Stacked Greenfield and Brownfield ROZ Fairways in the Illinois Basin Geo-Laboratory: Co-optimization of EOR and Associated CO_2 Storage

DOE Project Number DE-FE0031700

Nathan Webb - PI

Nathan Grigsby, Fang Yang, Scott Frailey

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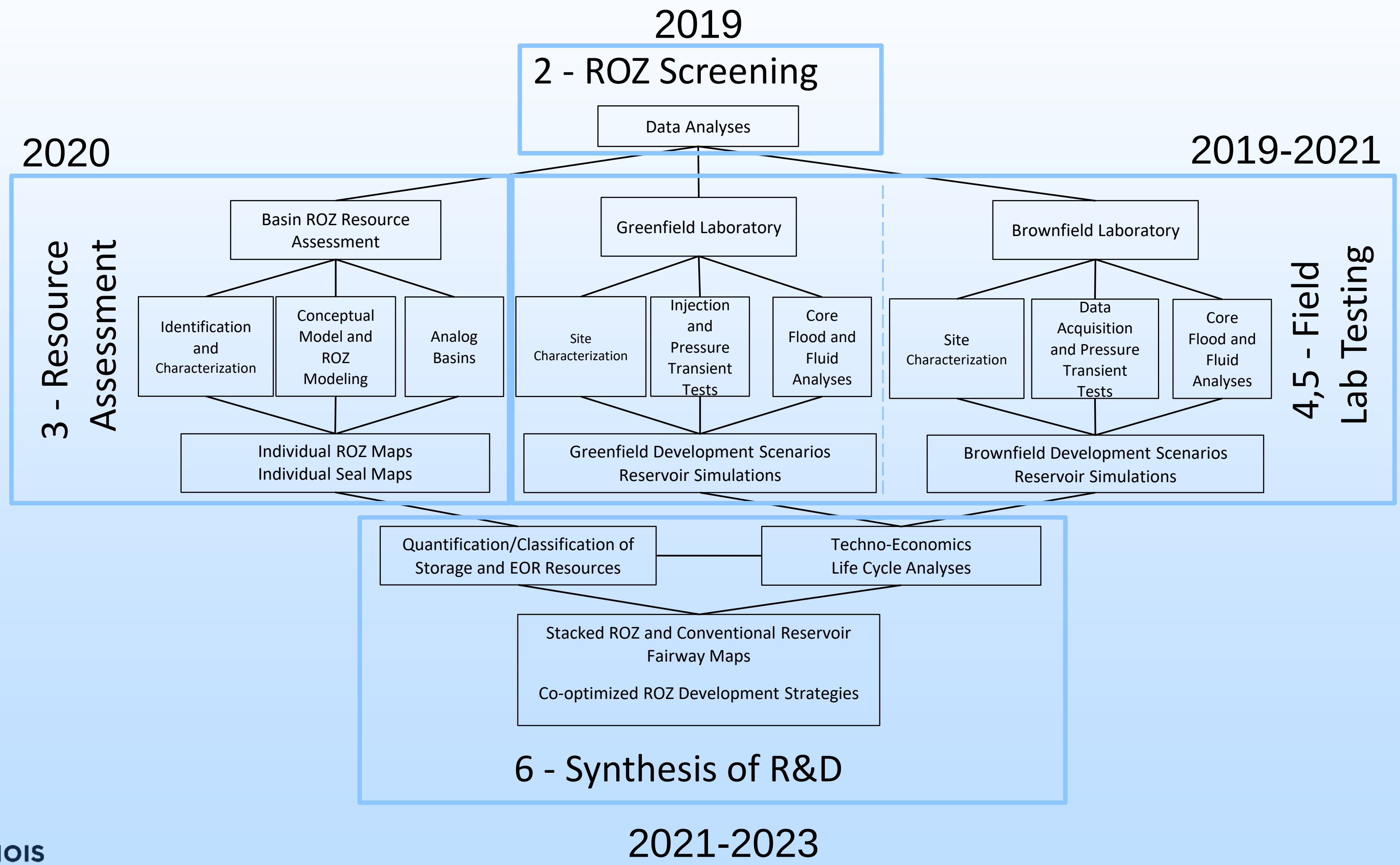
Program Overview

- Funding: $4,373,828
  - DOE Share: $3,455,947
  - Cost Share: $ 917,881
- Project Performance Dates: 2/1/19 to 1/31/23
- Project Participants:
  - University of Illinois – Illinois State Geological Survey (Prime)
  - Podolsky Oil Co.
  - Projeo Corp.
  - Indiana Geological and Water Survey

Project Tasks



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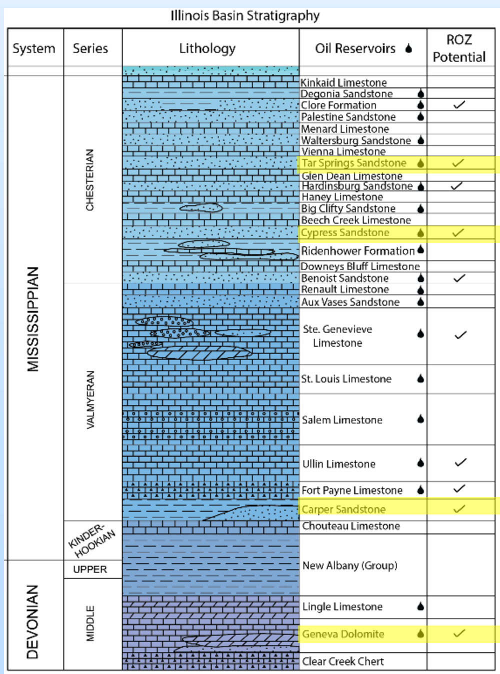
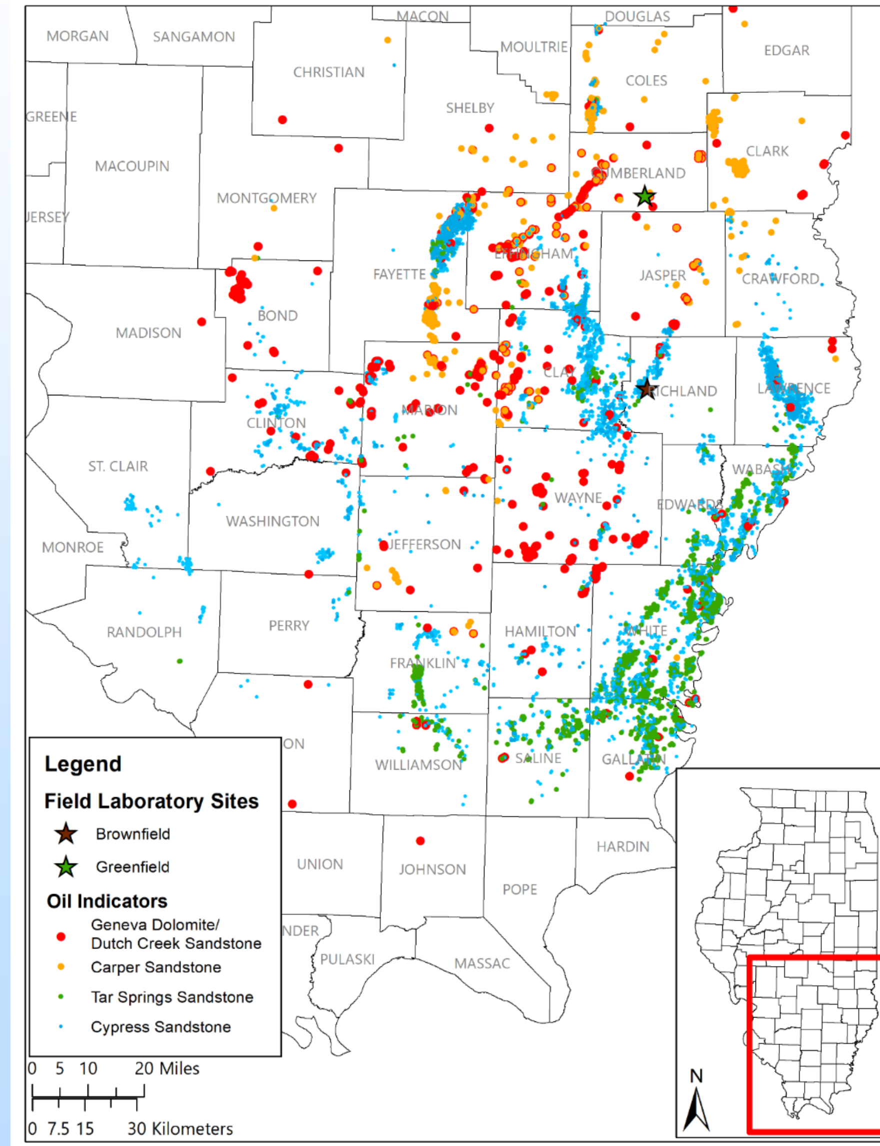
ROZ Screening

- Selected four formations for resource assessment based on:
  - Geologic properties (porosity, permeability, fairway potential)
  - ROZ indicators (oil shows, core with S_o>0, DSTs with sulfur water – e.g. Trentham and Melzer 2013)
  - Data availability (well logs, core)





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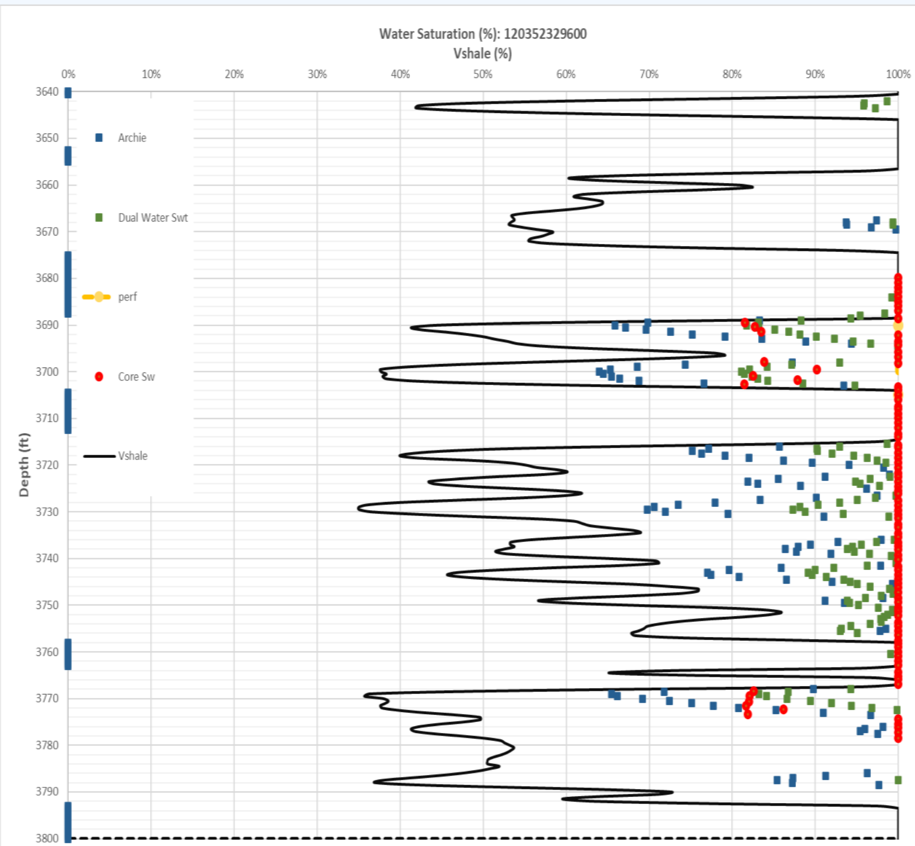
Resource Assessment

Characterizing ROZs in selected formations

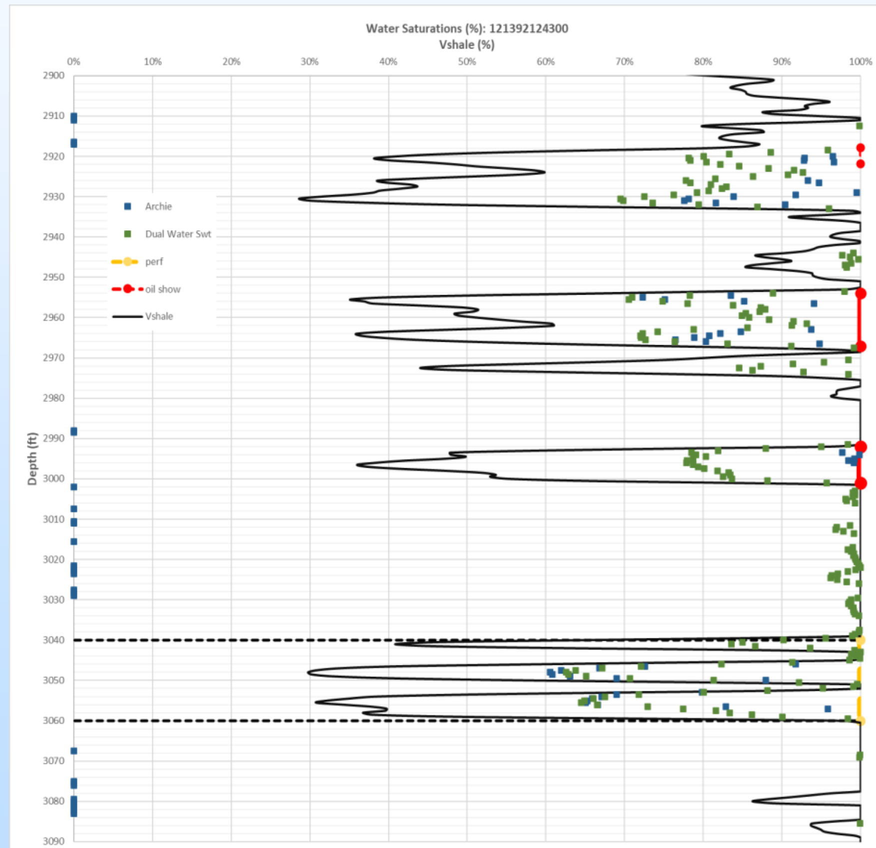
- Generating regional maps of reservoir rocks and seals
- Identifying ROZs based on historical data
- Characterization using well log analysis
  - Constrain parameters by formation for log analysis
    - Input: R_w, porosity, *m*, clay properties
    - Output: POWC, OWC, S_{or}

Resource Assessment

- Greenfield Example: Holsapple 2B
- Oil saturation observed in core
- Archie saturations never exceed 20% So
- Perforated 3690-3705, not productive

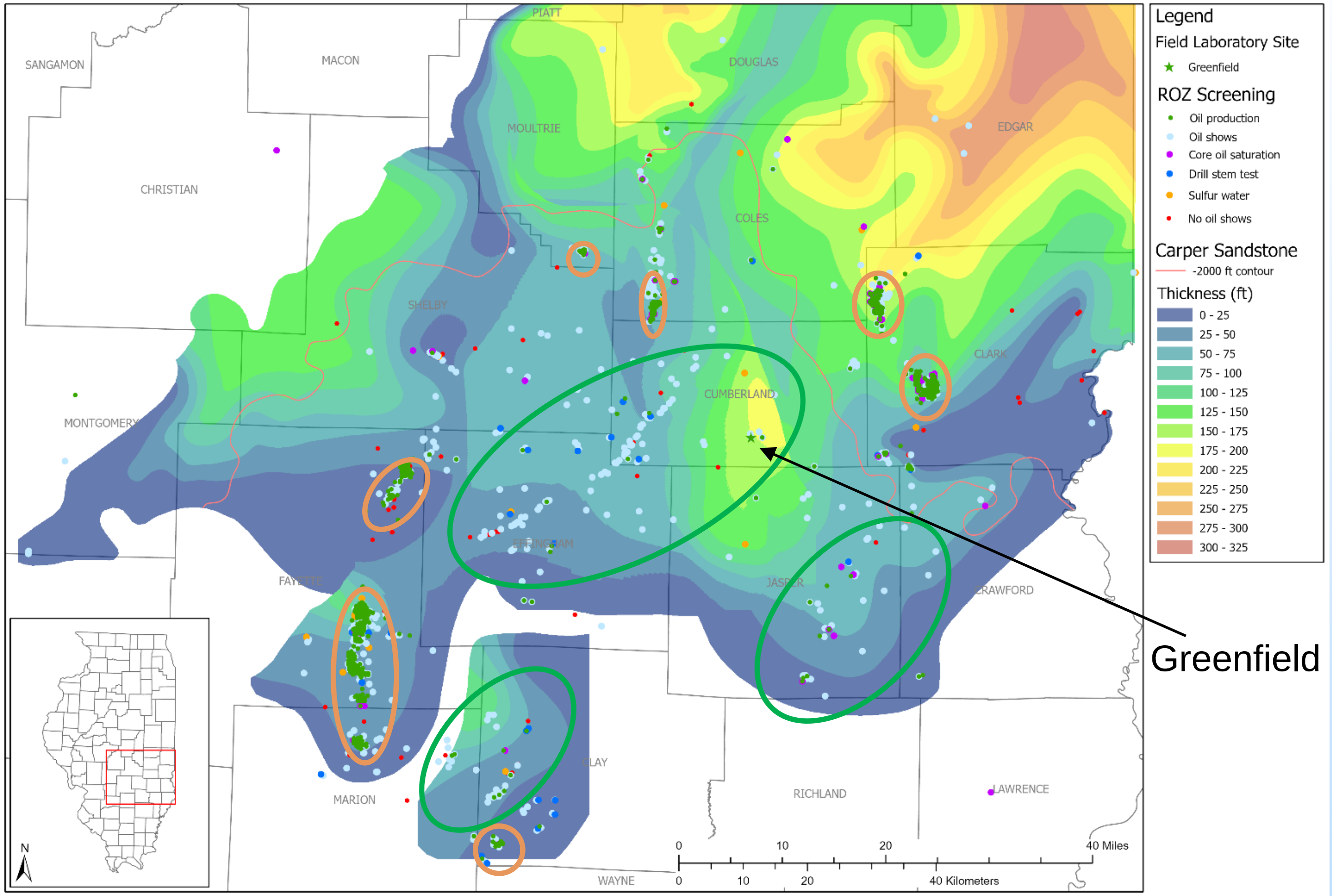


- Brownfield Example: Swits 1
- Oil shows in upper sandstone beds; tested but are not productive
- Archie saturations 35-40% So in lower bed, <30% in other beds
- Perforated 3040-3060 was productive



Resource Assessment

Carper Sandstone Example



- Next: Define prospect boundaries and Extrapolate OWC and S_{or} and to estimate OOIPs

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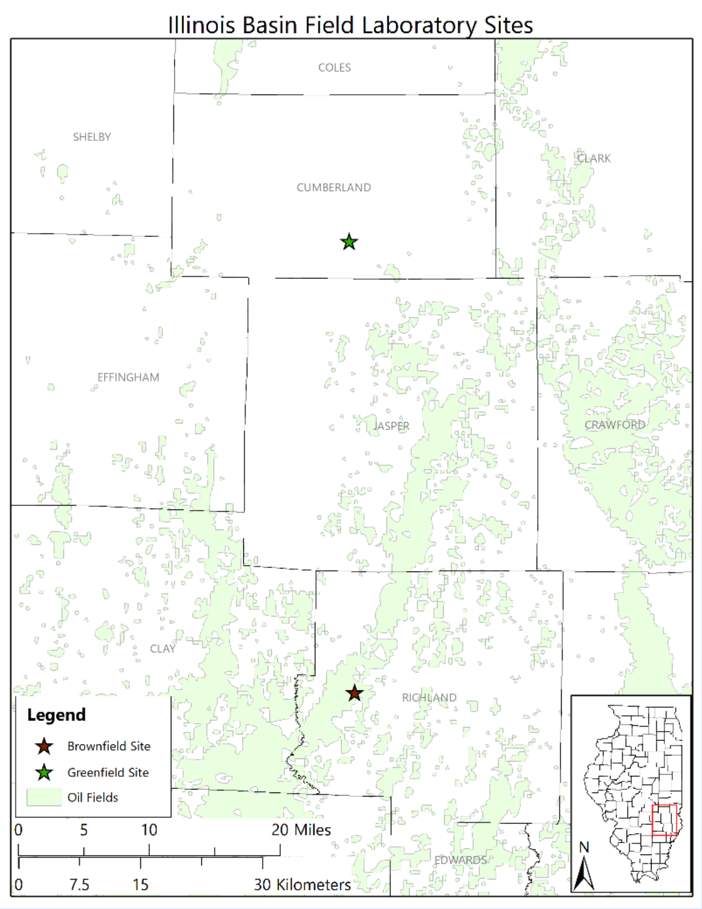
Field Laboratory Tests

Greenfield Test ✓

Existing well with validated greenfield ROZ

- Completed pressure transient tests (9/20)
- Completed CO_2 injection test (huff n' puff) to acquire oil rate change (12/20)
  - Characterize ROZ
  - Demonstrate efficacy of CO_2-EOR in ROZ
- Continuing post-CO_2 production
- Field work concluding fall 2021



Brownfield Test ✓

New well in previously characterized brownfield ROZ

- Drilled new well for reservoir characterization
  - Collected core and logs to validate Cypress ROZ
    - Correlating with previous field laboratory RST logging
    - Investigating geologic controls on residual oil saturation
    - Refining geologic interpretation
  - Sampled reservoir fluids
  - Performed drill stem test
- Field work completed fall 2019

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Greenfield Test: Challenges

Well: Drilled in 2016 to Carper Ss., pumped ~6 months, no measurable oil production

- Observed fluid production (~200 bbl/d) not possible (15’ perforated zone; 0.2 mD)
  - Suspect natural fracture network
- Simulations indicated:
  - 1-2 bbl/day oil rate from CO_2 test
  - Injected CO_2 likely to remain in fractures and have limited contact with oil in low permeability matrix
  - High pressure could stimulate production, but quickly depletes once injection stops
  - Fracture/matrix communication hard to quantify

Greenfield Test: Design

- Pressure transient test
  - Attempt to confirm natural fracture network and determine if it permits communication between units
- CO_2 test
  - Designed to maximize oil rate increase
    - Use equipment from previous ISGS CO_2-EOR projects
    - Inject volume of CO_2 that the budget allows (1,000 tons) at pump capacity (up to 60 tons/day)
  - Use findings to calibrate reservoir simulations to determine parameters that most influence oil rate
    - Injection rate, volume, more injectors would yield more oil

Greenfield Test: Field Activities

- Pressure Transient Tests (8/19/20 – 10/6/20)
- Baseline Production (10/16/20 - 11/10/20)
  - Produced 5,000 bbl water; no oil
- CO_2 Injection (11/13/20-12/13/20)
  - Injected 1,000 tons of CO_2
- CO_2 Gas Production (12/22/20 - 2/12/21)
  - Produced ~150 tons
  - Restored reservoir fluids into well

Well Fluid Production

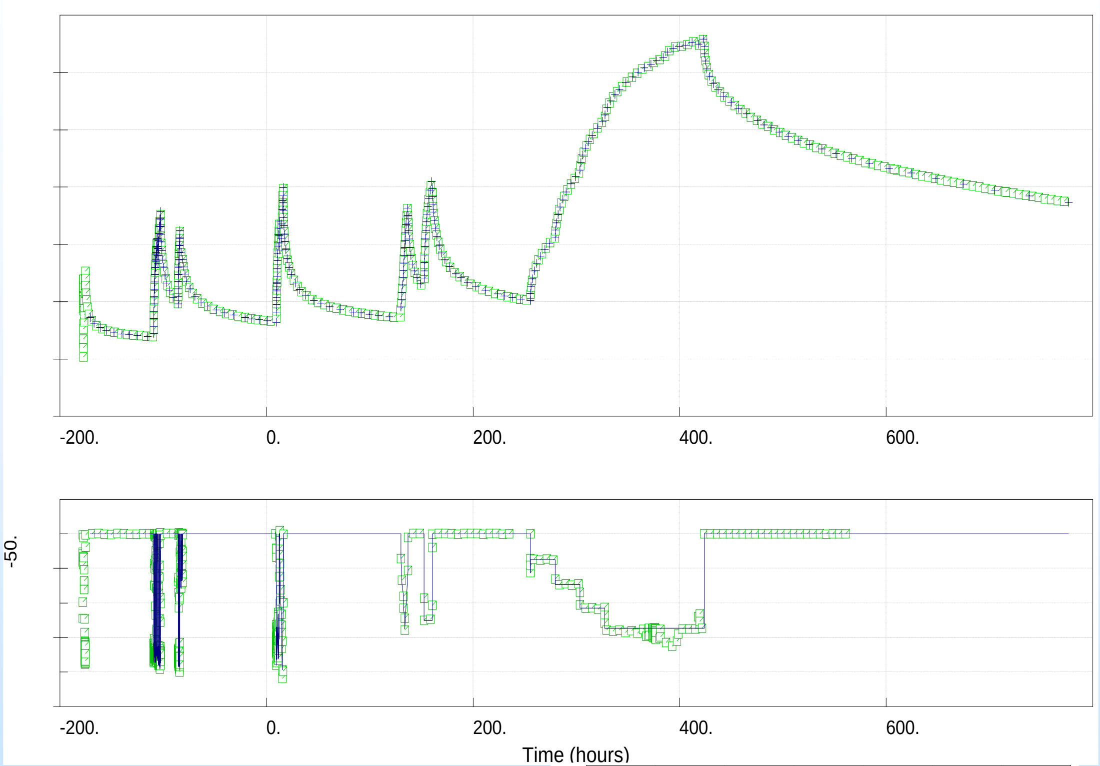
- Flowing (3/2/21 - 4/15/21)
  - 2,000 bbl water, <5 bbl oil
  - 240 tons of CO_2
- Pumping (4/21/21 - 5/18/21; 6/10/21 - present)
  - ~11,000 bbl water, ~35 bbl oil
  - 320 tons CO_2

Greenfield Test: Field Activities

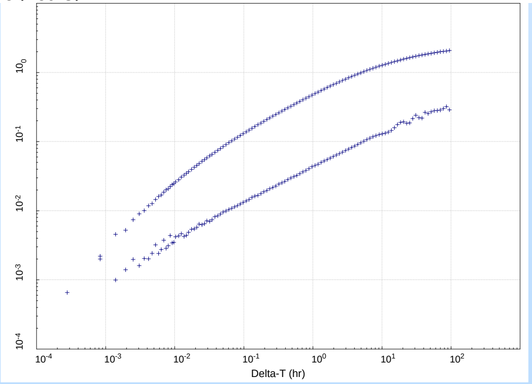
- Images depicting the 3 major stages of the project
  - Left – Pump operation during baseline production
  - Center – CO_2 tank, CO_2 injection pump skid, and line heater during CO_2 injection
  - Right – Post-CO_2 production with instrumented wellhead and gas/liquid separator with gas prover. Dynamometer test in progress to evaluate pump efficiency.

Greenfield Test: Results

- Pressure Transient Tests
  - Step rate tests
  - Pressure falloff tests
  - Designed for 20 mD
- Results
  - Expected 1,000s psi response; found 10s psi response
  - Very slow pressure falloff
  - Hydraulic fracture dominated

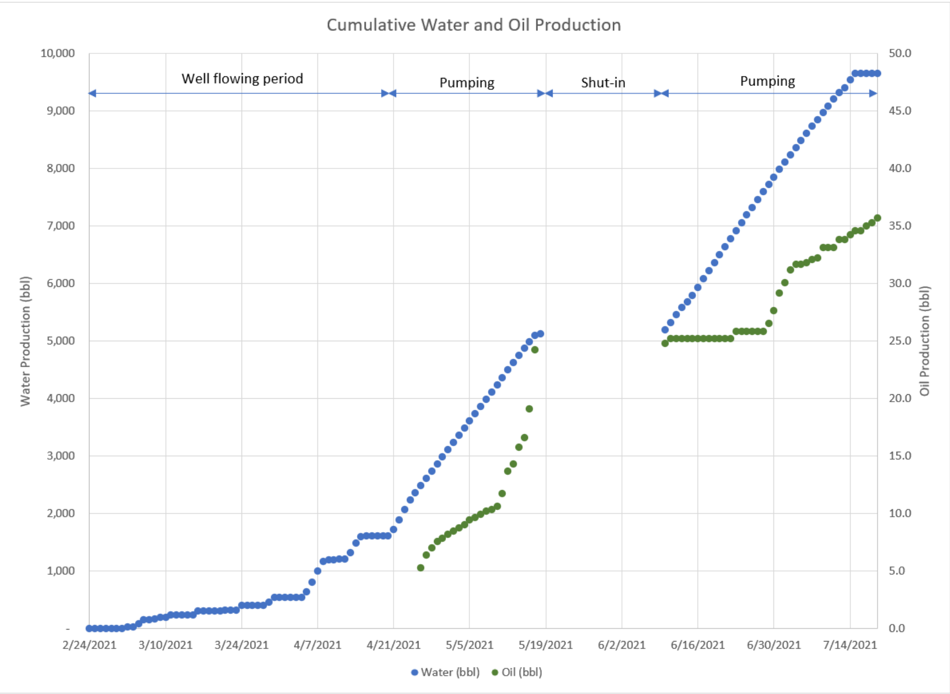


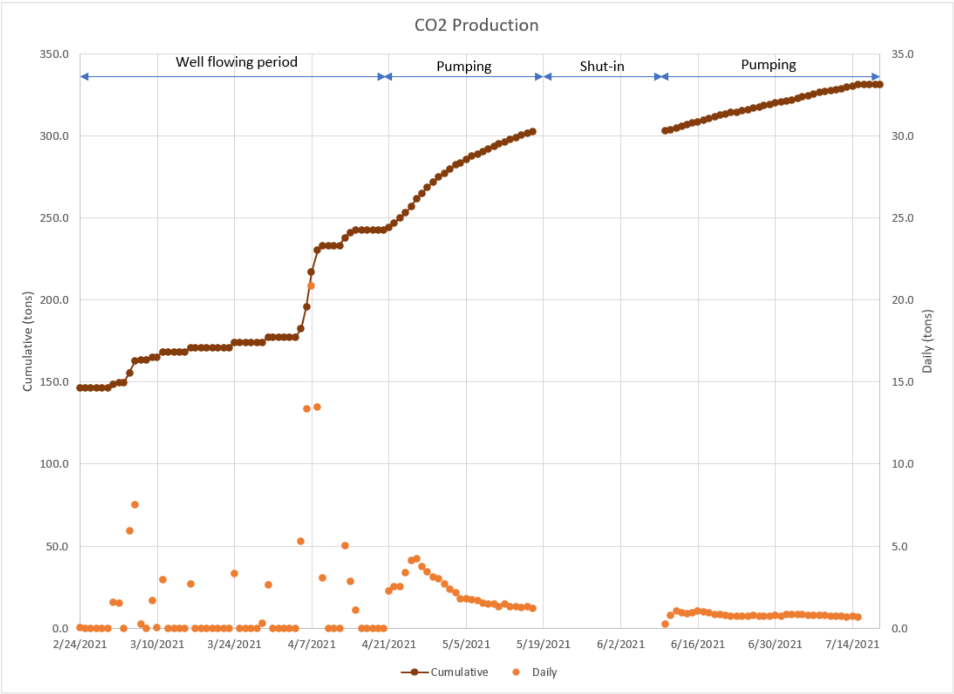
After discussing with operator, we learned of earlier water rates > 200 bbl/d



Greenfield Test: Results

- Measurable oil production with continuous pumping
  - Oil rate variations related to operational issues (flow rate, +/-chemical demulsifier)





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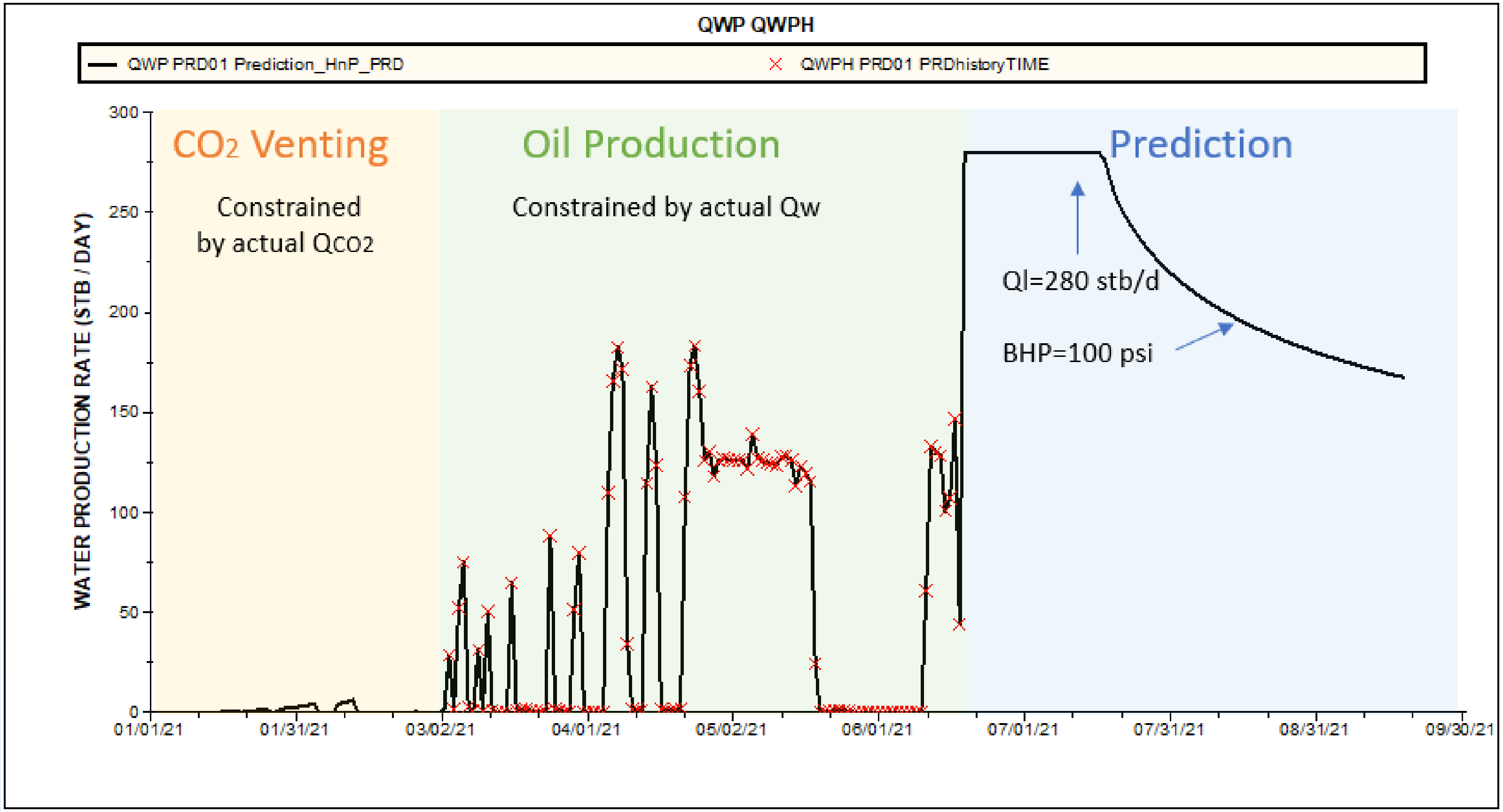
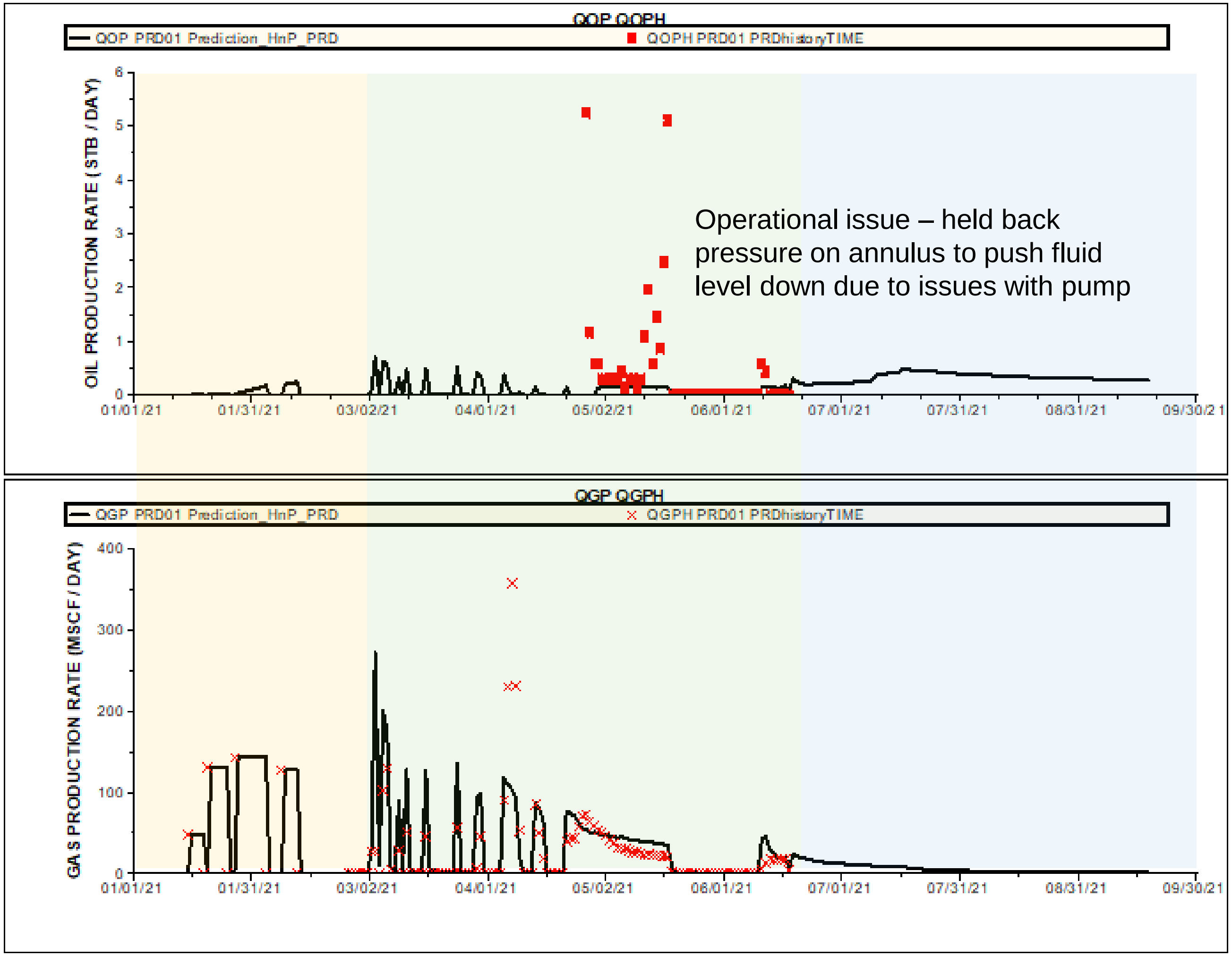
Greenfield Test: Calibrating Sims

- Purpose: Match historical fluid production (incorporating operational constraints) to predict future oil rate



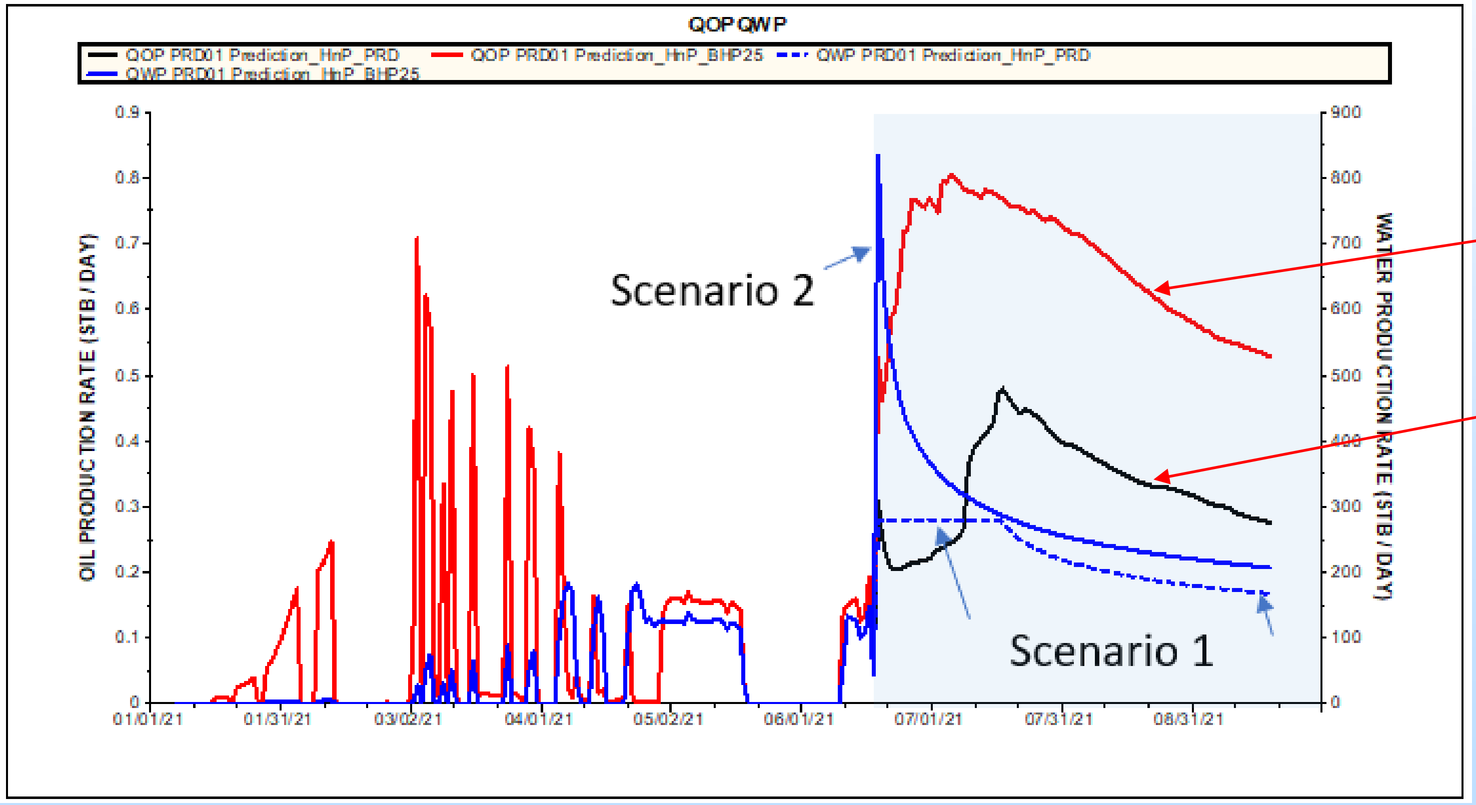
Greenfield Test: Calibrating Sims

- Simulated (black) vs. actual (red) oil and gas production rates



Greenfield Test: Calibrating Sims

- Prediction: Improve oil production by pumping the well off
  - Scenario 1: produce at 280 stb/d, then constrain BHP=100 psi
  - Scenario 2: quickly pump well off, then constrain BHP=25 psi



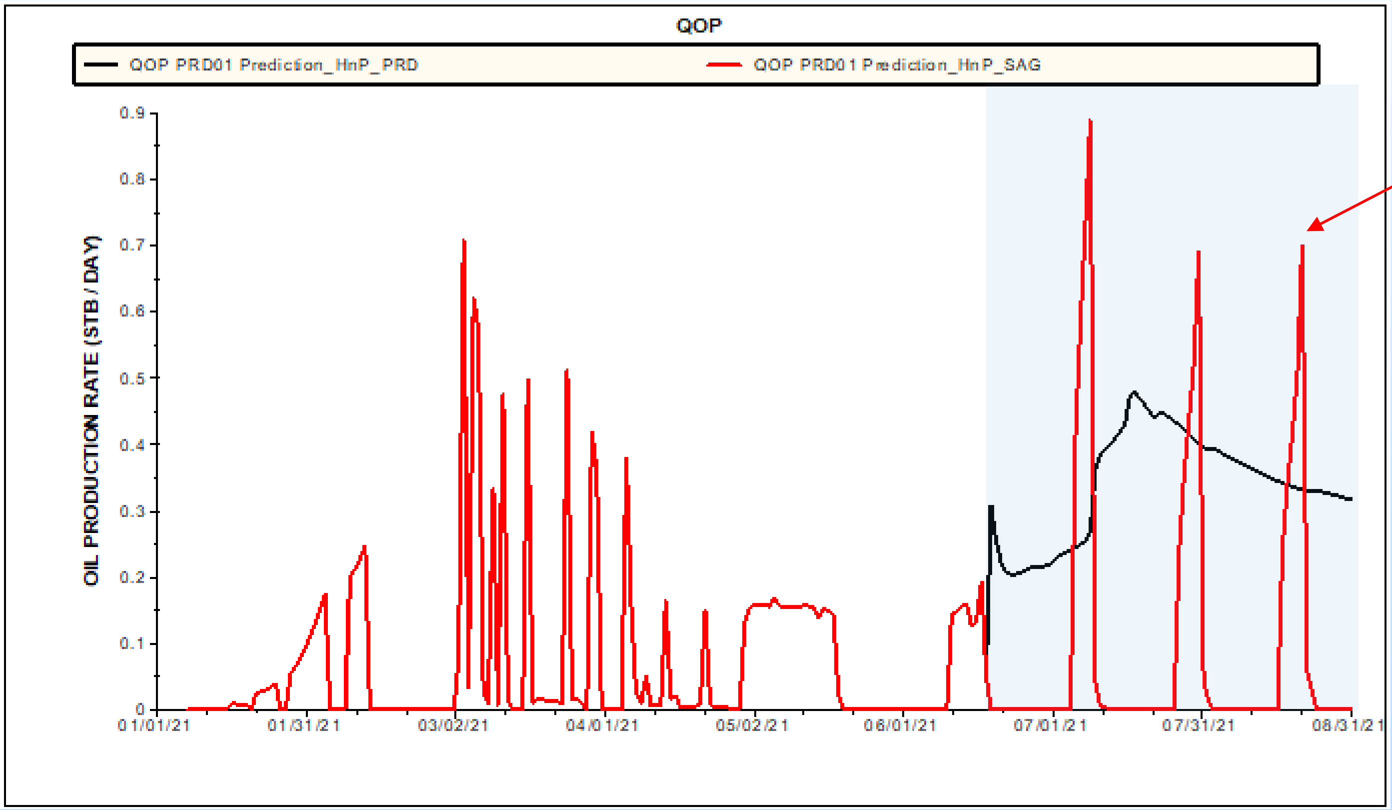
Scenario 2

~2x oil rate vs.

Scenario 1

Greenfield Test: Calibrating Sims

- Improve oil production-Recycle CO_2 with SAG
  - Baseline: produce at 280 stb/d total fluid limit
  - SAG: inject CO_2@ 40t/d for 7 days, soak 7 days, then produce 7 days at 280 stb/d total fluid limit
  - Implication: SAG not reasonable for single well, but could be effective as part of greenfield ROZ development



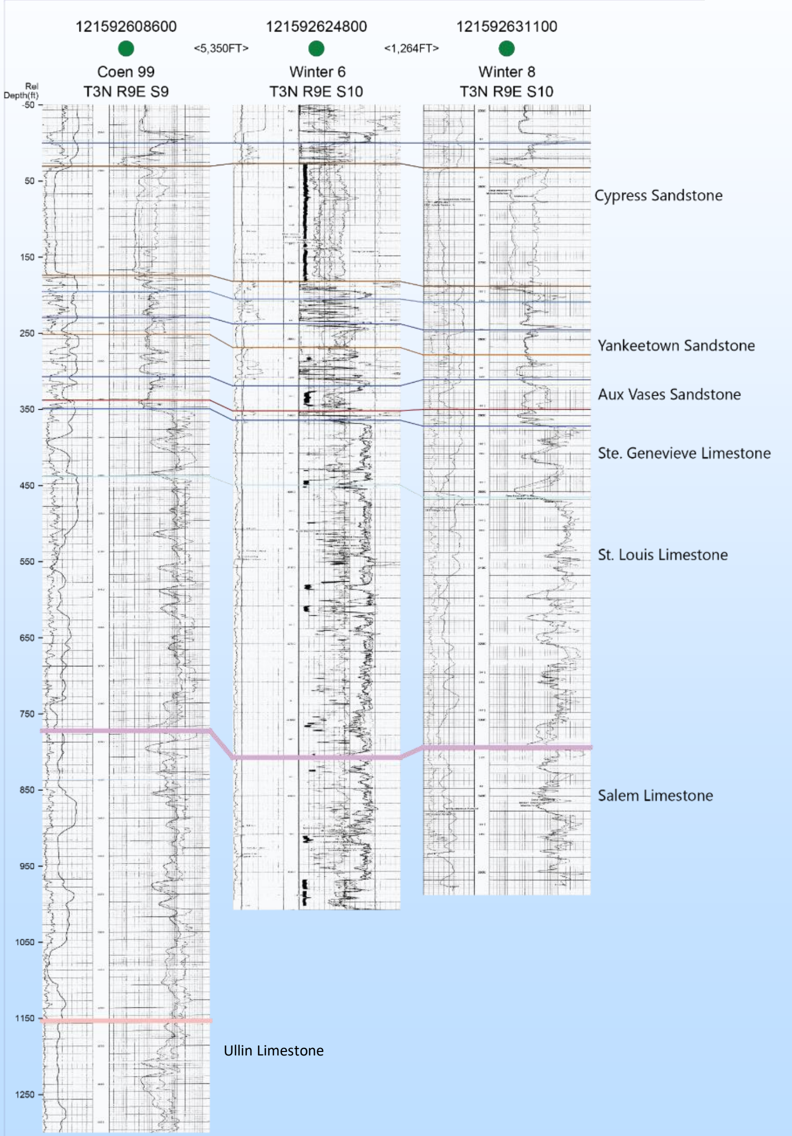
SAG greatly increases oil rates

Greenfield Test: Conclusions

- Demonstrated CO_2-EOR from greenfield ROZ
  - Limited oil, but production is ongoing
    - Operational factors have a big impact
  - Using field data to calibrate reservoir simulations
    - Additional oil production predicted as well is pumped off
    - Simulations indicate SAG may have efficacy at field-scale development
- Challenges
  - Geologically complex reservoir
  - Equipment limitations
    - Production rate limit reduced oil production
    - Oil/brine emulsion difficult to break without chemical
    - Some CO_2 and oil bypasses meters
    - Disagreement between meters

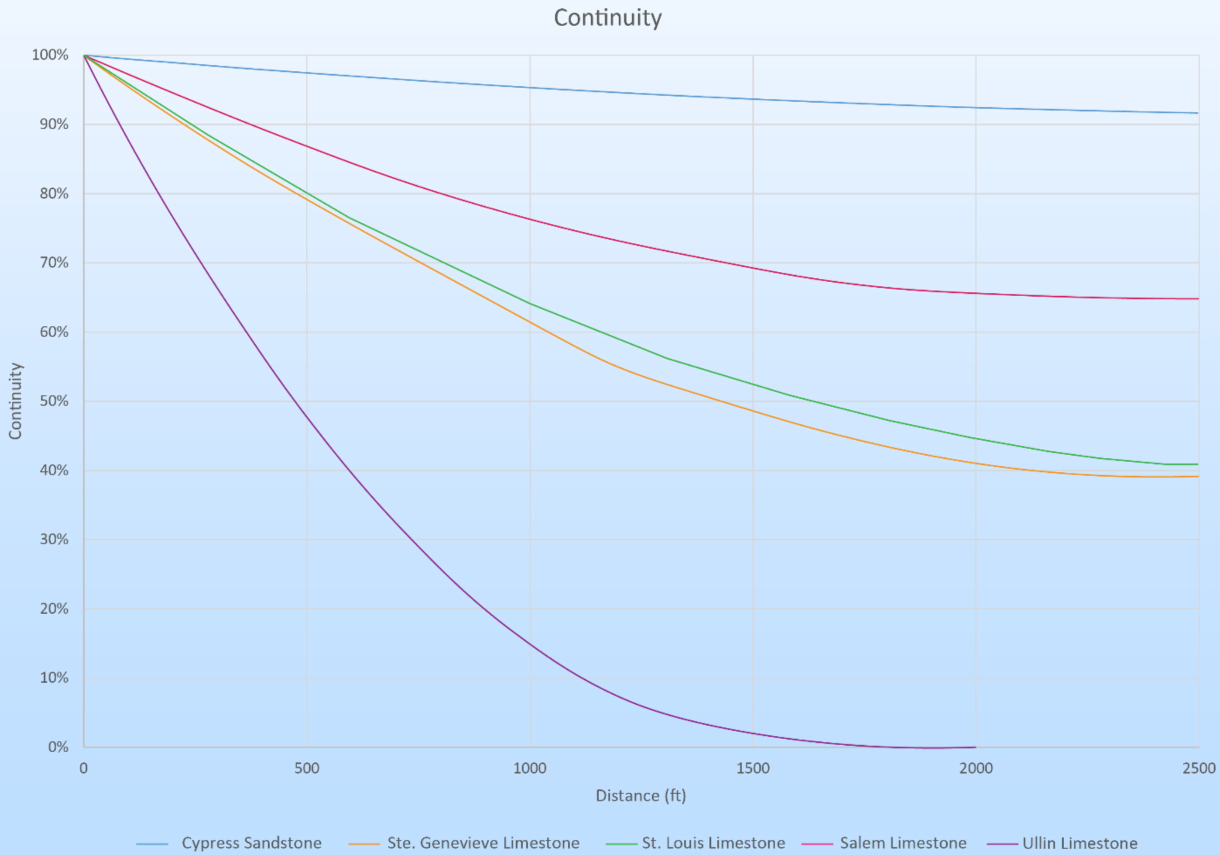
Brownfield Lab: Stacked Characterization

- Correlated and mapped stacked ROZs and conventional reservoirs across Noble Field
  - Six producing reservoirs; additional formations with oil indicators
  - Leveraging data from new well for determining oil saturations



Brownfield Lab: Stacked Characterization

- Characterizing formations separately to identify development scenarios for EOR and storage prior to simulation and co-optimization
- Evaluating reservoir continuity (e.g. Stiles 1976)
  - Helps in determining efficacy of different pattern configurations



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Brownfield Lab: Stacked Characterization

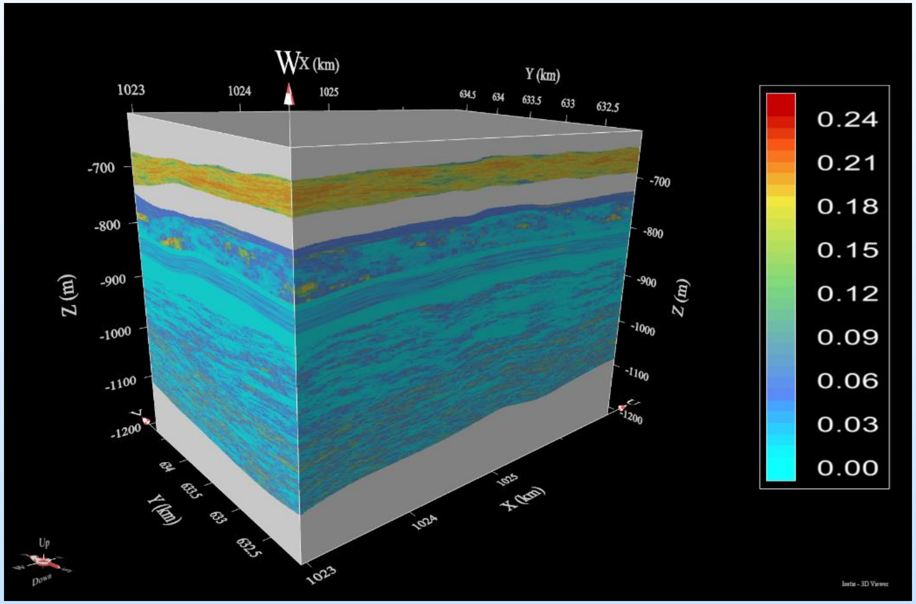
Predicting (pre-simulation) effect of heterogeneity, continuity, and pattern size on CO_2 EOR and storage using dimensionless performance curves

Formation	Heterogeneity	EOR%		Storage%	
		40-acre	80-acre	40-acre	80-acre
Cypress	Low	13.0%	14.5%	48.5%	48.5%
Aux Vases	Moderate	11.1%	12.0%	42.6%	41.3%
Ste. Genevieve	Moderate	11.1%	12.0%	42.6%	41.3%
St. Louis	High	9.2%	9.6%	36.7%	34.1%
Salem	Moderate	11.1%	12.0%	42.6%	41.3%
Ullin	Moderate – Low*	12.1%	13.2%	45.6%	44.9%

- CO_2 EOR and storage decrease with increasing heterogeneity
- CO_2 EOR increases with larger pattern size
- CO_2 storage efficiency decreases with increasing pattern size for moderate and high heterogeneity formations

Brownfield Lab: Stacked Model

- Developed geocellular model tailored to each formation
  - Different lithology, geometry, data coverage
  - 2,000 ft gross thickness results in large cell count (~7.5M)
- Uncertainty in oil saturation
  - Logs capture depleted reservoir(s)
  - Comingled production
  - Connectivity
- Next: begin reservoir simulations of stacked ROZ/reservoir EOR and storage



Synergy opportunities

- Methodologies for finding and characterizing ROZs in mature basins developed as part of this study are applicable in other basins
  - We look forward to comparing the results with findings from the Williston and Powder River Basins
- Siliciclastic ROZs in other basins are expected to have similar characteristics to Illinois Basin ROZs
  - Lessons learned from CO_2 flooding in siliciclastics in the Powder River Basin would be applicable to our ROZs

Project summary

Key Findings

- Carper Sandstone greenfield ROZ oil can be mobilized with CO_2
  - Continued production will reveal the magnitude of success for EOR and storage

Lessons Learned

- Field laboratory research requires extra attention to detail to:
  - Reconcile schedule (project vs. operator vs. weather), meet **all** stated objectives, stay on budget
  - Ensuring safe operations (managing pressure) when working with CO_2 in the field can be time consuming and expensive

Next Steps

- Leverage field data to calibrate simulations as we pivot to co-optimization, LCA, and classification of CO_2-EOR and storage resources in stacked reservoirs

Acknowledgments

- Research herein supported by US Department of Energy contract number DE-FE0031700, FPM Andrea McNemar
- Through a university grant program, IHS Petra, Geovariences Isatis, and Landmark Software were used for the geologic, geocellular, and reservoir modeling, respectively
- For project information, including reports and presentations, please visit:

  http://www.isgs.illinois.edu/research/ERD/NCO2EOR

Appendix: Program Overview

Objectives

DOE Program

- Develop specific subsurface engineering approaches leveraging CO_2 injection field tests and applied research and development, that address research needs critical for advancing CCS to commercial scale

Stacked ROZ Fairways in ILB Geo-Laboratory

- Screen for ROZs using analysis of empirical data and basin evolution modeling
- Characterize stacked brownfield/greenfield siliciclastic ROZs at field laboratory sites
- Conduct injection tests and collect and analyze core and logs at field laboratory sites
- Employ calibrated simulation models and life-cycle analyses for identifying development strategies

Appendix: Technical Approach

Project Milestones

Milestones provide success criteria for gaging the qualitative and quantitative performance of the project and are decision points to determine if the project should proceed.

BP: Task	Milestone title	Planned completion	Actual completion	Verification method
BP 1 Task 1	Complete project management plan	03/01/2019 (year 1)	03/01/2019	PMP file
BP 1 Task 1	Project kickoff meeting	02/01/2019 (year 1)	11/06/2018	Presentation file
BP 2 Task 4	Finalize plan for data collection and testing at greenfield laboratory sites	07/31/2020 (year 2)	7/31/2020	Report in subsequent quarterly report
BP 2 Task 5	Finalize plan for data collection and testing at brownfield laboratory sites	04/30/2020 (year 2)	11/28/2019	Report in subsequent quarterly report
BP 2 Task 5	Complete testing of fluid and core samples of target CO_2 reservoir(s) from field laboratory sites	03/01/2021 (year 3)	07/2021	Report in subsequent quarterly report
BP 3 Task 6	Complete strategies for co-optimization of CO_2-EOR and storage in stacked reservoirs (w/ROZs and depleted reservoirs)	01/31/2022 (year 3)		Report in subsequent quarterly report
BP 3 Task 6	Complete fairway maps	10/31/2022 (year 4)		Report in subsequent quarterly report
BP 3 Task 1	Document project results	01/31/2023 (year 4)		Submit final report

Appendix: Technical Approach

Risk Matrix

The risk matrix is used to identify, assess, monitor and mitigate technical uncertainties and schedule, budgetary and environmental risks associated with the project

Perceived Risk	Risk Rating (Low, Med, High)			Mitigation/Response Strategy
	Prob.	Impact	Overall	
Financial Risks:				
Field laboratory test budget exceeded	Low	Med	Low	If additional cost occurs due to the delay of field personnel or equipment issues, change in duration or number of ROZs tested would be reduced
Cost/Schedule Risks:				
Delay in field activities due to severe weather condition	Low	Med	Low	A project meeting would be held among research team and field personnel to reschedule and reprioritize tasks
Technical/Scope Risks:				
Delay in acquiring data	Low	Med	Low	Assemble and digitize existing ISGS and literature data to provide preliminary estimates and update data when available
Injection test failure due to a well integrity	Low	Med	Low	Identify analogous wells within the field operated by the same company

Perceived Risk	Risk Rating (Low, Med, High)			Mitigation/Response Strategy
	Prob.	Impact	Overall	
Management Risks:				
Occasional unavailability of personnel	Med	Low	Low	If staff time is mandatory to keep on schedule, non-project staff will be available to work on project temporarily.
Loss of key personnel	Low	Med	Low	Temporarily allocate tasks among team and initiate hire
Planning and Oversight Risks:				
Well cannot be drilled in year 2 due to rig availability or weather	Low	Low	Low	Greenfield lab schedule will be moved up and switched with the brownfield schedule
EH&S Risks:				
Field laboratory sites in environmentally sensitive areas	Med	Med	Med	Use existing infrastructure and non-invasive sampling and testing techniques
External Factor Risks:				
An operator becomes unavailable to facilitate data collection and testing in the field laboratory	Low	Med	Med	Coordinate with backup operators at other suitable field laboratory sites

Appendix: Benefit to the program

- Goal: The Storage Infrastructure Technology Area research effort is carrying out regional characterization and small- and large-scale field projects to demonstrate that different storage types in various formation classes, distributed over different geographic regions, both onshore and offshore, have the capability to permanently store CO_2 and provide the basis for commercial-scale CO_2 projects. This, working together with the two other research areas, address significant technical challenges in order to meet program goals that support the scale-up and widespread deployment of CCS.
- Benefits Statement: This research will potentially demonstrate CO_2 -EOR and associated storage as an economically feasible option for small-middle size operators in the Illinois Basin and drive demand for CO_2 and investment in infrastructure.

Appendix: Project Overview

Goals

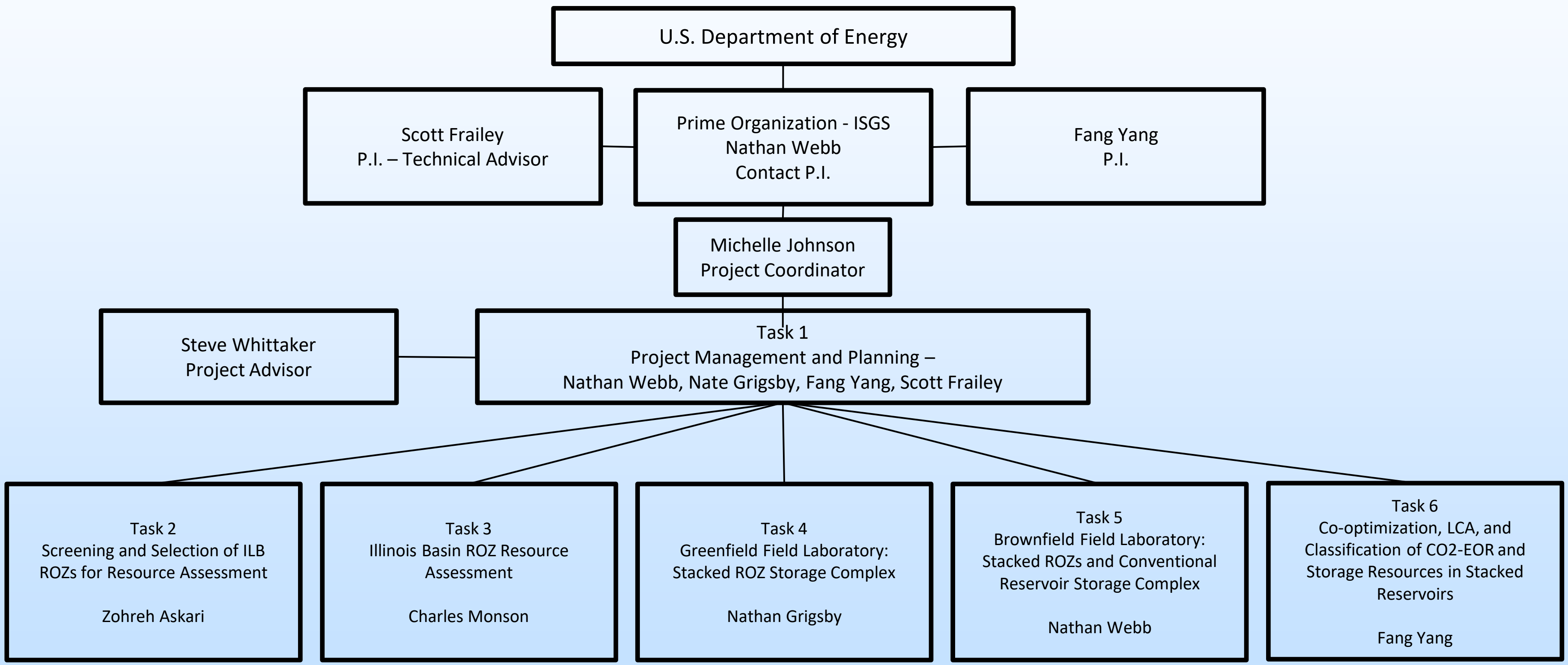
DOE Program

- ROZs:- formation, characterization, and associated storage in conjunction with EOR
- Co-optimizing CO_2-EOR with associated storage in storage complexes that have stacked reservoirs

Stacked ROZ Fairways in ILB Geo-Laboratory

- Identify and characterize primarily siliciclastic ROZs and quantify the CO_2-EOR and associated storage resource using data collected and test results from greenfield and brownfield field laboratory sites
- Design economic development strategies to co-optimize CO_2-EOR and associated storage in stacked storage complexes using reservoir simulations calibrated to field laboratory test results

Appendix: Organization chart



Appendix: Gantt chart