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Critical Challenges. Practical Solutions.

Energy & Environmental Research Center (EERC)

CO_2 ENHANCED OIL RECOVERY IMPROVEMENT IN CONVENTIONAL FIELDS USING RICH GAS

DE-FE0031789

U.S. Department of Energy National Energy Technology Laboratory

Oil and Gas Virtual Project Review Meeting

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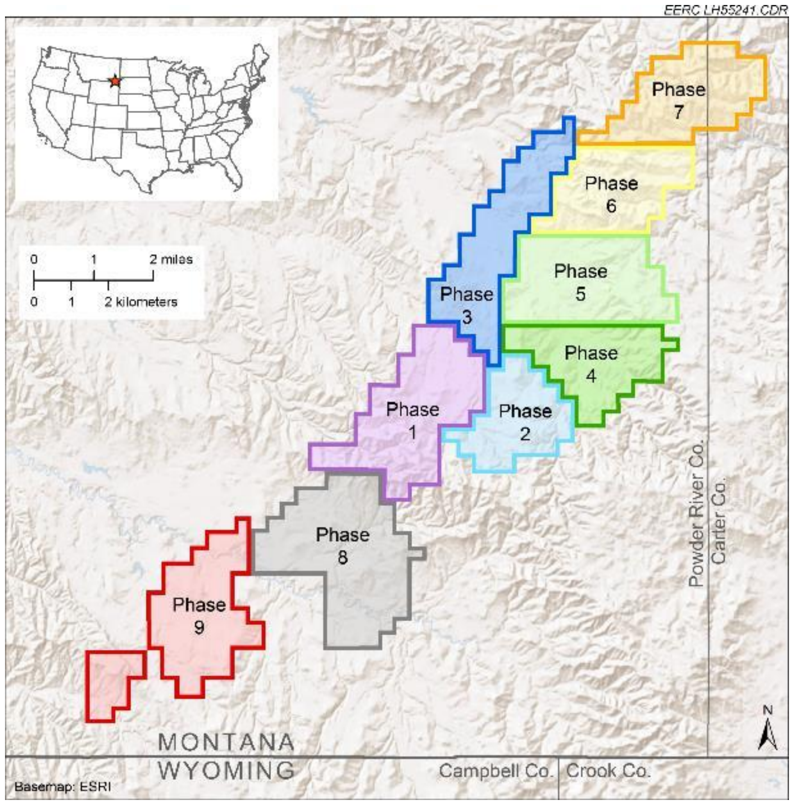
CO_2 BLENDED WITH RICH GAS

Research Hypothesis: *The injection of a blend of rich hydrocarbon gas and CO_2 into an oil reservoir will reduce molecular weight (MW) selectivity, lower minimum miscibility pressure (MMP) and viscosity of the oil, and improve gas solubility, resulting in an overall improvement in enhanced oil recovery (EOR) performance.*

PROJECT GOAL AND OBJECTIVES

Project Goal: *Determine the effect of injecting blended CO_2 and rich gas into an active CO_2 EOR field to improve production performance.*



Project Objectives: The goal will be accomplished by completing several specific research objectives:

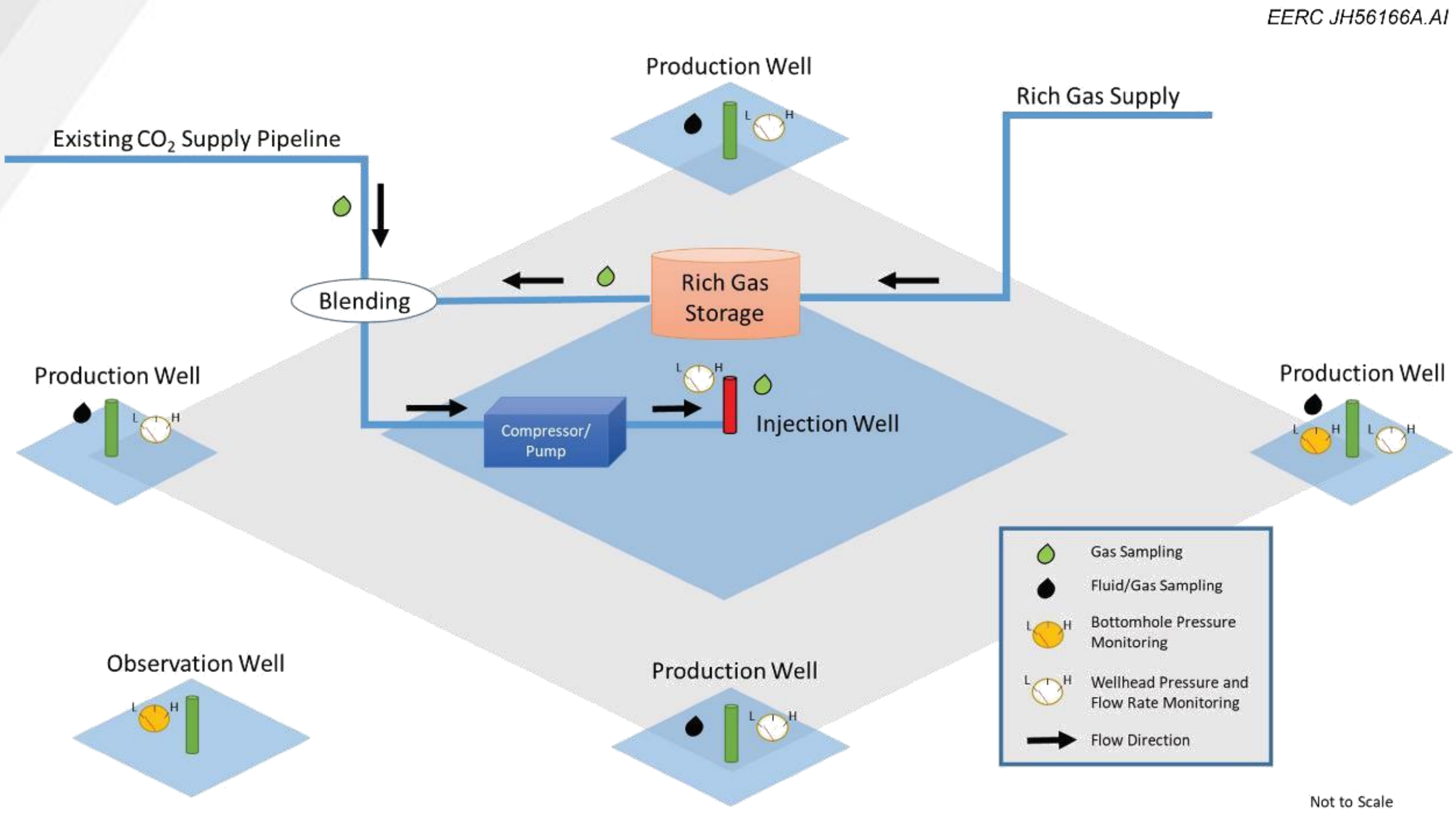
- Determine the quantity, transportation, compression, and injection needs for a field-based injection test.
- Inject blended CO_2 and rich gas in the Bell Creek Field for incremental recovery and associated CO_2 storage.
- Develop field-based data to determine the effects of rich gas additives in CO_2 on oil production.
- Use laboratory experiments and reservoir simulation to determine the potential for varying compositions of rich gas blended with CO_2 to improve oil recovery in other conventional reservoirs currently undergoing CO_2 EOR.
- Develop business case scenarios to assess the potential for using rich gas added to CO_2 at other EOR locations in the United States.

FUNDING AND PROJECT PERFORMANCE DATES

	BP1 ($) 10/1/2019–9/30/2021		BP2 ($) 10/1/2021–9/30/2024		Total	
	Federal	Nonfederal	Federal	Nonfederal	Federal	Nonfederal
DOE	$2,184,364	–	$5,789,517	–	$7,973,881	–
Schlumberger	–	$334,400	–	$501,600	–	$836,000
CMG	–	$212,993	–	$951,007	–	$1,164,000
Total	$2,184,364	$547,393	$5,789,517	$1,452,607	$7,973,881	$2,000,000
Total Cost Share %	80%	20%	80%	20%	80%	20%

Note: ***Denbury*** *– Additional collaboration in the form of field support, infrastructure development, design and implementation, gas supply, and injection/production operations.*

TECHNOLOGY BACKGROUND: CO_2 BLENDED WITH RICH GAS



- Previous laboratory and modeling work showed ethane can solvate a wider MW range of hydrocarbons than CO_2 alone, which could lead to more oil from the reservoir with better efficiency.
- Blending rich gas components with CO_2 may provide means of improving oil recovery in fields either undergoing or planned for tertiary recovery.
- Use of rich gas or rich gas–CO_2 blends for flooding operations can greatly reduce the quantity of CO_2 needed for EOR injection.

TECHNICAL APPROACH/PROJECT SCOPE

- Task 1.0 – Project Management and Planning

- Task 2.0 – Engineering Design
  - 2.1 – Rich Gas Source, Compression, and Transportation Evaluation

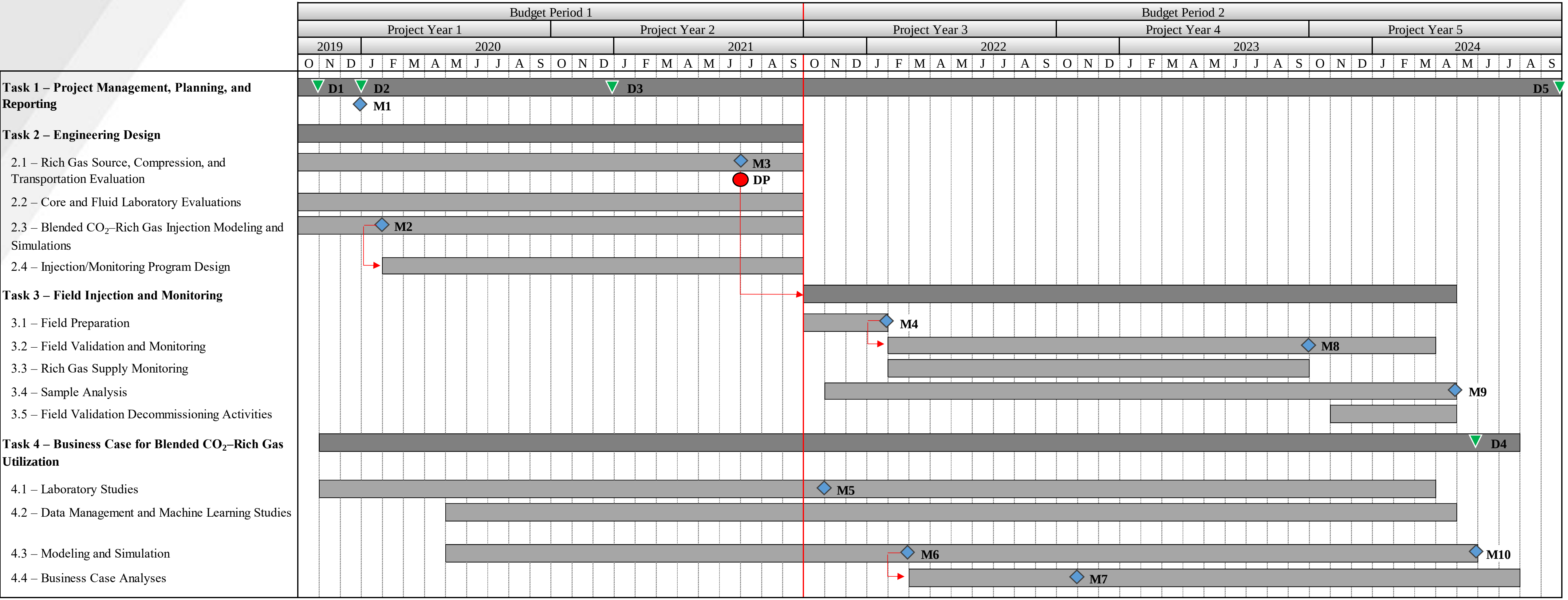
  DP: Go/no-go decision based on whether rich gas source is secured 6/30/2021
  - 2.2 – Core and Fluid Laboratory Evaluations
  - 2.3 – Blended CO_2-Rich Gas Injection Modeling and Simulation
  - 2.4 – Injection/Monitoring Program Design

TECHNICAL APPROACH/PROJECT SCOPE (CONT.)

- Task 3.0 – Field Operations and Monitoring (BP2)
  - 3.1 – Field Preparation
  - 3.2 – Field Validation and Monitoring
  - 3.3 – Rich Gas Supply Monitoring
  - 3.4 – Sample Analysis
  - 3.5 – Field Validation Decommissioning Activities

- Task 4.0 – Business Case for Blended CO_2-Rich Gas Utilization (BP1 and BP2)
  - 4.1 – Laboratory Studies
  - 4.2 – Data Management and Machine Learning Studies
  - 4.3 – Modeling and Simulation
  - 4.4 – Business Case Analysis

CO_2 BLENDED WITH RICH GAS TIMELINE



Key for Deliverables (D)

D1 – Updated Project Management Plan
D2 – Data Management Plan
D3 – Workforce Readiness Plan
D4 – Laboratory Studies of Blended CO_2–Rich Gas EOR
D5 – Data Submitted to NETL EDX

Key for Milestones (M)

M1 – Kickoff Meeting Held
M2 – Injection Site Verified
M3 – Rich Gas Source Secured
M4 – Field Preparation Completed
M5 – All Core Samples Obtained
M6 – Initial Geostatic Models Completed
M7 – First Field Business Case Developed
M8 – Blended CO_2–Rich Gas Injection Completed
M9 – Validation Test Fluid Sample Analyses Completed
M10 – Modeling and Simulation Completed

Summary Task
Activity Bar
Deliverable (D)
Milestone (M)
Decision Point (DP)
Critical Path

LH 3/8/2021

PROGRESS AND CURRENT STATUS OF PROJECT

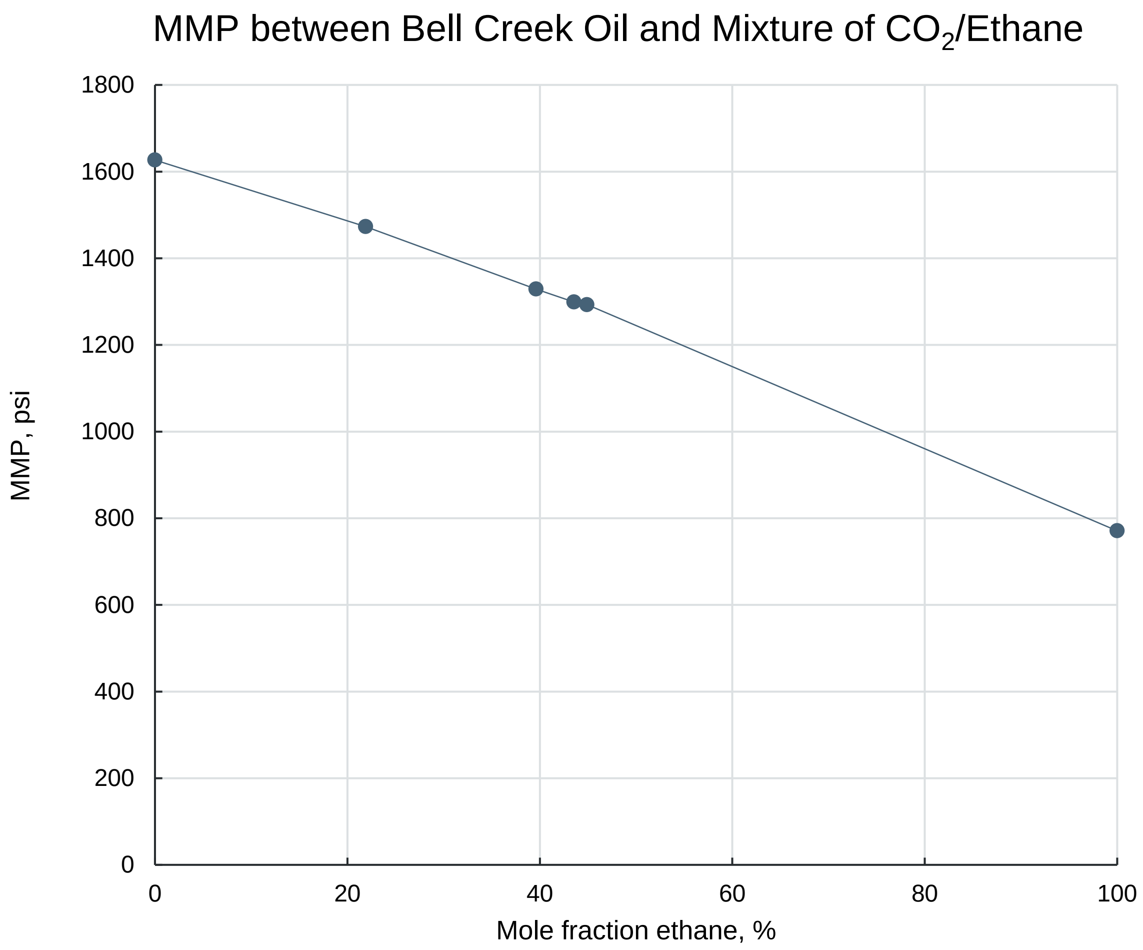
Subtask 2.1 Rich Gas Source, Compression, and Transportation Evaluation

- The EERC and Denbury are working toward a gas delivery plan and contract with a gas supplier.
- Preliminary considerations:
  - Trucking with 1-week storage at the location
  - Natural gas liquid (NGL) with injection rate of 150 bbl/day
  - Total blended gas injection rate is 2.5 MMscf/day
  - Water alternating gas (WAG) cycle or NGL + CO_2 followed by chasing CO_2
  - Monitor gas rate of each stream, gas composition, well production, and production oil composition

PROGRESS AND CURRENT STATUS OF PROJECT

Subtask 2.2 – Core and Fluid Laboratory Evaluations

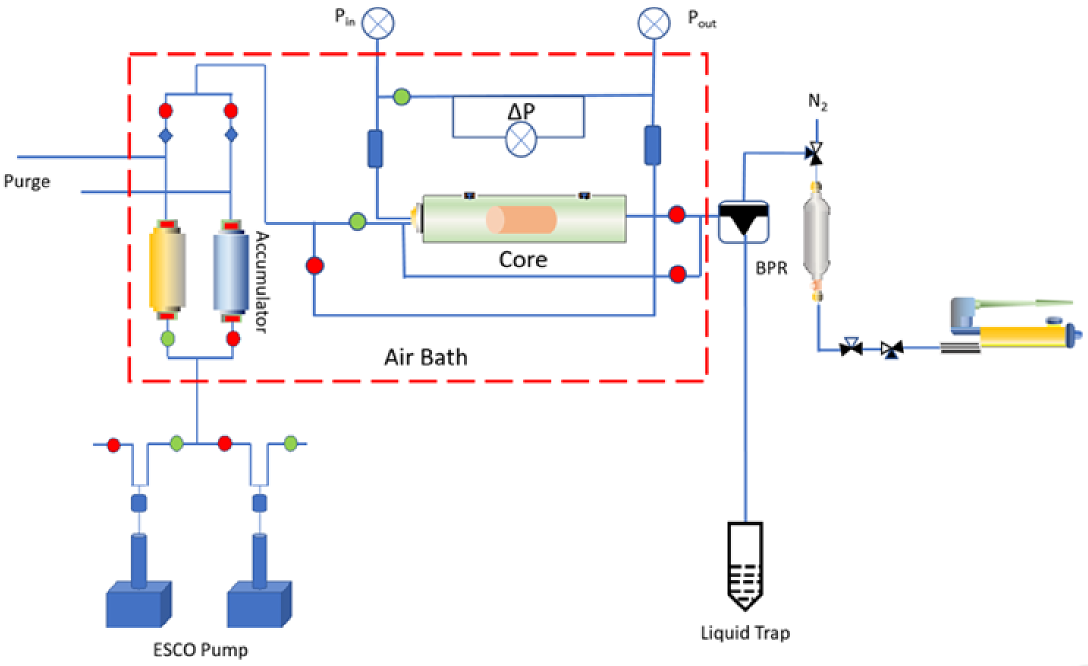
- Core and oil samples were collected for the Bell Creek Field.
- Testing was performed to determine:
  - Porosity/permeability.
  - Relative permeability of CO_2–ethane blends.
  - Pressure, volume, temperature (PVT) data regarding swelling and solubility of CO_2–rich gas blends in the presence of Bell Creek oil.
  - CO_2–rich gas MMP.



CORE FLOODING SETUP

- Purpose: to test the oil recovery performance in the Bell Creek Field using CO_2, C2 and C3, and verify the oil recovery improvement by C2 and C3.

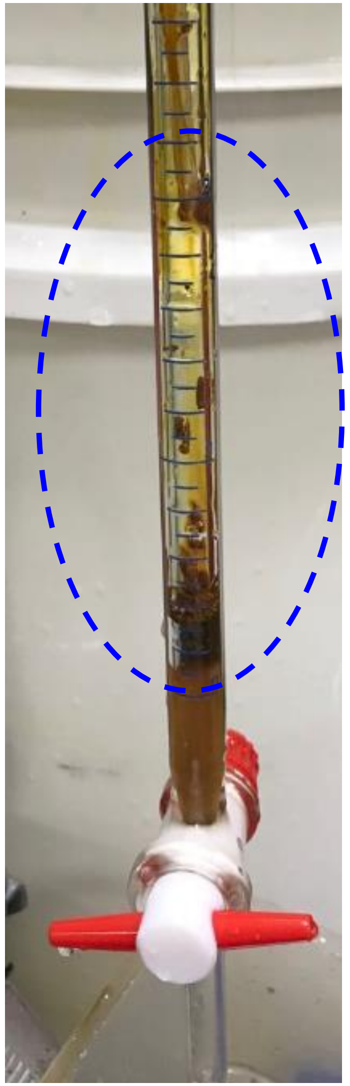
Vinci Core Flood System Used for CO_2/C2/C3 Injection



Schematic of the Core Flooding System

OIL COLLECTION PROCESS

Co_2-Flooded Oil – Easy To Flow

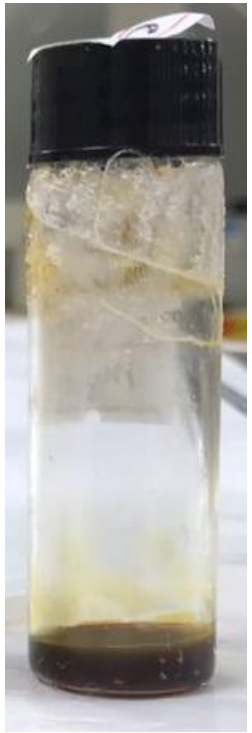


C3-Flooded Oil – Sticky, Viscous, And Foamy

OIL RECOVERED FROM CO_2, C2, AND C3 FLOODS

Co_2-Flooded Oil, 2 mL

C2-Flooded Oil, additional 1 mL after CO_2 flood



C3-Flooded Oil, additional 0.95 mL after C2 flood

More oil could be recovered after CO_2 flooding by sequential C2 and C3 floods.

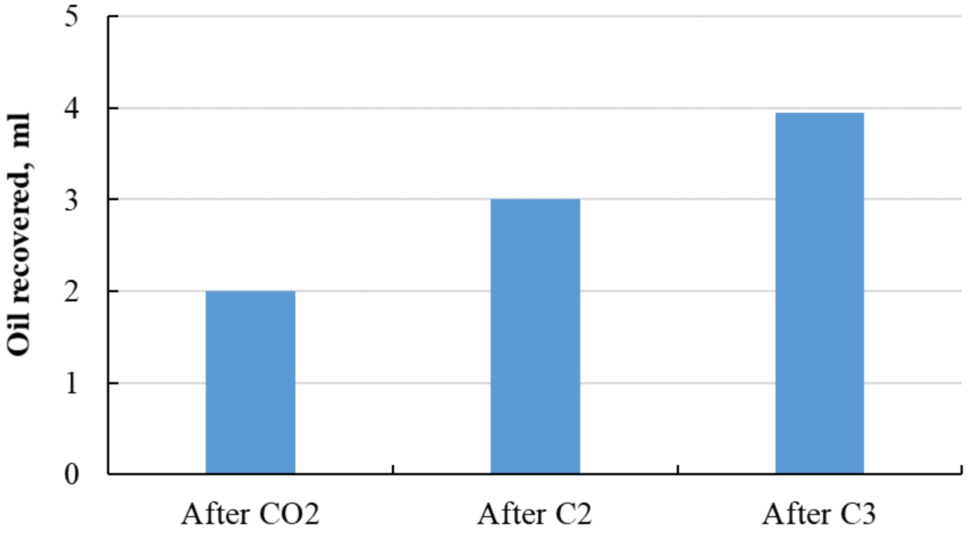
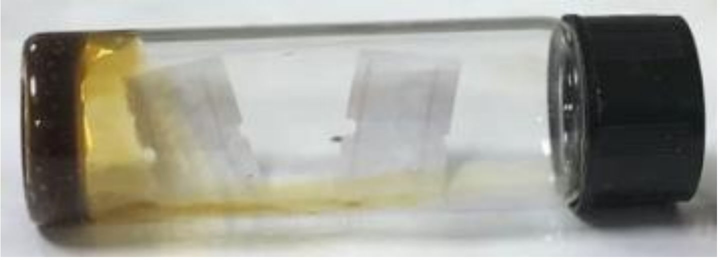


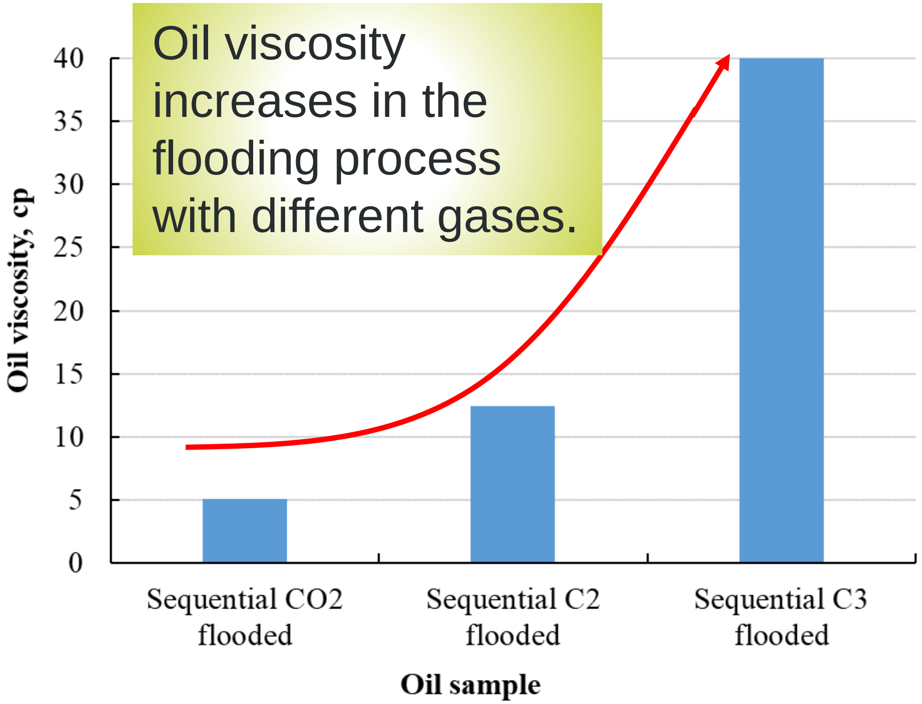
Figure 1. Oil recovered in the flooding process with different gases.

OIL COLLECTED FROM CO_2, C2, AND C3 FLOODS

CO_2-flooded oil; oil can flow under room temperature.

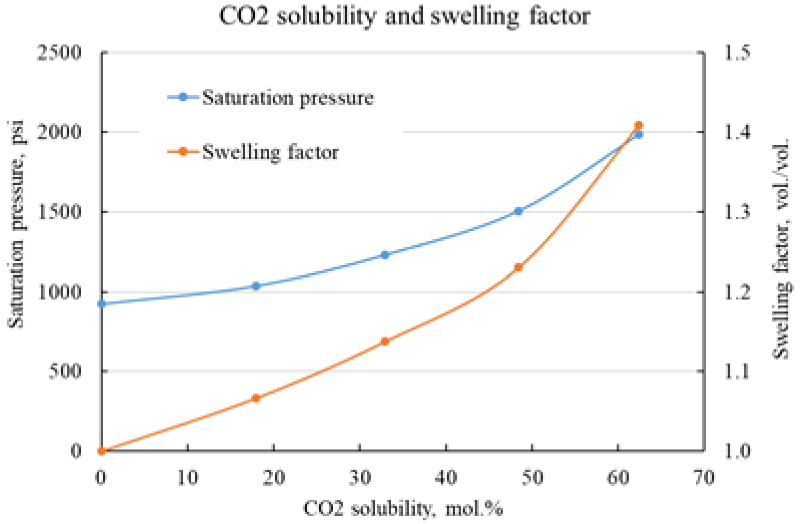


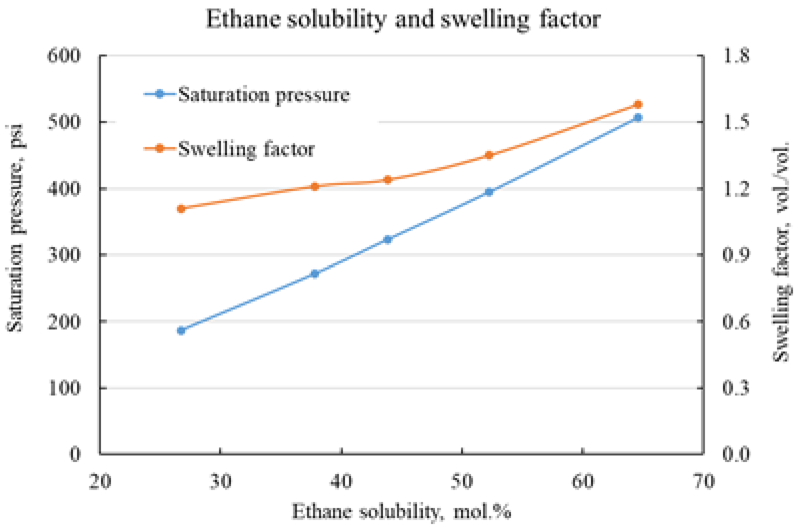
C2-flooded oil after CO_2 flood; oil is difficult to flow under room temperature.

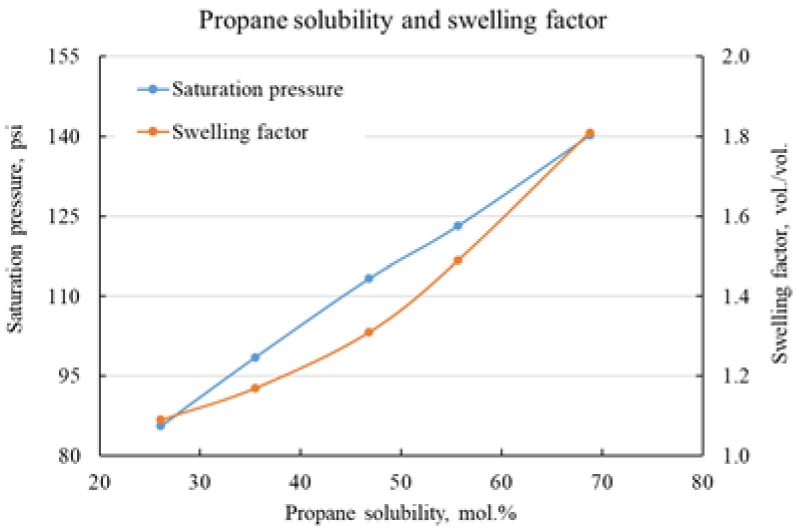


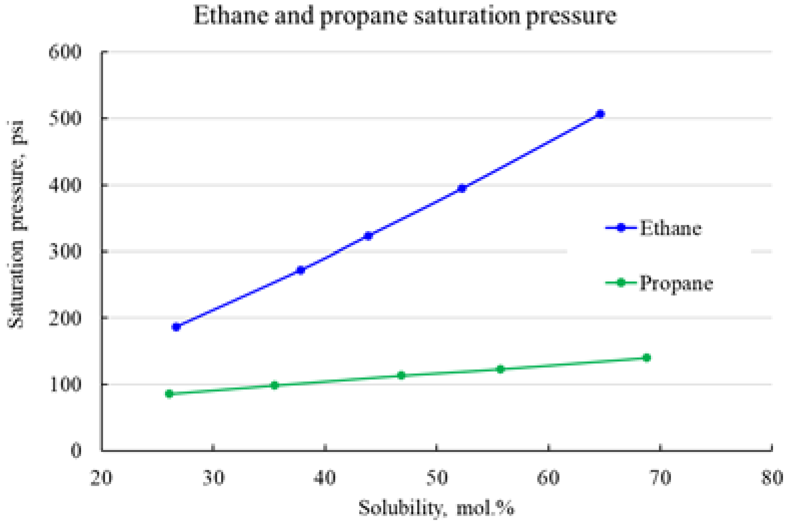
C3-flooded oil after C2 flood; oil cannot flow under room temperature.

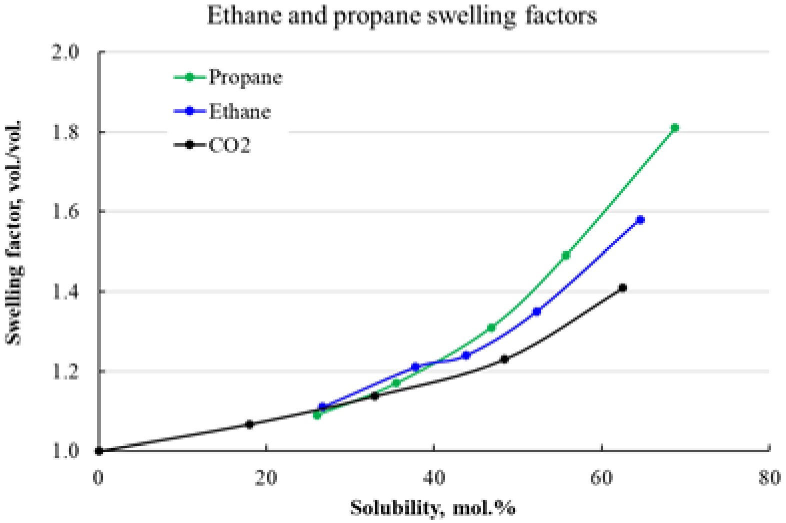
SWELLING AND SOLUBILITY DATA





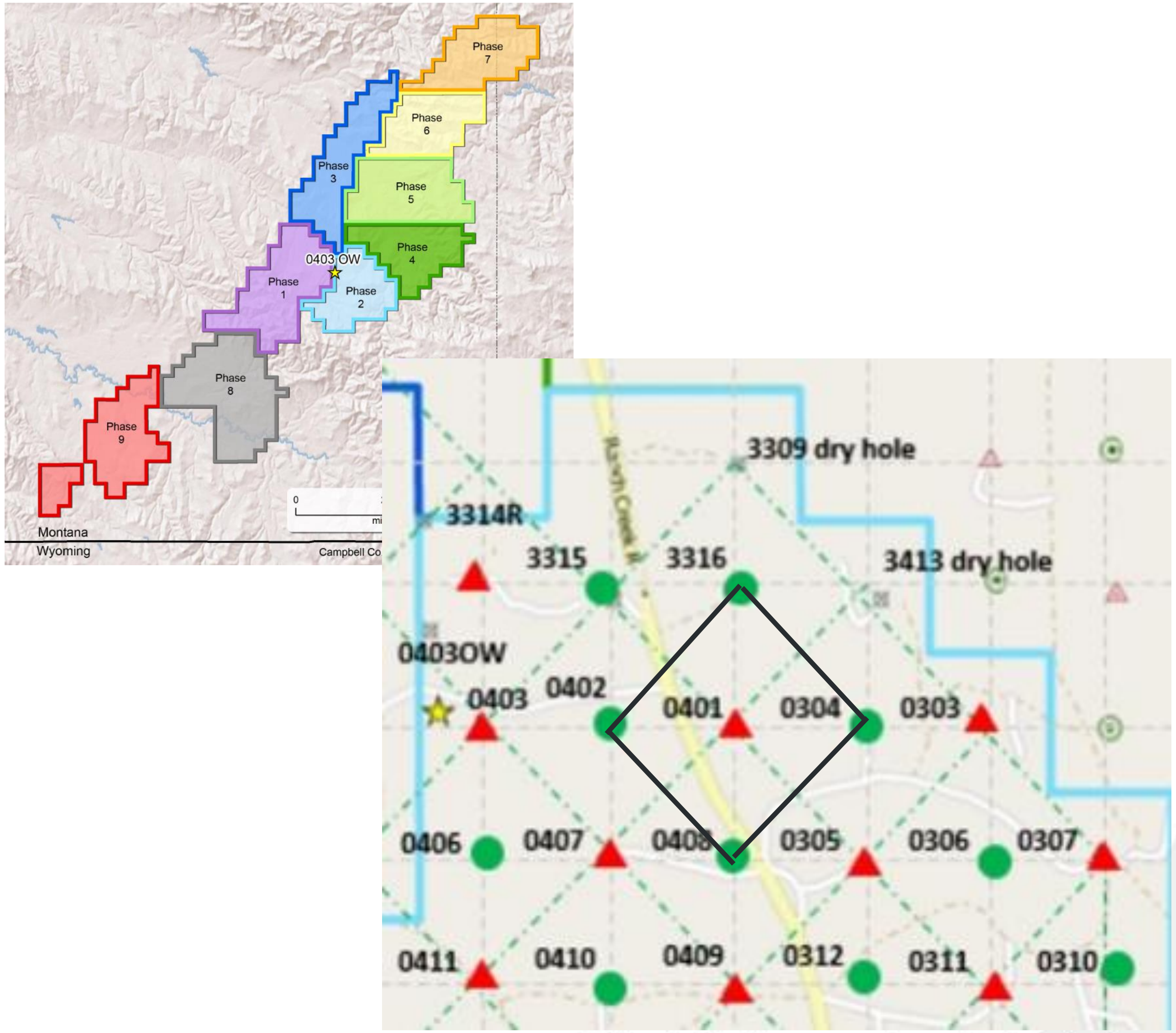






Critical Challenges. Practical Solutions.

PROGRESS AND CURRENT STATUS OF PROJECT

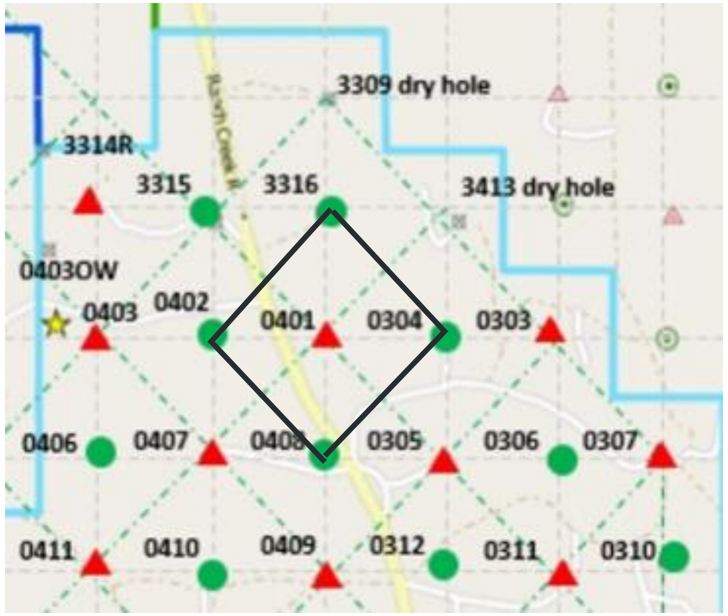


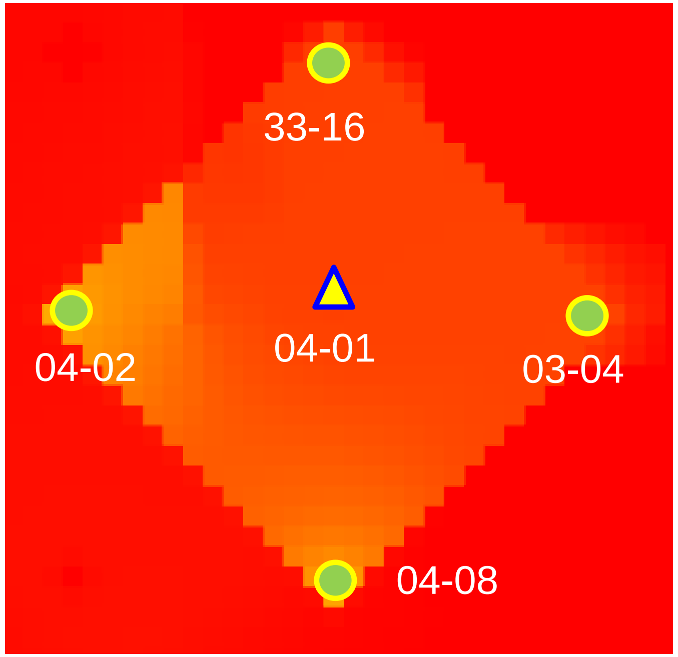
Subtask 2.3 – Blended CO_2–Rich Gas Injection Modeling and Simulation

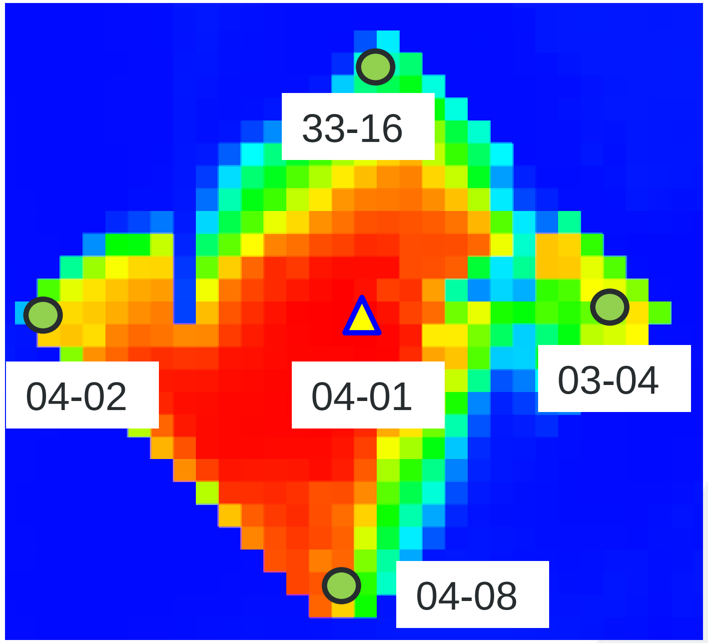
- The injection pattern and site were selected.
- The simulation model for the pilot pattern has been updated, and equation of state (EOS) modeling based on the injection gas composition is complete.
- The EERC and Denbury are working together on detailed EOR predictive simulation to optimize the sweep efficiency in the pilot pattern.

FIVE-SPOT SECTION FOR THE 04-01 PATTERN

- Based on the history-matched model, a sectional model was cut out to include wells in the 04-01 pattern only:
  - One water/gas injector: 04-01
  - Four producers: 03-04, 04-02, 04-08, and 33-16
- No injected rich gas flows out of the 04-01 pattern in the predictive cases to maximize the sweep efficiency in the pattern.



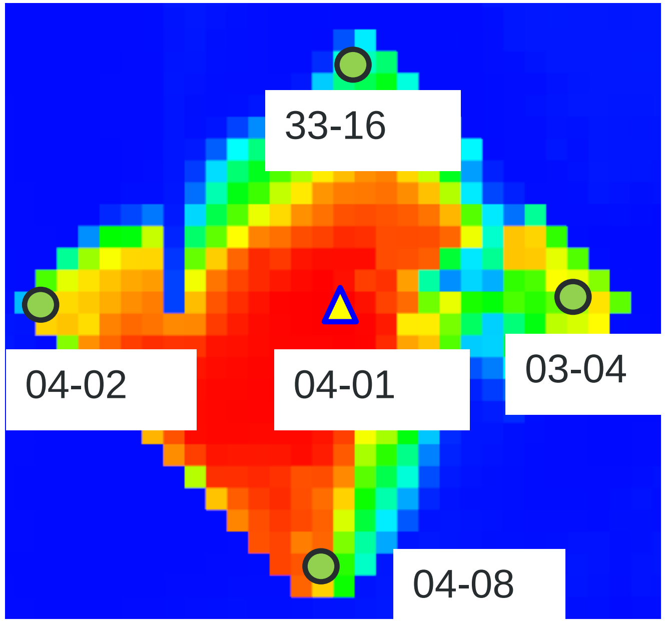




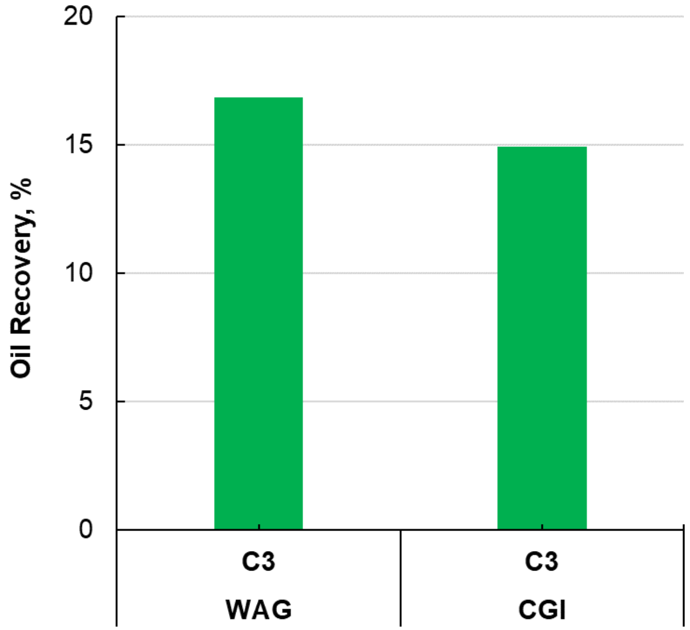
WAG AND CGI EOR SCENARIOS FOR AN ECONOMIC ANALYSIS

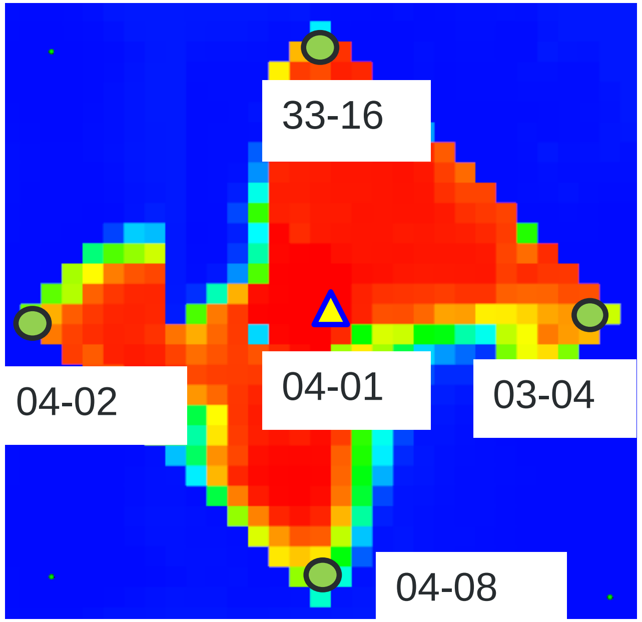
- CGI: Aimed at an even sweep in the 04-01 pattern for an upscaling purpose, the injection and production constraints were set up under bottomhole conditions for continuous gas injection (CGI) scenarios.

- WAG: Because of the uneven distribution of reservoir thickness around the wells in the 04-01 pattern, the production rate allocation may be adjusted to maximize the overall oil production from the pattern.



WAG with Uneven Surface Rate Allocation



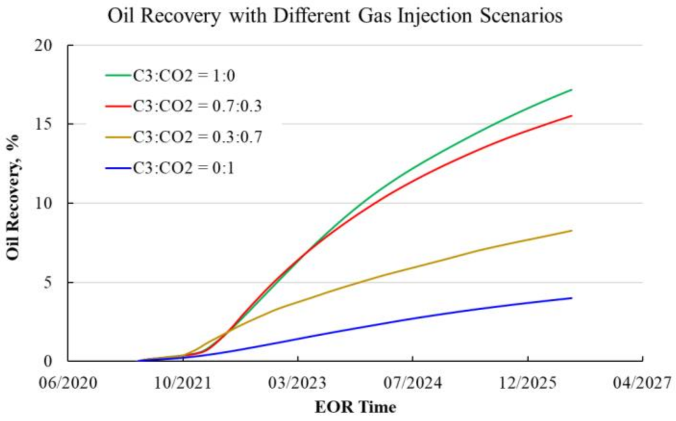


CGI with Even Bottomhole Rate Allocation

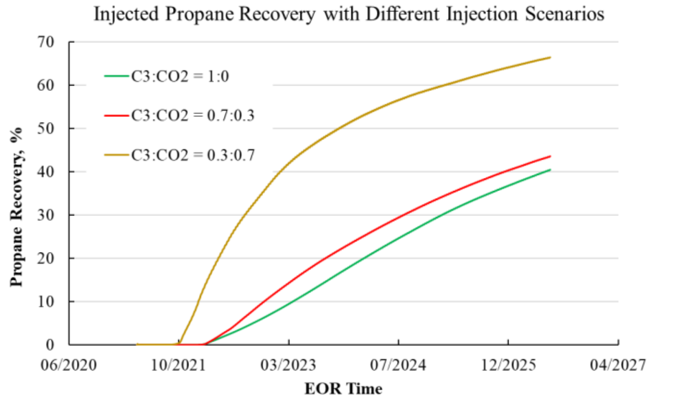
RECOVERIES OF OIL AND INJECTED PROPANE IN WAG AND CGI OPERATIONS

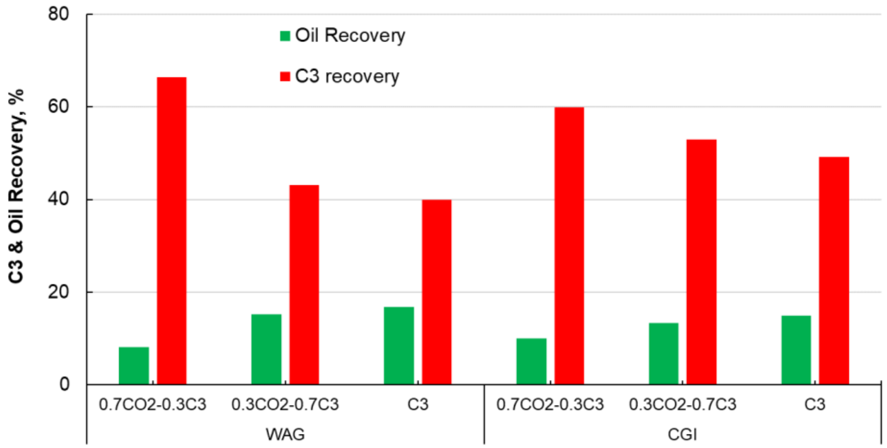
- Simulation shows that adding propane to the injection gas can effectively improve the oil recovery.
- A considerable quantity of injected propane can be produced back in both WAG and CGI operations.

WAG – Oil

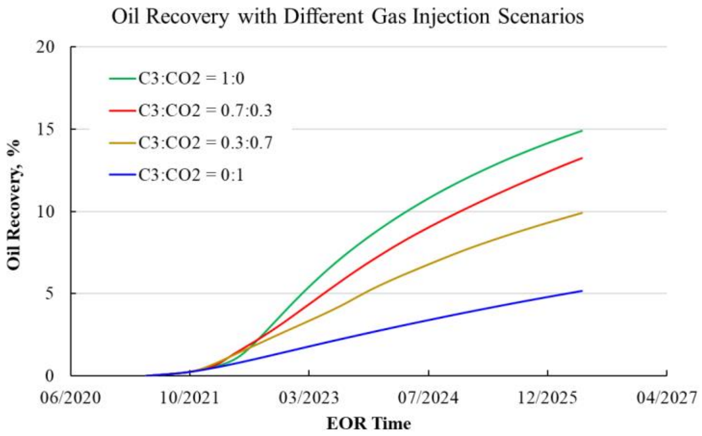


WAG – C3

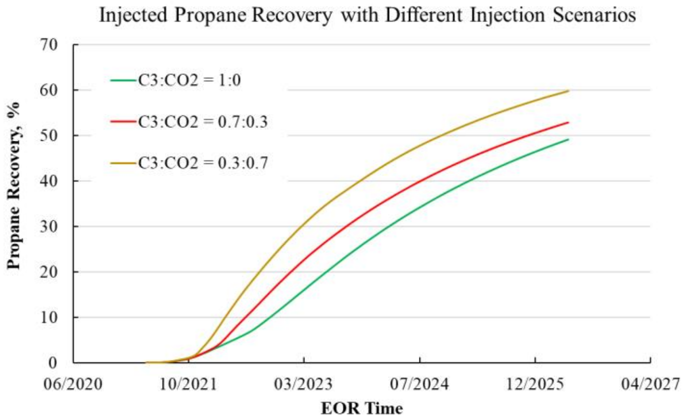




CGI – Oil



CGI – C3



DISCUSSION

- The density of liquid propane is unknown at this moment; specific data are needed from the vendor as gallon is volume unit and its numerical value changes with temperature and pressure.
- The preliminary economic analysis is optimistic, as the gas-processing cost was not included in the analysis.
- Blended gas injection has better economic performance, as less propane is needed for injection, although it yields lower oil recovery than the pure propane injection scenario.

PROGRESS AND CURRENT STATUS OF PROJECT

Task 4 – Business Case for Blended CO_2–Rich Gas Utilization

- Business case development has been initiated.
  - The EERC is working closely with Denbury on economic analyses to determine the potential for field-scale implementation of blended CO_2–rich gas EOR.
  - Rock samples were collected for the Rocky Mountain region.
  - Porosity, permeability, thin sections, and mercury injection capillary pressure (MICP) are all complete for this set.
  - Additional samples for the Gulf Coast region are being acquired.
  - Data collection for both regions continues.

PROGRESS AND CURRENT STATUS OF PROJECT

Characteristics of CO_2 EOR Fields in Proposed Project

Field	Basin	Zone	Dominant Lithology	Porosity Range, %	Permeability Range, mD	Thickness, ft	API Gravity
Bell Creek	Powder River	Muddy	Marine sandstone	25–35	150–1175	30–45	32–41
Cedar Hills	Williston	Red River	Dolostone	13–23	15	10	30
Tinsley	Mississippi Interior Salt	Woodruff	Shallow marine sandstone	26–28	1040–1300	80–90	32
Heidelberg	Mississippi Salt	Eutaw	Marine sandstone	28	10–3115	550	23

PRELIMINARY ECONOMIC ANALYSIS

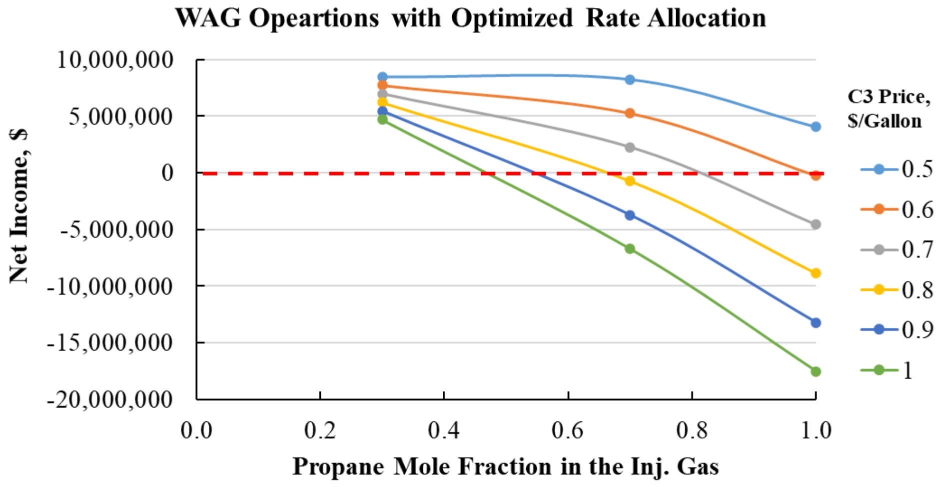
- A simplified equation was applied to evaluate economic feasibility of EOR with propane in the 04-01 pattern:

  net income = oil sale income + produced gas sale income – gas injection cost

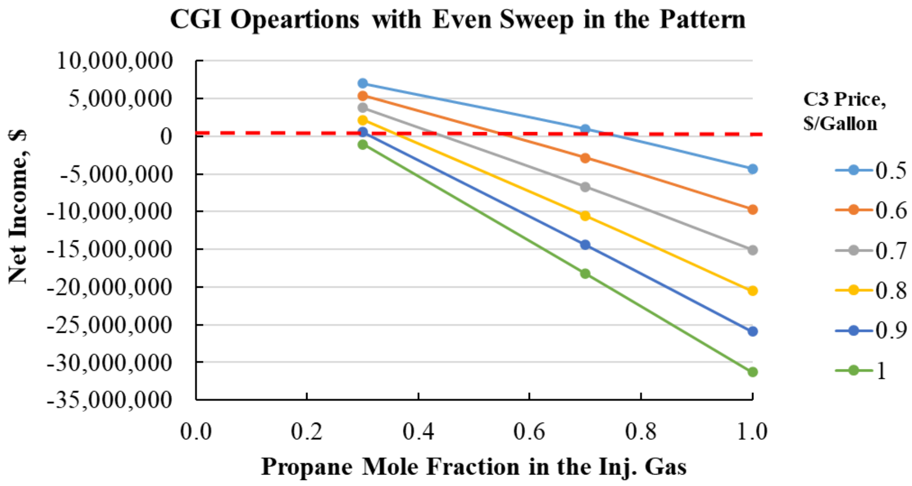
- Propane price varies between 0.5 and 1.0 $/gallon(US).
- Liquid propane density is 4.24 lb/gallon(US).
- Oil price is assumed at $74/bbl.

PRELIMINARY ECONOMIC ANALYSIS

C3 Price =	0.5	$/gallon			
Inj. Method	**C3 Mole Frac.**	Oil income, $	C3 income, $	C3 cost, $	**Net income, $**
WAG	0.3	12,290,457	7,516,415	11,312,728	8,494,143
	0.7	23,240,486	11,363,450	26,339,248	8,264,688
	1.0	25,671,562	14,326,593	35,922,667	4,075,488
CGI	0.3	15,109,857	12,048,495	20,127,076	7,031,275
	0.7	20,191,270	21,578,998	40,783,208	987,059
	1.0	22,725,252	26,110,694	53,132,029	-4,296,083

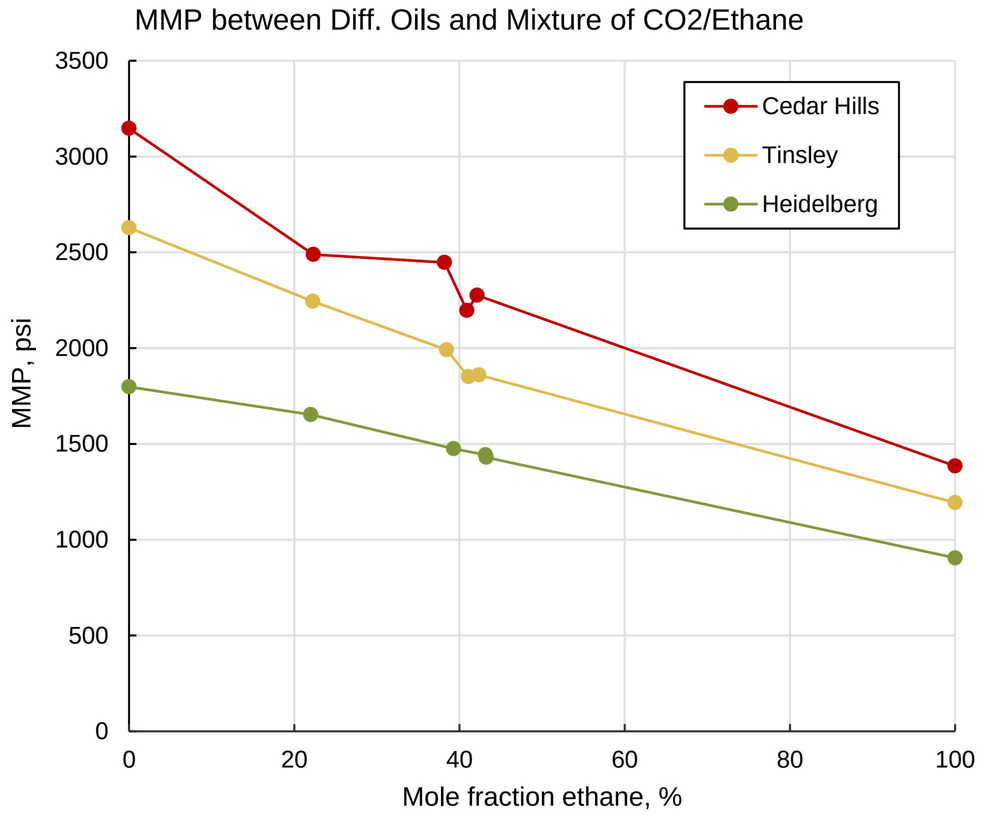


C3 Price =	1.0	$/gallon			
Inj. Method	**C3 Mole Frac.**	Oil income, $	C3 income, $	C3 cost, $	**Net income, $**
WAG	0.3	12,290,457	15,032,829	22,625,456	4,697,829
	0.7	23,240,486	22,726,900	52,678,496	-6,711,110
	1.0	25,671,562	28,653,186	71,845,335	-17,520,587
CGI	0.3	15,109,857	24,096,990	40,254,152	-1,047,306
	0.7	20,191,270	43,157,995	81,566,417	-18,217,151
	1.0	22,725,252	52,221,388	106,264,058	-31,317,417



PROGRESS AND CURRENT STATUS OF PROJECT

- **Subtask 4.1 – Laboratory Studies**
  - Rock samples were collected for the Rocky Mountain region.
  - Porosity, permeability, thin sections, and MICP are all complete for this set.
  - Oil samples for Tinsley, Heidelberg, and Cedar Hills Fields have been collected.
  - MMP studies are complete.
  - MW distributions for each oil sample have been determined.
  - Swelling and solubility testing will be initiated and completed during the next quarter.
  - Additional laboratory testing of rock samples will be performed to determine relative permeability using CO_2–rich gas blends.
- **Subtask 4.2 – Data Management and Machine Learning (ML) Studies**
  - Data for each field have been collected.
  - Development of ML algorithms will be initiated during the next quarter and applied to field cases during BP2.
- **Subtask 4.3 Modeling and Simulation**
  - The EERC is working with Denbury to refine a workflow process that can be applied to each business case scenario.
  - Bell Creek modeling is being used as the template that will be applied to each of the business case fields.
  - Wireline logs have been collected, and modeling for the Cedar Hills Field has been conducted.



BP2 ACTIVITIES

Field Validation and Monitoring

- Blended gas injection
- Well production
- Fluid sampling (gas and oil)
- Monitoring (rate, pressure, temperature)

Pilot Test Evaluation

- Improvement in oil recovery factor
- MW shifting

Business Case for Other Potential Target Fields

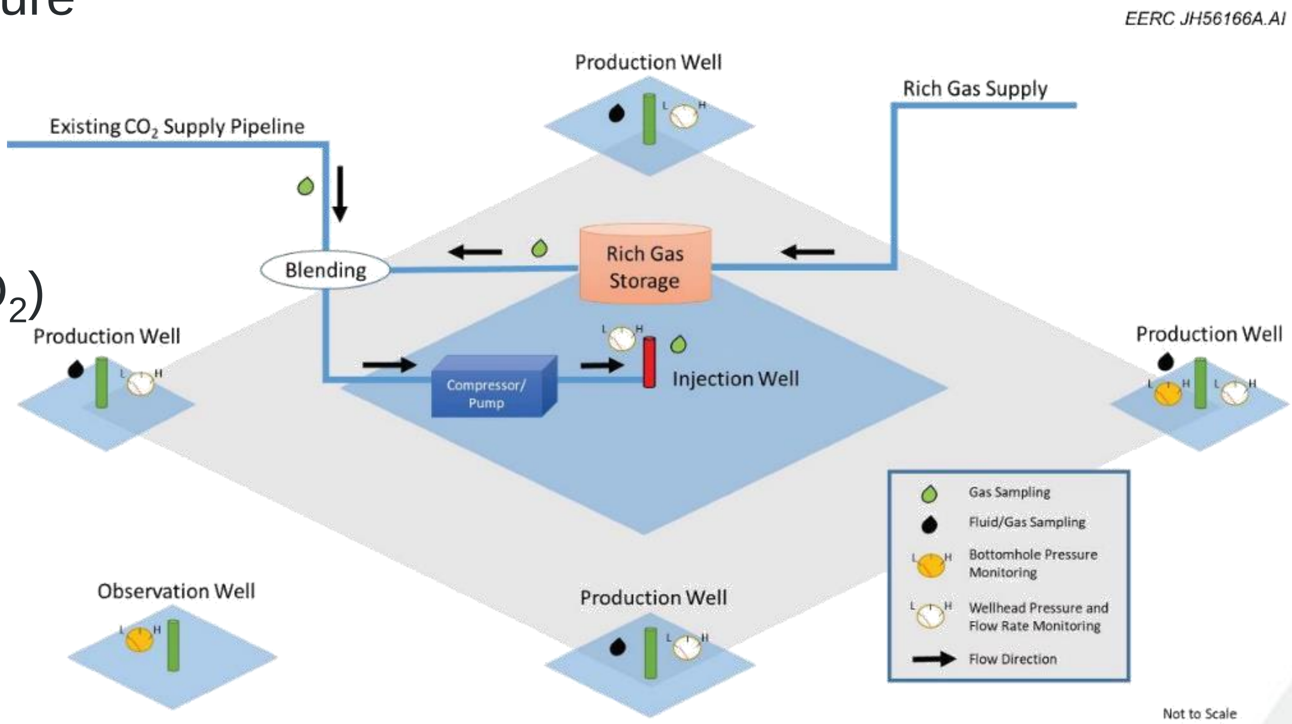
- Data management
- ML
- Modeling and simulation

PLANS FOR FIELD INJECTION AND MONITORING

- Field preparation
  - Build the rich gas field pilot test infrastructure (e.g., rich gas storage, compression, monitoring, sampling, etc.)

- Field validation and monitoring
  - Continuous blended gas (rich gas and CO_2) injection with WAG cycle or blended gas followed by chasing CO_2 gas
  - Production monitoring to evaluate the improvement on oil recovery
  - Periodic sample collection to monitor MW shifting

- Field validation decommissioning



PLANS FOR FUTURE TESTING/DEVELOPMENT/ COMMERCIALIZATION

- The pilot test during BP2 will provide a unique U.S. data set on rich gas EOR, paving the way for larger-scale tests and deployment.
- Positive pilot test results would support the development of infrastructure and a market for stranded rich gas.
- Results would be applicable to develop business cases for other potential target fields.
- Because of the ability to leverage existing oilfield infrastructure, commercial implementation of rich gas EOR could occur quickly.

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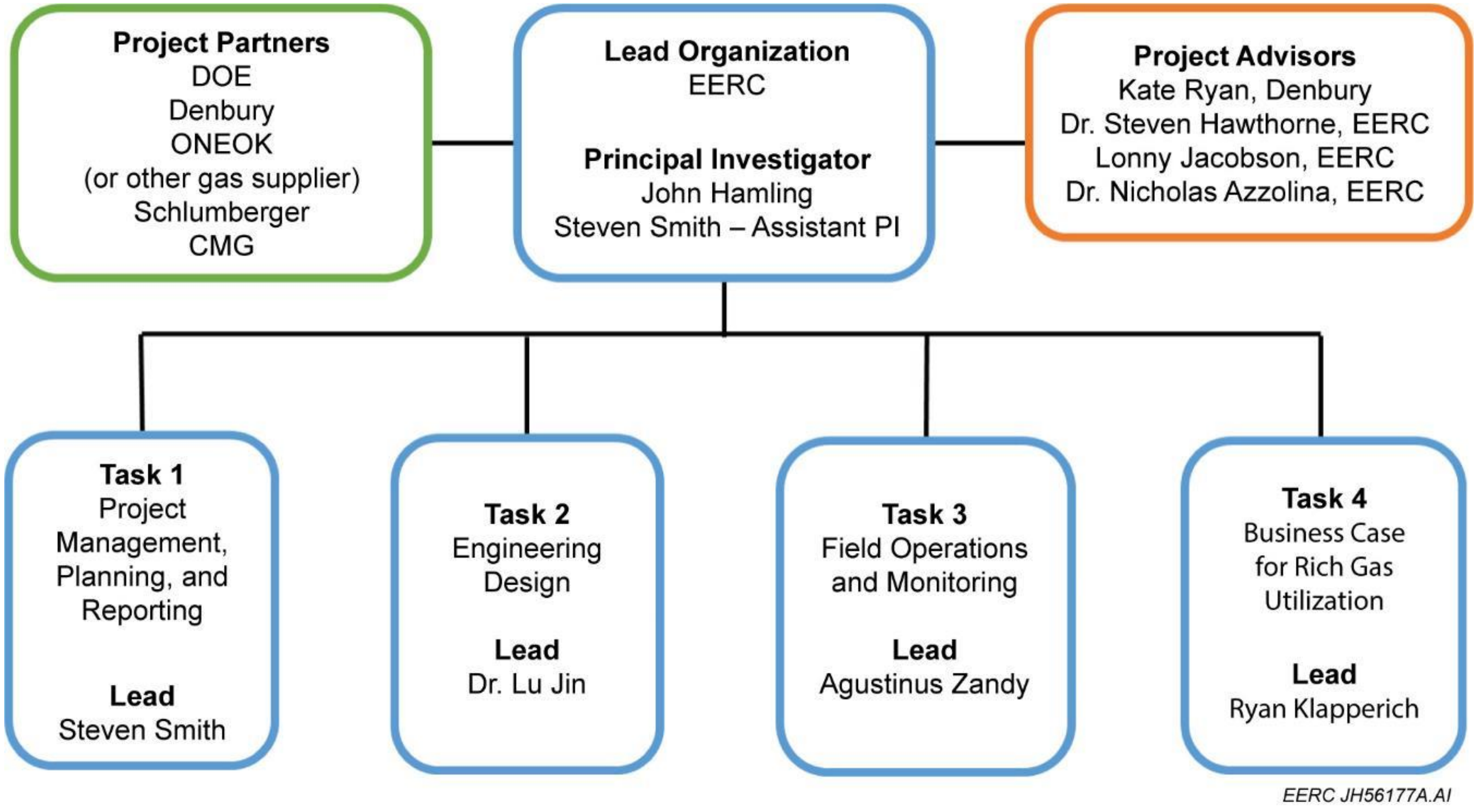
ORGANIZATION CHART



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