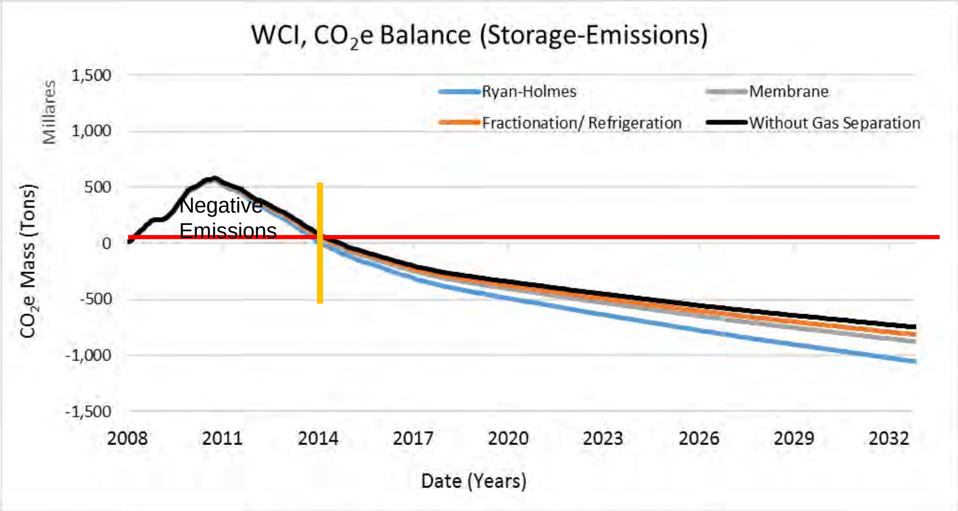
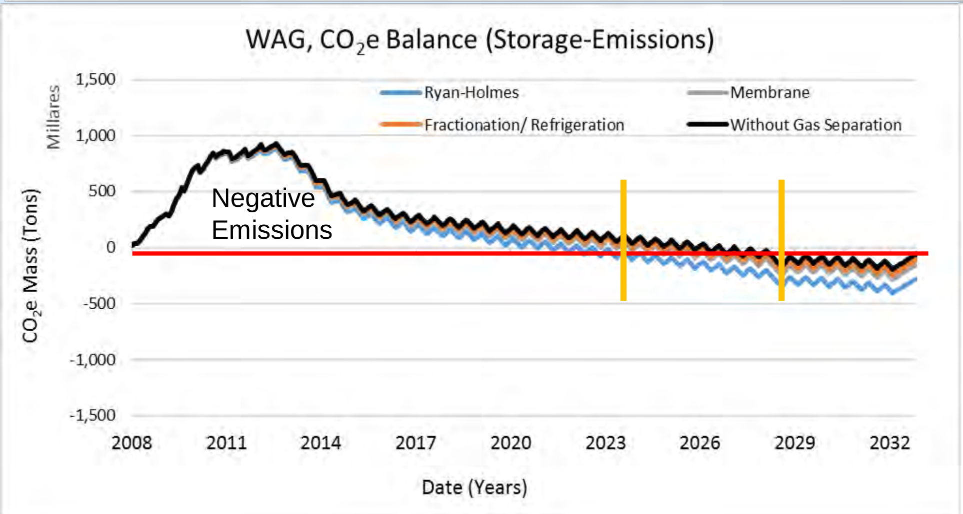
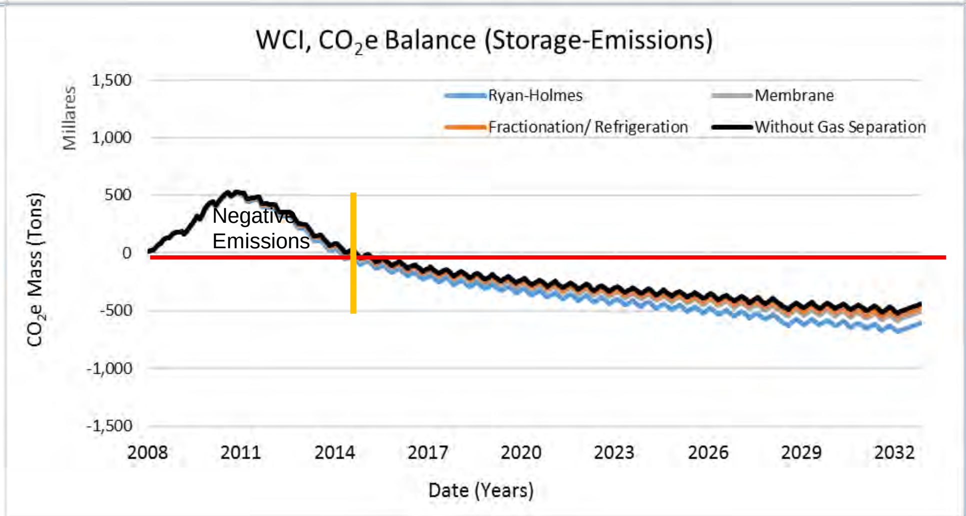








Accomplishments to Date

- ✓ Selection of system boundaries relevant to NCNO classification: gate-to-grave
- ✓ Identification of critical CO_2 emission components within the EOR site
- ✓ Gathered and classified Cranfield mass accounting data
- ✓ Developed an EOR site carbon mass accounting procedure
- ✓ Built Cranfield static model
- ✓ Completed historic and EOR history matching
- ✓ Complete the numerical simulation tasks
- ✓ Build a model for energy consumption of the CO_2-EOR operation
- ✓ Completed scenario analysis
- ✓ Linked results from numerical simulations with energy consumption model

Lessons Learned

- The need of a numerical compositional reservoir modeling to obtain the accurate outcomes for a NCNO project
- Subsurface and surface models needs to be in a close integration
- Accurate and detailed EOR energy consumption for the site’s facility is highly required
- Transition Point can be managed to last longer and is crucial aspect to consider for EOR as a GHG emission reduction option

Lessons Learned

- CO_2 storage is greatest in absolute volume terms for the CGI scenario, with 1.5 million tons (Mt) CO_2 stored. In decreasing order, this is followed by 1.3 Mt CO_2 stored for WAG, and 0.6 Mt for both WCI and WAG+WCI scenarios. CGI injects a larger gross volume of CO_2, so a larger volume is left behind.
- CO_2 net utilization ratio, defined as the amount of CO_2 purchased to produce 1 unit of oil, is lowest for hybrid WAG+WCI scenario, followed by WCI, WAG and CGI in increasing order.
- Oil production is greatest in absolute volume for the CGI scenario, with 4 million barrels (MMbbl) of incremental oil produced, versus 3 MMbbl for WAG, 2.5 MMbbl for WCI and 2 MMbbl for the hybrid WAG+WCI scenario.
- Our numerical simulations, demonstrate that flood efficiency variations are significant and mostly depend on the operator‘s selected field development strategy. These variations greatly affect the carbon balance of a project.
- A dynamic analysis allows to accurate determine the NCNO performance during EOR operations.

Synergy Opportunities

- Our NCNO methodology can be applied to the development of any hydrocarbon resource (conventional or unconventional) for Carbon Balance assessments.
- Opportunities to couple capture analyzes of different CO2 sources
- Use the outcomes of NETL cost analysis of CTUS
- Integrating NCNO to CCUS commercial scaling projects

Technical Summary/Next Steps

- ✓ Assessed the impact on carbon balance of critical geotechnical and operational parameters, such as solvent flood performance (CO_2 utilization ratios), gas separation technologies, and fluid handling, which are often overlooked in carbon lifecycle studies and their repercussion on cradle-to-grave carbon systems.
- ✓ Our numerical simulations, demonstrate that flood efficiency variations are significant and mostly depend on the operator‘s selected field development strategy. These variations greatly affect the carbon balance of a project.
- ✓ Assessed the carbon life cycle evolution of CO_2-EOR from start of CO_2 injection to operation closure.
- ✓ Developed a reservoir mass accounting methodology inclusive of CO_2 losses at the surface through operating equipment and in the subsurface outside a pre-established CO_2 storage complex.

Technical Summary/Next Steps

✓Obtained results that show how in a gate-to-grave system, all considered CO_2-EOR injection strategies at Cranfield start producing NCNO and at some point transition into producing net carbon positive oil (NCPO).

✓The NCNO period (with beneficial implications for carbon credits or tax deduction) can be engineered to last longer, as it is highly dependent on the CO_2 injection strategy.

Next Steps:

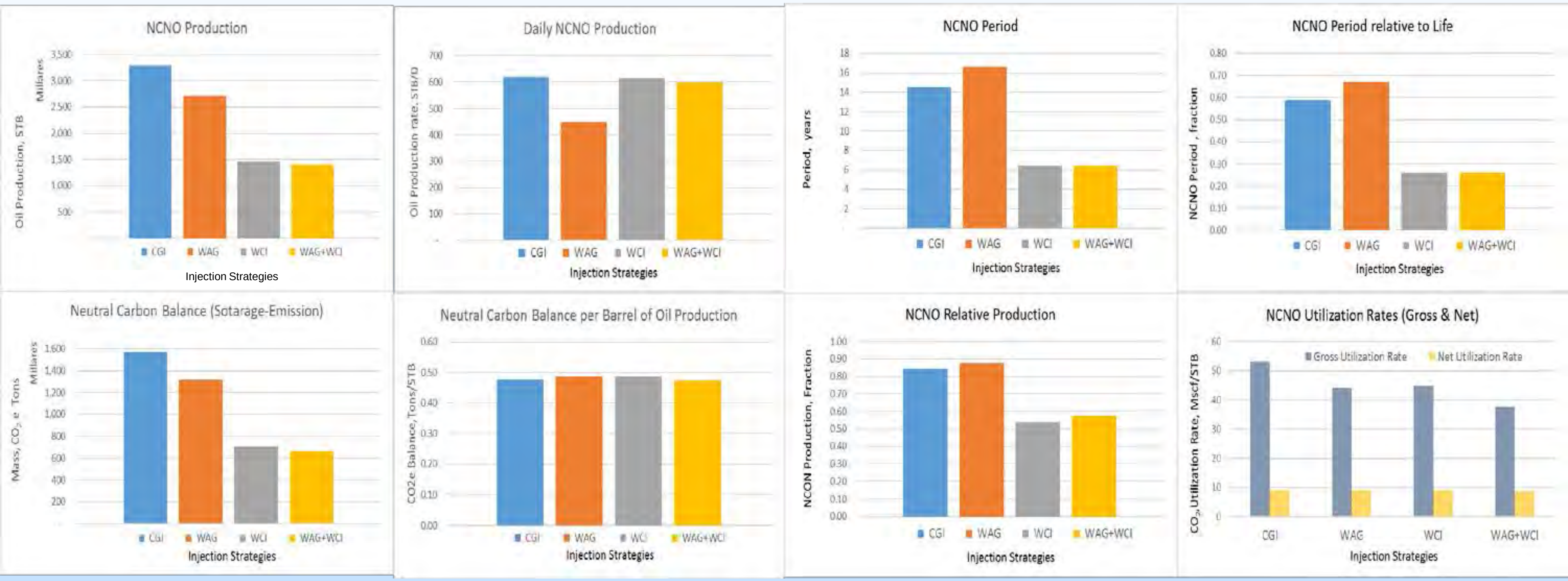
- ✓ Expand the system to include the elements upstream of the EOR site
- ✓ Finish the development of a commercially applicable, monitoring, verification, and accounting (MVA) methodology.
- ✓ Start a new project assessing the economics of this outcomes

Appendix

EOR performance:
Gate to Grave Transition Point

	Wihtout GS	Fract-Refrgt	Ryan-Holmes	Membrane	AVERAGE
CGI					
Emissions-Storage	1,536,364	1,554,983	1,608,031	1,571,174	1,567,638
Oil Prodt	3,388,676	3,331,494	3,157,432	3,283,279	3,290,220
Date	8/1/2024	10/1/2023	7/1/2021	2/1/2023	3/25/2023
(Emss-Strg)/Oil Prod	0.45	0.47	0.51	0.48	0.48
Oil Prodt/Total Oil Prodt	0.87	0.86	0.81	0.84	0.85
Date/Tot Period	0.64	0.61	0.52	0.58	0.59
Gross Utilization Rate (MscF/STB)	55.96	54.20	49.45	52.79	53.10
Net Utilization Rate (MscF/STB)	8.75	9.00	9.82	9.22	9.20
WAG					
Emissions-Storage	1,313,907	1,319,101	1,309,218	1,319,175	1,315,350
Oil Prodt	2,821,167	2,766,926	2,551,722	2,709,545	2,712,340
Date	3/1/2027	3/1/2026	9/1/2022	3/1/2025	45,763
(Emss-Strg)/Oil Prod	0.47	0.48	0.51	0.49	0.49
Oil Prodt/Total Oil Prodt	0.91	0.90	0.83	0.88	0.88
Date/Tot Period	0.74	0.70	0.56	0.66	0.67
Gross Utilization Rate (MscF/STB)	46.12	45.07	41.44	44.03	44.16
Net Utilization Rate (MscF/STB)	8.82	9.03	9.72	9.22	9.20
WCI					
Emissions-Storage	690,772	697,240	720,105	704,862	703,245
Oil Prodt	1,478,911	1,467,437	1,398,593	1,444,489	1,447,357
Date	5/1/2015	4/1/2015	10/1/2014	2/1/2015	2/7/2015
(Emss-Strg)/Oil Prod	0.47	0.48	0.51	0.49	0.49
Oil Prodt/Total Oil Prodt	0.48	0.57	0.55	0.56	0.54
Date/Tot Period	0.27	0.26	0.24	0.26	0.26
Gross Utilization Rate (MscF/STB)	51.46	42.73	42.07	42.52	44.69
Net Utilization Rate (MscF/STB)	7.86	9.16	9.92	9.41	9.09
WAG+WCI					
Emissions-Storage (Tons)	657,513	654,784	687,434	668,197	666,982
Oil Prodt (STB)	1,433,482	1,405,692	1,373,938	1,415,080	1,407,048
Date	5/1/2015	2/1/2015	11/1/2014	3/1/2015	2/7/2015
(Emss-Strg)/Oil Prod (Ton/STB)	0.46	0.47	0.50	0.47	0.47
Oil Prodt/Total Oil Prodt (STB/STB)	0.46	0.61	0.60	0.62	0.57
Date/Tot Period	0.27	0.26	0.25	0.26	0.26
Gross Utilization Rate (MscF/STB)	52.72	32.53	32.82	32.76	37.71
Net Utilization Rate (MscF/STB)	8.05	8.71	9.34	8.84	8.74

EOR performance:
Gate to Grave Transition Point



End of period EOR performance

		CGI	WAG	WCI	WAG+WCI
Production & Storage	Oil Production (STB)	3,889,432	3,086,764	2,563,531	2,287,839
	CO_2 storage (Tons)	1,467,821	1,399,204	549,464	639,849
	Storage (Tons/Bbl)	0.38	0.45	0.21	0.28
Impact of Gas Separation Process and System Boundary Expansion	**Total Emissions Wihtout GAS Process**				
	CO_2 Balance (Tons)	1,229,164	1,292,458	368,332	558,480
	CO_2 Balance (Tons/Bbl)	0.32	0.42	0.14	0.24
	Emissions(*)/Bbl (Tons/Bbl)	0.061	0.035	0.071	0.036
	Emissions$^{(*)}$/Storage (Tons/Tons)	0.163	0.076	0.330	0.127
	Total Emissions With Gas Process				
	CO_2 Balance (Tons)	1,004,654	1,170,987	200,273	466,975
	CO_2 Balance (Tons/Bbl)	0.26	0.38	0.08	0.20
	Emissions(*)/Bbl (Tons/Bbl)	0.12	0.07	0.14	0.08
	Emissions$^{(*)}$/Storage (Tons/Tons)	0.32	0.16	0.64	0.27
	Total Emissions Downstream				
	CO_2 Balance (Tons)	(597,791)	(176,174)	(917,183)	(531,510)
	CO_2 Balance (Tons/Bbl)	(0.15)	(0.06)	(0.36)	(0.23)
	Emissions(*)/Bbl (Tons/Bbl)	0.53	0.510	0.57	0.512
	Emissions$^{(*)}$/Storage (Tons/Tons)	1.41	1.13	2.67	1.83
Utilization ratios	**Production Efficiency: Gross Utilization Ratio $^{(**)}$**				
	MScf/STB	73.63	53.88	79.33	51.67
	STB/MScf	0.01	0.02	0.01	0.02
	Production Efficiency: Net Utilization Ratio (***)				
	MScf/STB	7.27	8.55	4.13	5.20
	STB/MScf	0.14	0.12	0.24	0.19

$^{(*)}$ Emissions (Tons CO_2e)

$^{(**)}$ Gross Gas Injection

$^{(***)}$ Purchased CO_2

- 🟩 Best
- 🟩 Good
- 🟥 Regular
- 🟧 Worst

End of period EOR performance

Benefit to the Program

Program goals being addressed.

(4) Develop Best Practice Manuals for monitoring, verification, accounting (MVA), and assessment; site screening, selection, and initial characterization; public outreach; well management activities; and risk analysis and simulation.

In support of:

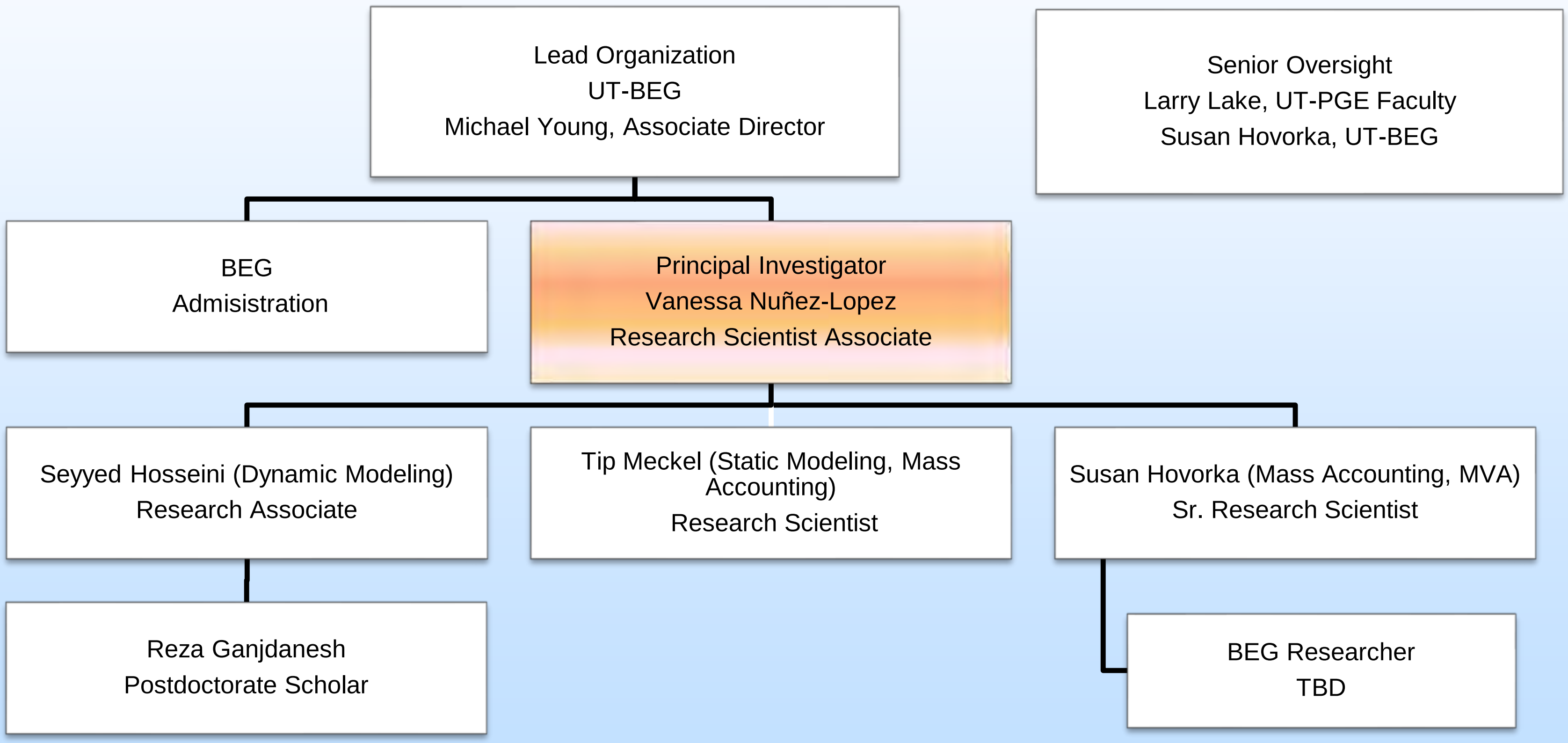
(1) Develop and validate technologies to ensure 99 percent storage permanence.

Project benefits statement.

The project will conduct research under Quantifying the Carbon Balance of CO_2-EOR Operations and Identifying "Net Carbon Negative Oil", via development of a reliable, clear, repeatable and universal CO2-EOR mass accounting methodology. The overall impact of this study will be the economic influence that a project classified as Net Carbon Negative Oil (NCNO*) would have on a CO2-EOR operation, if future laws and regulations provide value to the emissions and/or storage of CO_2.

*NCNO is defined in the FOA as oil whose carbon emission to the atmosphere, when burned or otherwise used, is less than the amount of carbon permanently stored in the reservoir in order to produce the oil

Organization Chart



Gantt Chart

		BUDGET PERIOD 1				BUDGET PERIOD 2				BUDGET PERIOD 3				BUDGET PERIOD 4 (EXTENSION)				
		Year 1:FY 2015				Year 2: FY 2016				Year 3: FY 2017				Year 4: FY 2018				TOTAL
		qtr1	qtr2	qtr3	qtr4	qtr1	qtr2	qtr3	qtr4	qtr1	qtr2	qtr3	qtr4	qtr1	qtr2	qtr3	qtr4	
Task	Tasks																	
	Carbon Life Cycle Analysis of CO_2-EOR for Net Carbon Negative Oil (NCNO) Classification																	
1	Project Management, Planning, and Reporting	8,140	10,854	9,497	9,497	8,605	7,171	7,171	5,737	5,000	5,000	5,000	5,000	3,340	3,340	3,340	3,340	100,031
1.1	Revision and Maintenance of Project Management Plan	D 1.1																
1.2	Management and Reporting	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	
2	Project Framework and Data Gathering	18,994	21,707	28,491	28,491	24,815												122,498
3	Reservoir Mass Accounting Methodology		21,707	28,491	28,491	24,815	32,269	21,513										157,286
			I, 2					D, 3.1										
4	Static and Dynamic Modeling			28,491	28,491	74,538	78,991	68,235	72,536	85,810	85,810	48,277	48,277	55,000	55,000	55,000		784,456
4.1	Static Model																	
4.2	EOR-storage performance model development										D, 4.2							
5	Monitoring, Verification, and Accounting (MVA) methodology							21,513	25,815	37,531	37,531	47,261	47,261	35,000	35,000			251,912
													D, 5.0					
	Q = Quarterly Report; A = Annual Report; F = Final Report																	
	D = Deliverable	27,134	54,268	94,969	94,969	132,773	118,431	118,431	104,088	128,341	128,341	100,538	100,538	93,340	93,340	58,340	3,340	**1,416,182**
		271,341				**473,723**				**457,758**				**248,360**				

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