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

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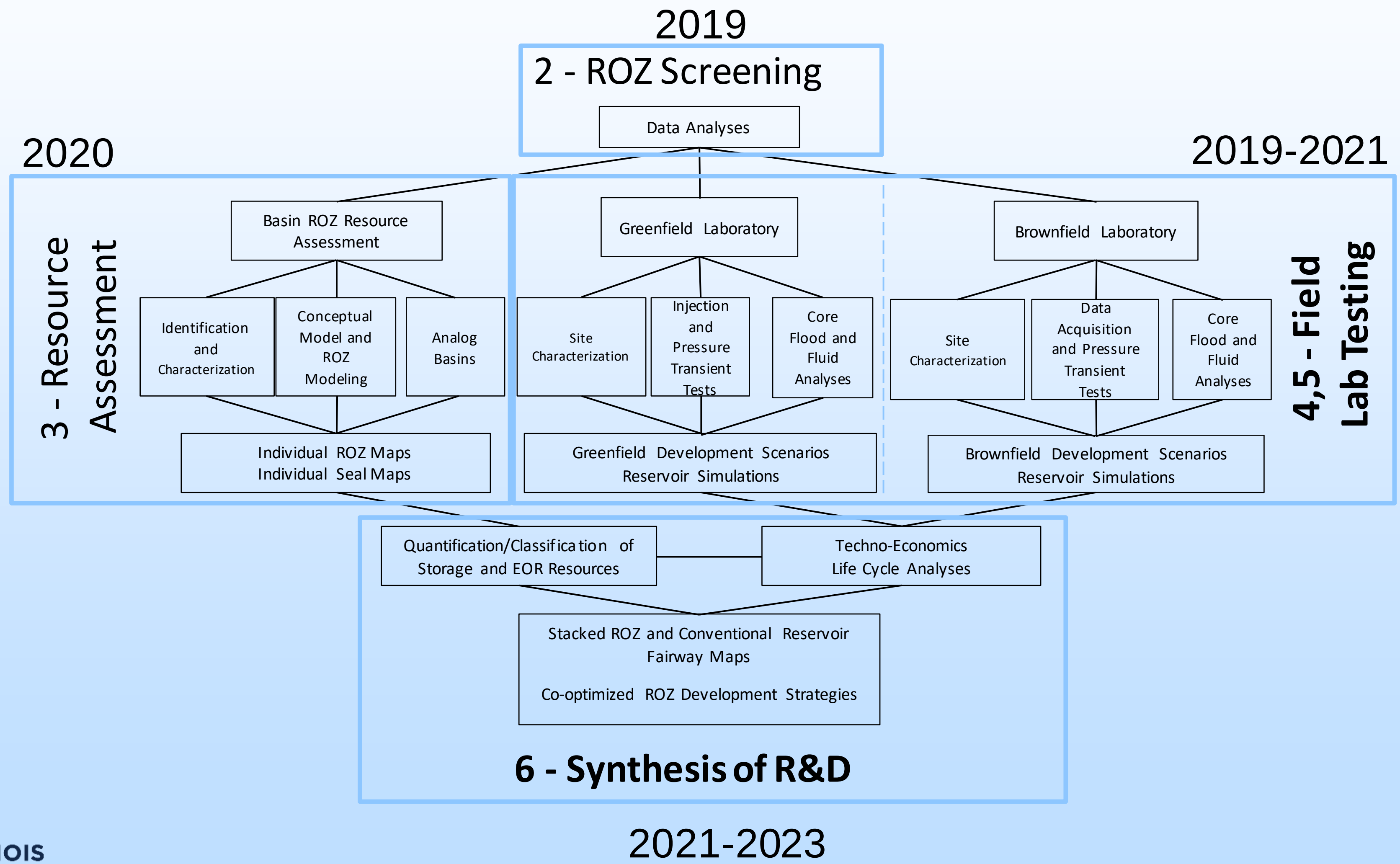
Program Overview

- 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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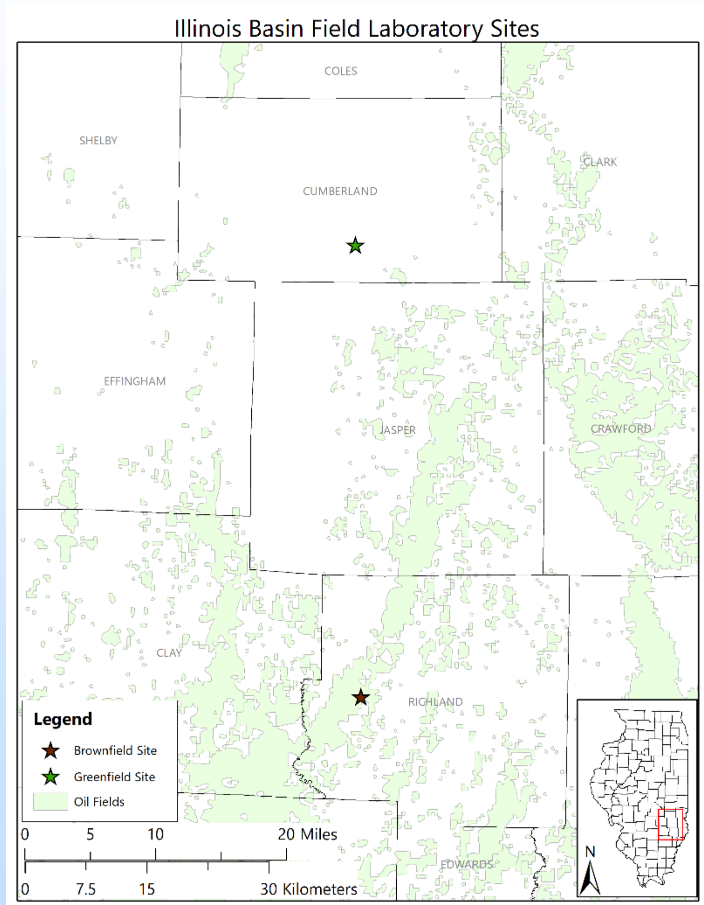
Field Laboratory Tests

Greenfield Test ✓

Existing well with validated greenfield ROZ

- Conducted Huff n' Puff to characterize efficacy of CO_2-EOR in siliciclastic ROZ
  - Completed pressure transient tests (9/20)
  - Completed 1,000-ton CO_2 injection test (huff n' puff) to acquire oil rate change (12/20)
  - Completed post-CO_2 production (9/21)
- Concluded field work and reclaimed site (2/22)



Brownfield Test ✓

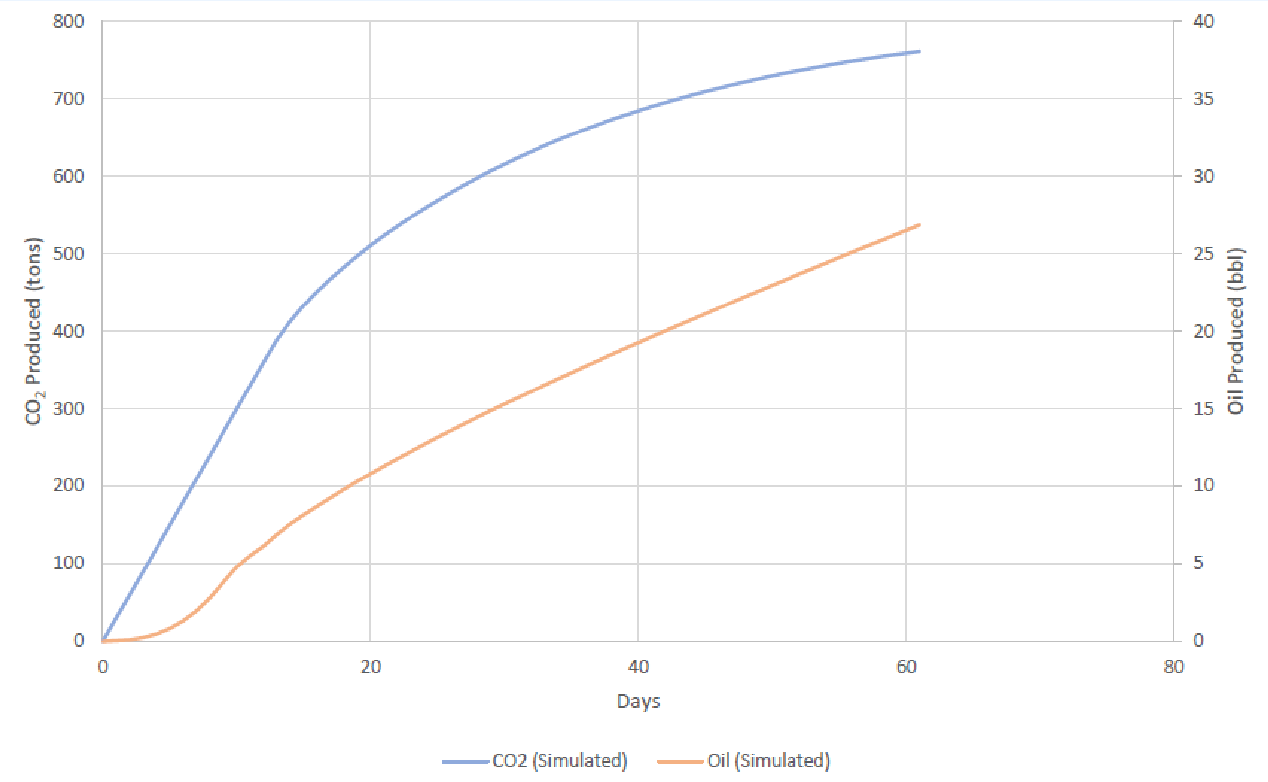
New well in previously characterized brownfield ROZ

- Drilled new well for reservoir characterization
  - Collected core and logs to validate Cypress ROZ
    - Correlated with previous field laboratory RST logging
    - Investigated geologic controls on residual oil saturation
    - Refined geologic interpretation
  - Sampled reservoir fluids
  - Performed drill stem test
- Concluded field work (11/19)

Greenfield Test: Pre-test Predictions

Carper Sandstone has low permeability matrix (0.2 mD), is naturally fractured, and pre-HnP water injection tests found hydraulic fracture dominated pressure response. Thus, pre-HnP simulations predicted:

- Low EOR and CO_2 storage due to low permeability matrix relative to natural fracture network
- CO_2 would stay in fractures, has no interaction with matrix; CO_2 readily produced when pumping starts
- Produced oil derived from 2% S_{OI} added to fractures to get models to run; oil in matrix not produced



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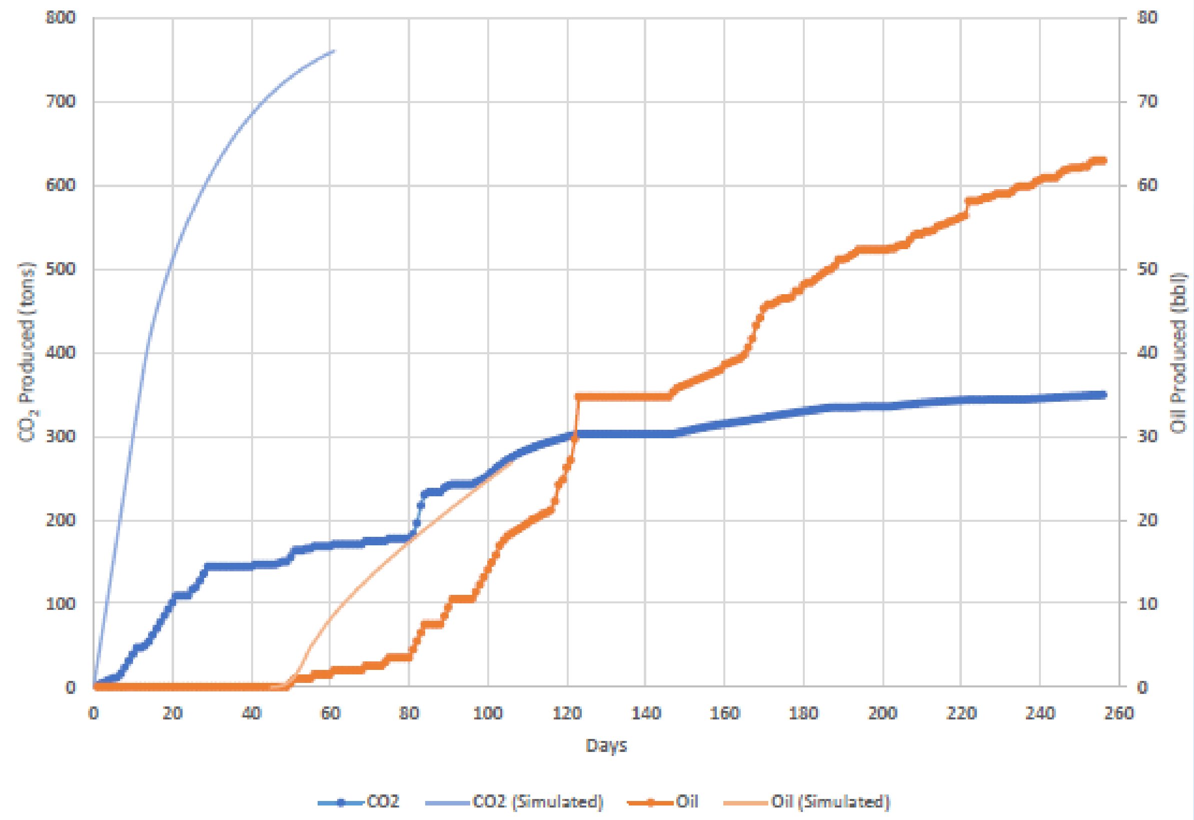
Greenfield Test: Observations

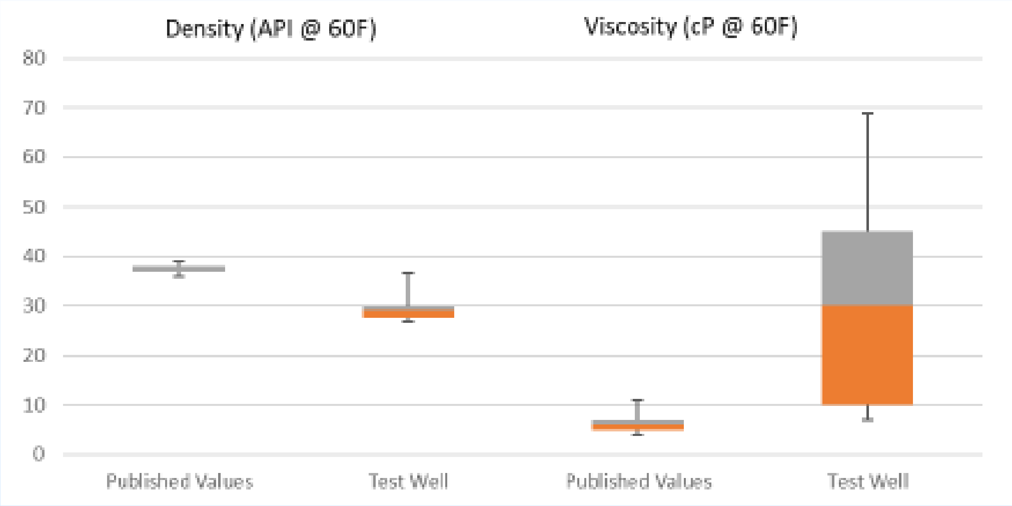
- Injected: 1,000 tons of CO_2
- Produced: 350 tons of CO_2; 65 bbls of oil; 25,000 bbl of water
- Stored: 650 tons of CO_2
- EOR and CO_2 storage outperformed simulations

Graph of oil and CO_2 production
Pre-test simulation projections are shown with simulated oil production shifted to match lag in actual oil production following a few months of CO_2 venting.



Greenfield Test: Observations

- Operational factors affected production:
  - Vented 150 tons CO_2 to pull fluids into wellbore before pumping began
  - Pressure constrained by surface equipment
  - Oil/brine produced in emulsion; required chemical demulsifier; resulted in some oil bypassing oil/water separator
  - Reduced pumping rate resulted in lower oil production
- Produced oil was denser and more viscous than expected
  - GC analysis showed that light hydrocarbons were naturally attenuated before CO_2 injection (typical of ROZs); more severely stripped after
- Core flood using 30 cP oil:
  - S_{ORW}= 60%; S_{ORCO2}= 16%
  - CO_2 could mobilize oil from tight matrix but needs 25% S_{OI} to swell to 60% for Darcy flow



Box and whisker plots of density (left) and viscosity (right) of oil collected from the test well compared to published values of Carper oils. Oil from the test well was significantly denser and more viscous than published values.

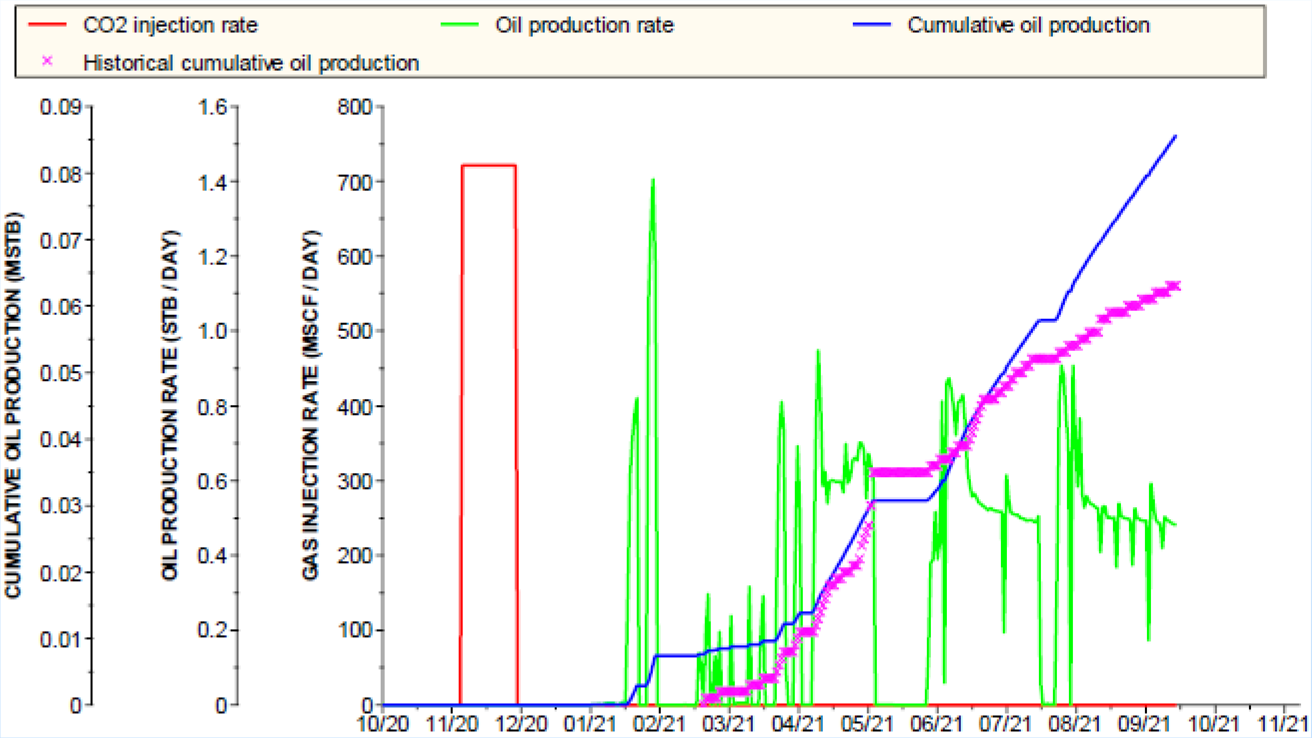
Greenfield Test: Evolved Characterization

Observations from field test permitted an evolved characterization of the Carper ROZ and we revisited the reservoir model to:

- Add hydraulic fractures and adjust natural fracture parameters to match observed pressure responses
- Tune EOS data to measured oil properties (29° API and 30 cP at 60 °F); adjust S_{OI} and S_{OR} in both matrix (60%) and fracture (15%)
- Constrain CO_2 venting and fluid production rates according to observed gas and water production rates

Greenfield Test: Revised Model Simulations

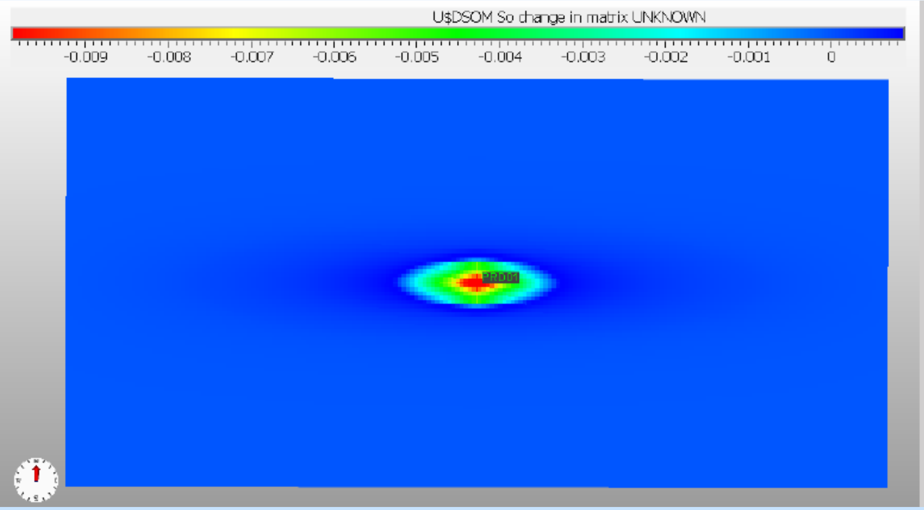
- Simulated total oil production at 7 month 86 stb (vs. measured 63 stb)
- Better character match than before, but difficult to account for all operational constraints that impacted real production in simulation

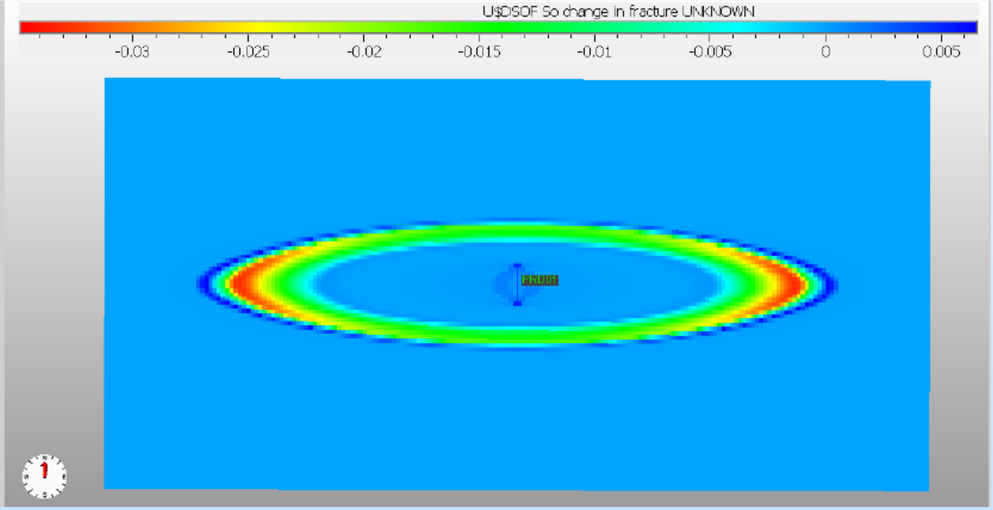


Graph of observed oil production rate (green), cumulative production (pink), and simulated oil production (blue) after adjusting model per the evolved characterization.

Greenfield Test: Revised Model Simulations

- Produced residual oil **from fractures** via Darcy flow
- Stored CO_2 via flow through fractures
  - CO_2 moved far enough away that it was not produced during pumping



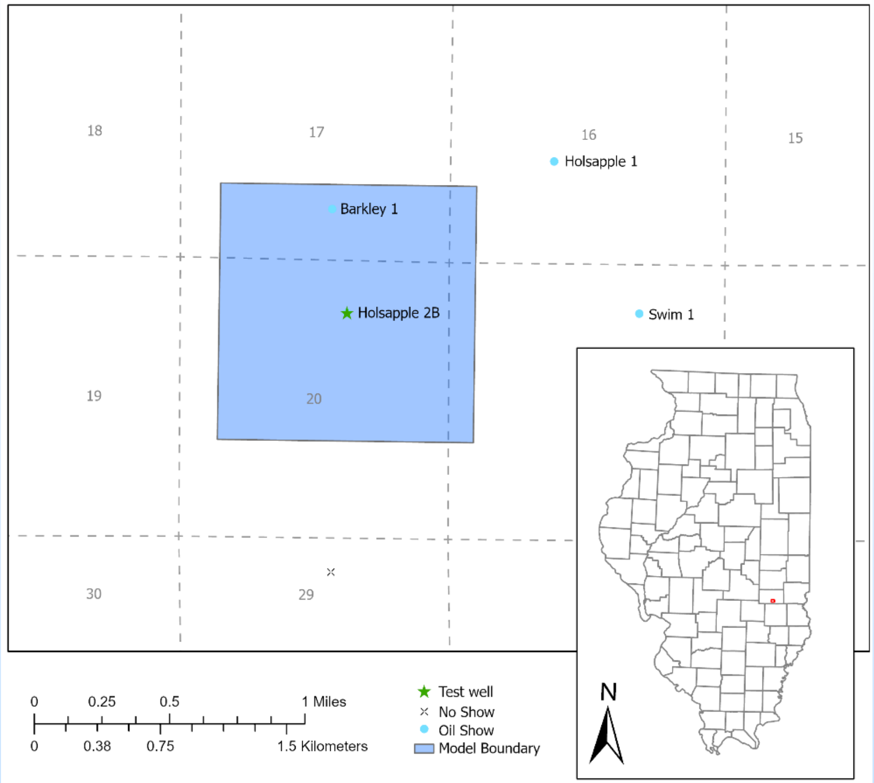


Map view of change in oil saturation in the matrix (left) and fractures (right)
Note: scales are different for each map. Almost no saturation change in matrix.

Greenfield Test: Conclusions

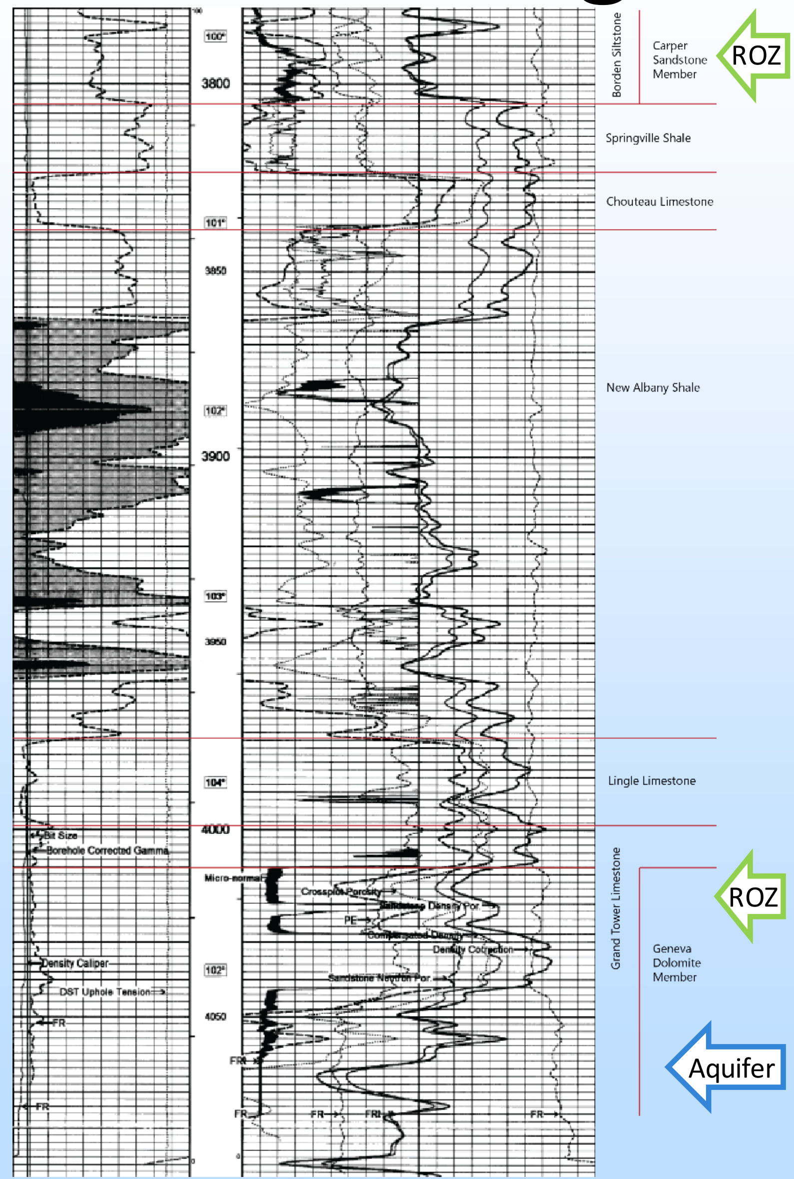
- Rock and fluid properties impacted injection and production behavior
  - Natural fractures were more pervasive and influential than expected
  - Natural fractures diminished EOR but improved CO_2 storage
- Oil was denser and more viscous than expected but still able to be produced
  - S_O must be 15% in the fractures to match historical production
  - Simulations suggest no contribution from matrix, but core flood indicates it is possible
- The Carper Greenfield ROZ extends over a large area and has potential as CCS reservoir with limited EOR potential
  - Additional data is needed to characterize the natural fracture network

Greenfield
Co-optimization of EOR and Storage



Field development area (640 acre=1 mi x 1 mi)

	Carper Ss ROZ	Geneva Dol ROZ + Aq.
Thickness	15 ft	18 ft ROZ, 40 ft Aq.
Poro/Perm	11.5%, 0.2 mD	10%, 20mD ROZ; >20%, >350 mD Aq.
S_{OR}	25% (matrix) 15% (fractures)	20% ROZ



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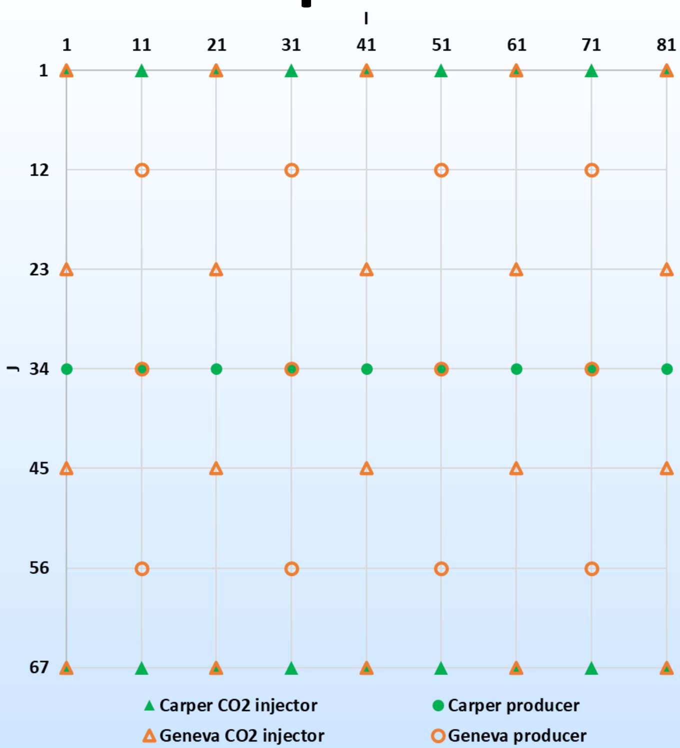
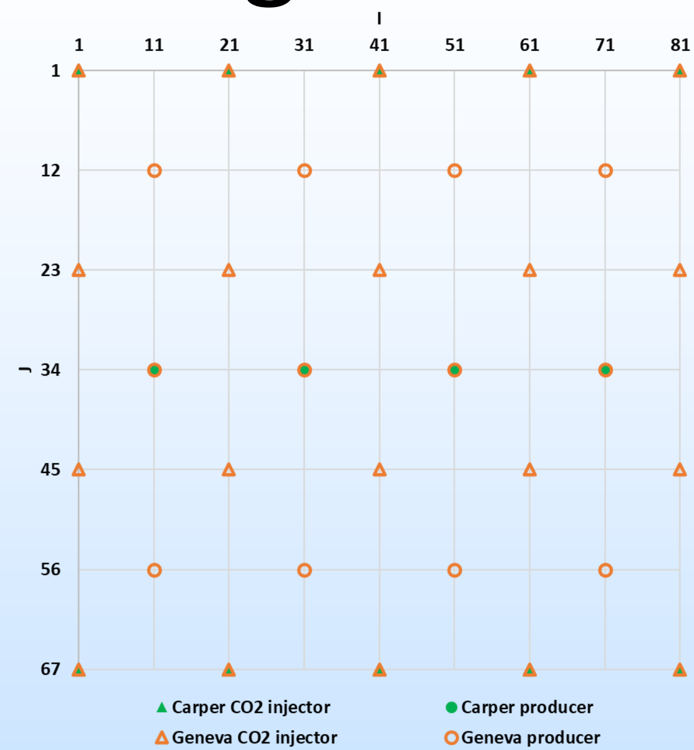
Greenfield
Co-optimization well arrangement



For improved economics, Carper pattern size increased and well count reduced due to low EOR potential



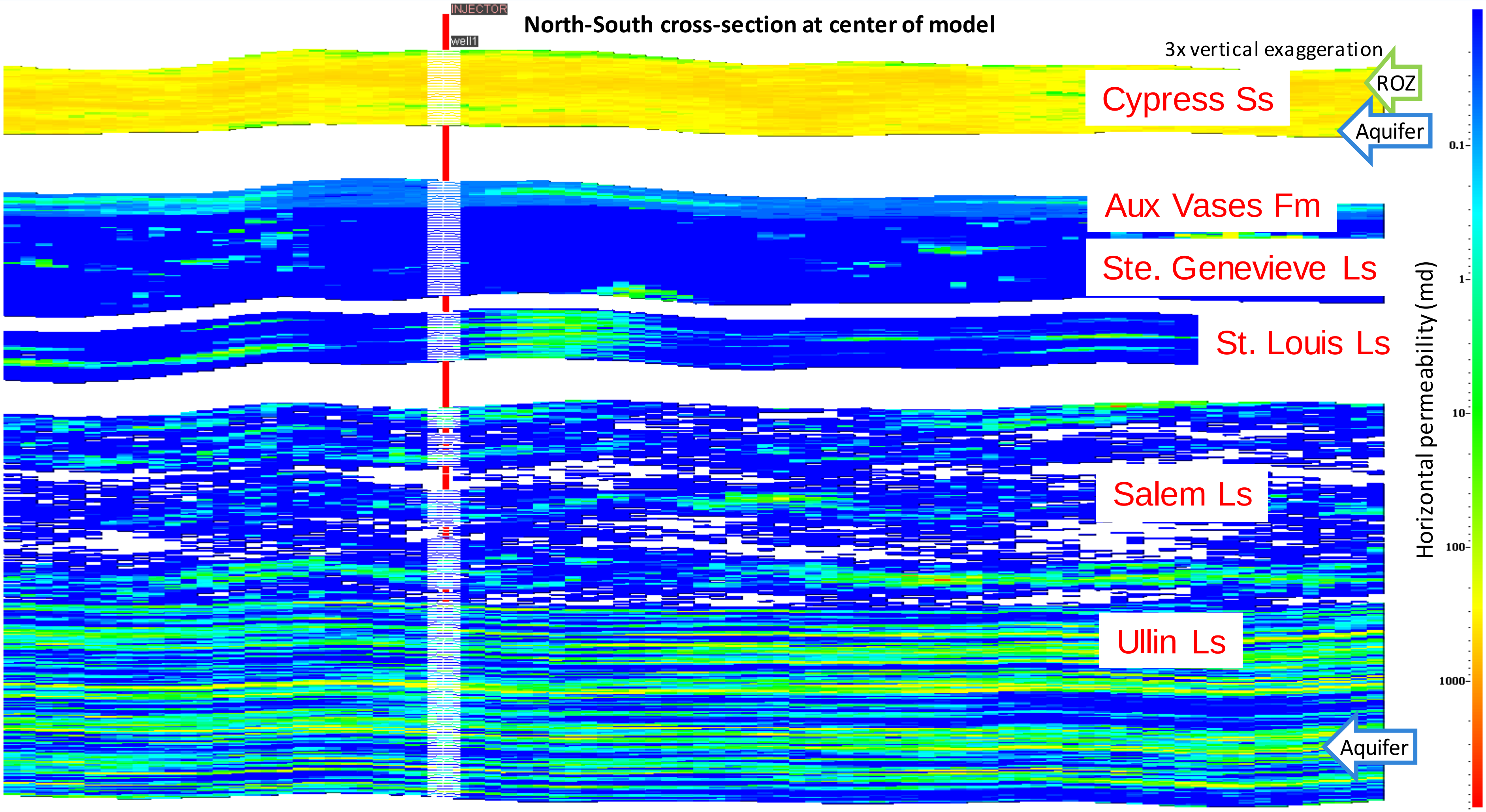
Formation	Producer	CO_2 injector	Pattern count	Pattern size	Perforation interval, ft in MD
Carper ROZ	9	18	8	80-acre	3688-3703
Geneva ROZ	12 (4 shared)	20 (10 shared)	12	53-acre	4010-4028
Geneva Aquifer	12 (all shared)	20 (all shared)	12	53-acre	4045-4085
Total	17	28		640-acre	

Formation	Producer	CO_2 injector	Pattern count	Pattern size
Carper ROZ	4	10	4	160-acre
Geneva ROZ	12 (4 shared)	20 (10 shared)	12	53-acre
Geneva Aquifer	12 (all shared)	20 (all shared)	12	53-acre
Total	12	20		640-acre

Carper: Line drive leverages natural fracture anisotropy

Geneva: 5-spot for isotropic reservoir properties

Brownfield Lab: Stacked Model



Brownfield Reservoir Simulations

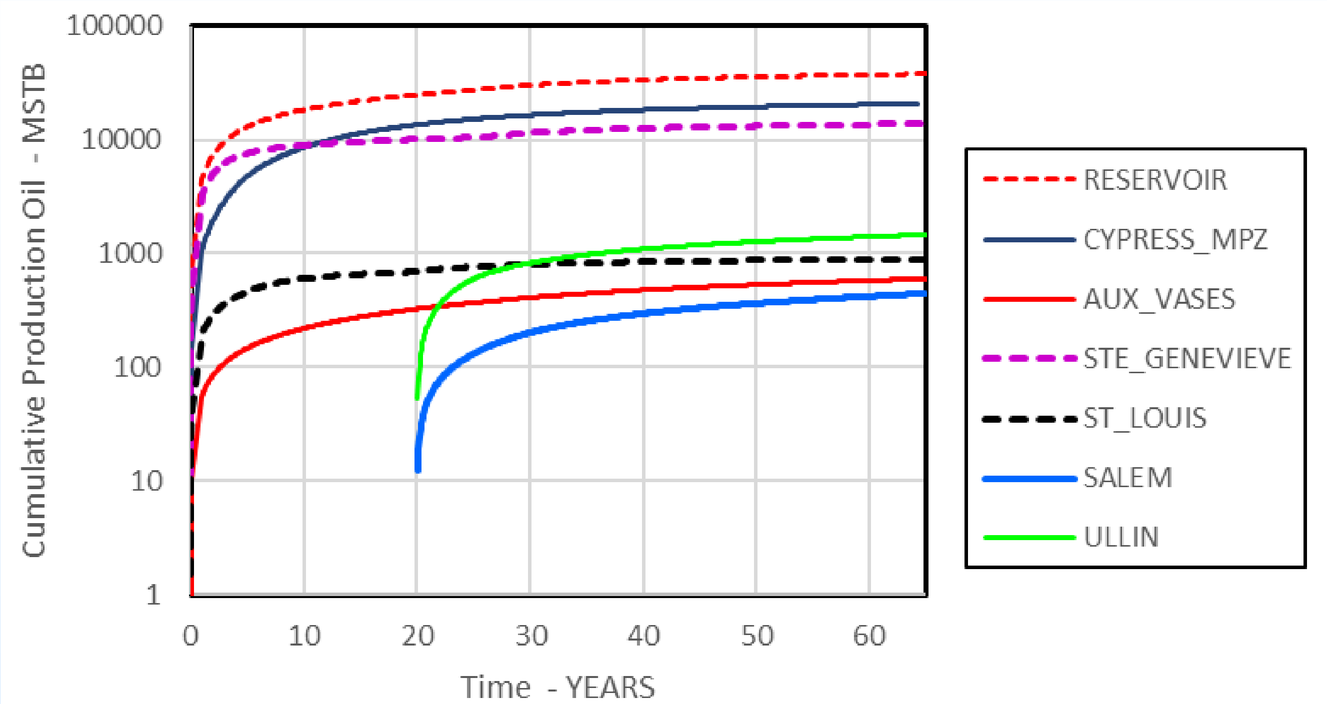
Calibration

- Primary production (25 years for Ste. Gen; 45-65 years for others depending on field history)
  - 10-acre well spacing: Cypress and Aux Vases Sandstones
  - 20-acre well spacing: Ste. Genevieve, St. Louis, Salem, and Ullin Limestones
- Waterflooding (40 years)
  - Ste. Genevieve Limestone (5-spot, 40-acre pattern size)

Forward simulation

- CO_2 flood (5-spot pattern, 20 years)
  - 80-acre pattern size: Cypress and Aux Vases Sandstones
  - 40-acre pattern size: Ste. Genevieve, St. Louis, Salem, and Ullin Limestones

Brownfield Model Calibration

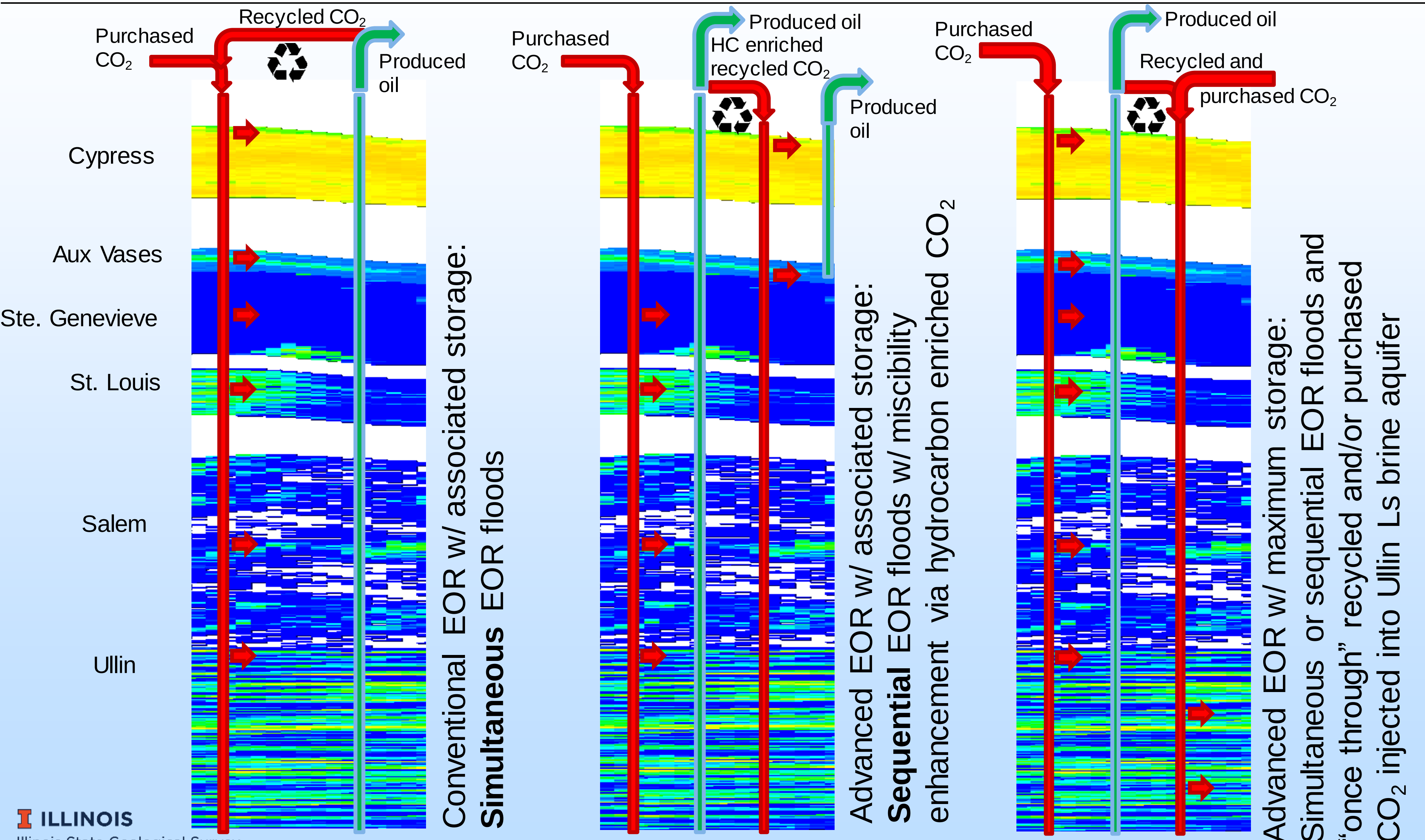


- Cypress Sandstone and Ste. Genevieve Limestone are the most prolific oil producers in the field
  - EOR strategies for the stacked reservoirs designed to prioritize these formations

Brownfield Development Strategy

- Perform miscible CO_2 EOR and associated storage
- Estimate CO_2 EOR and associated storage by formation
- Estimate CO_2 EOR and associated storage of the stacked reservoir complex
- Identify and simulate strategies for co-optimizing CO_2 EOR and storage in the stacked reservoirs
- Provide input for performance of economic and CCUS system analyses

Brownfield Development Strategy



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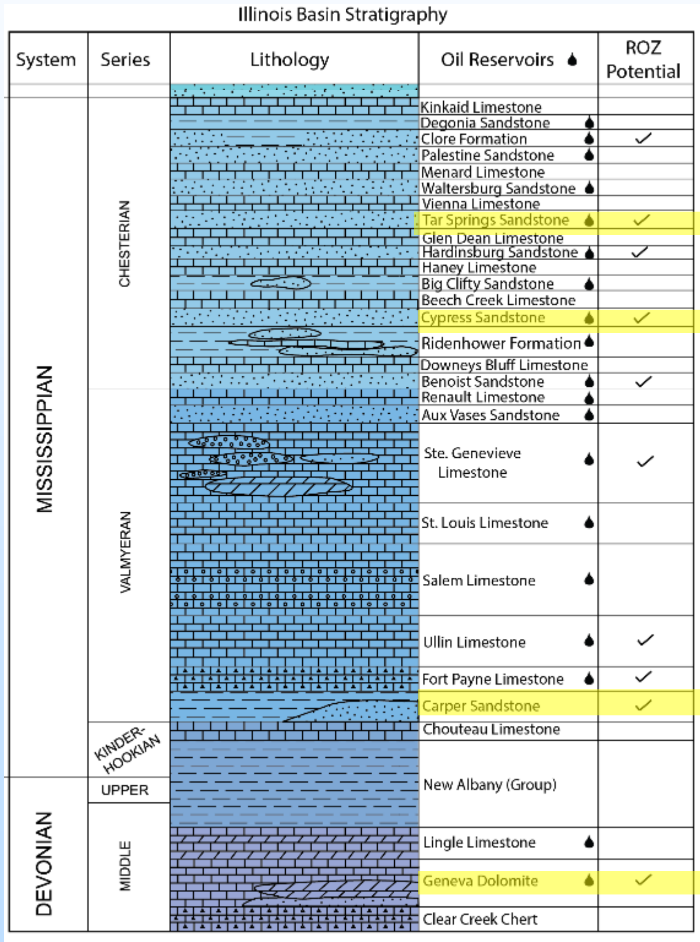
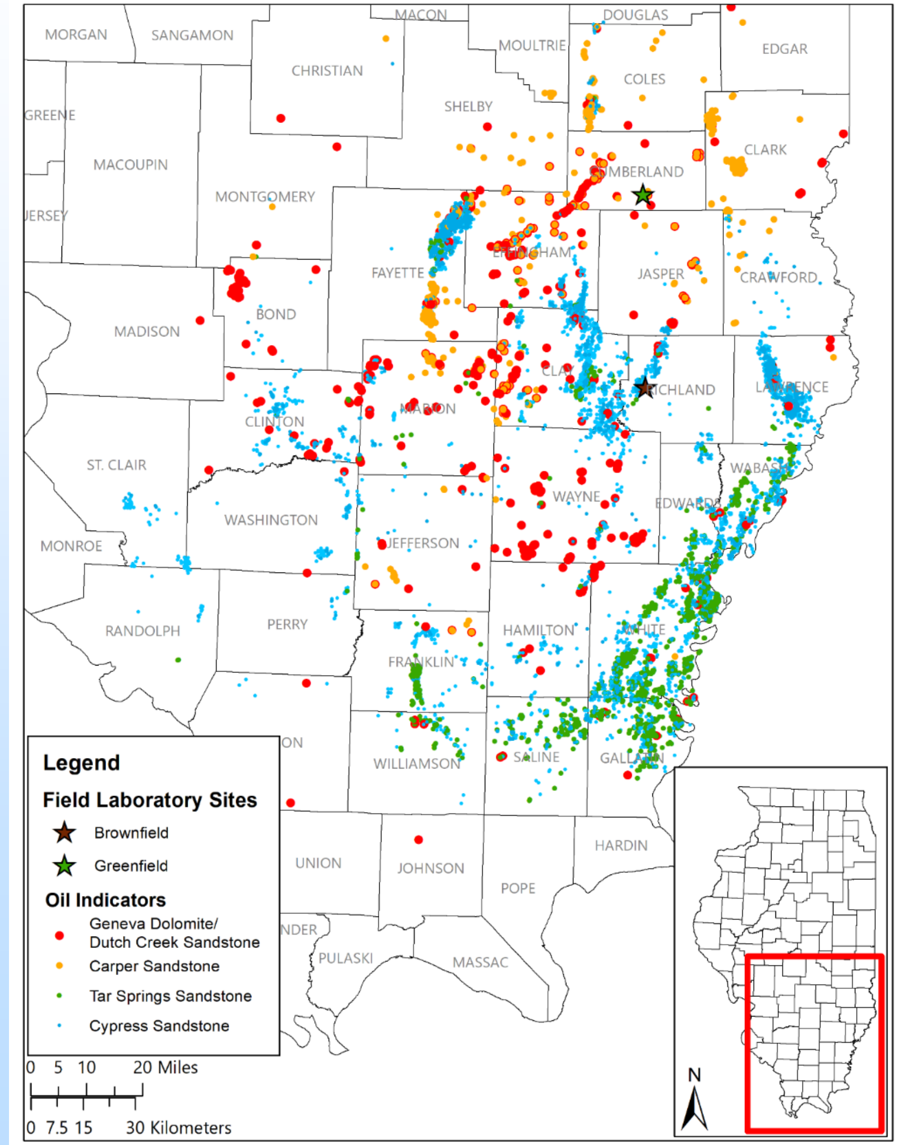
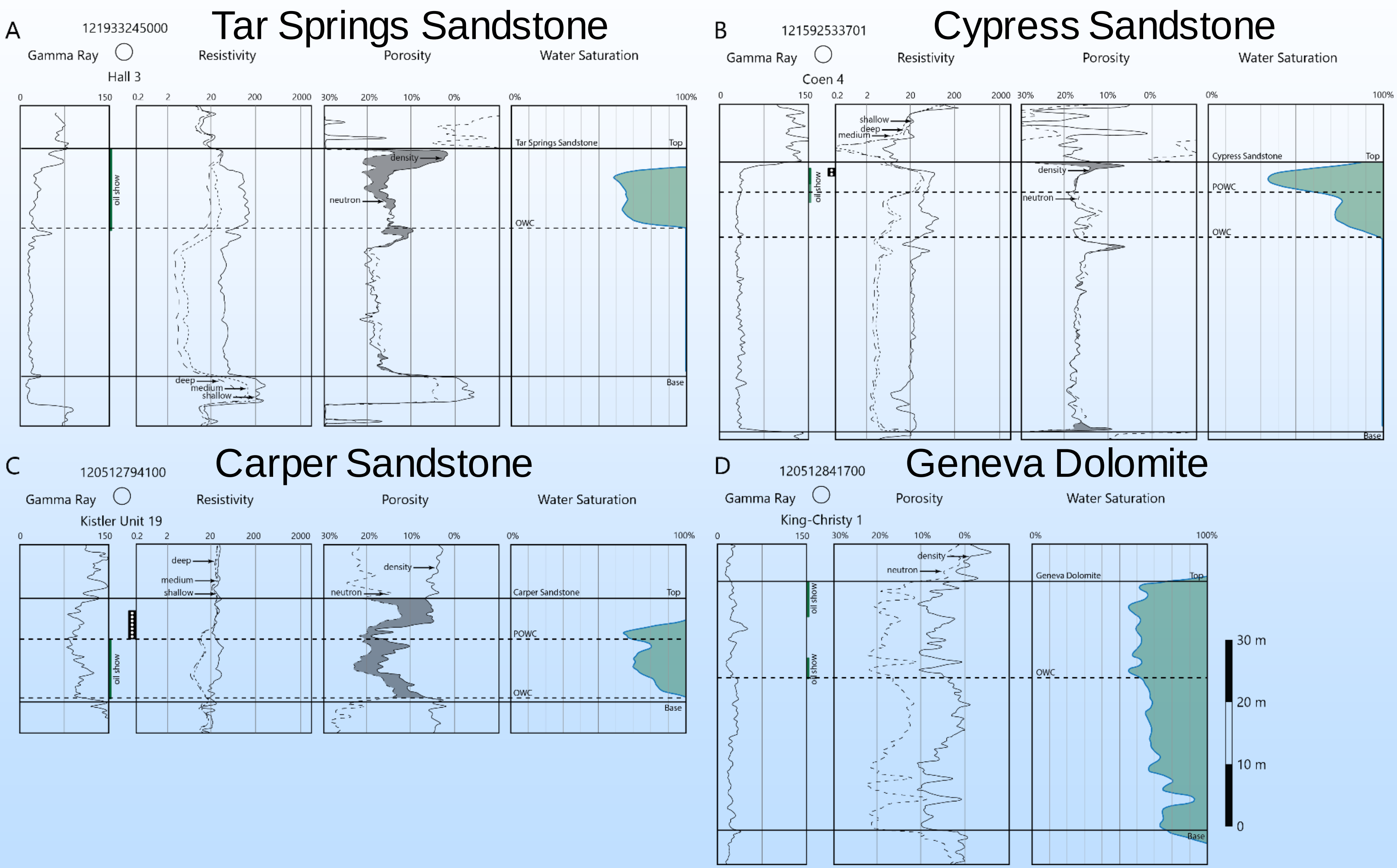
Resource Assessment

- Conducting resource assessment of four formations based on ROZ screening





Resource Assessment



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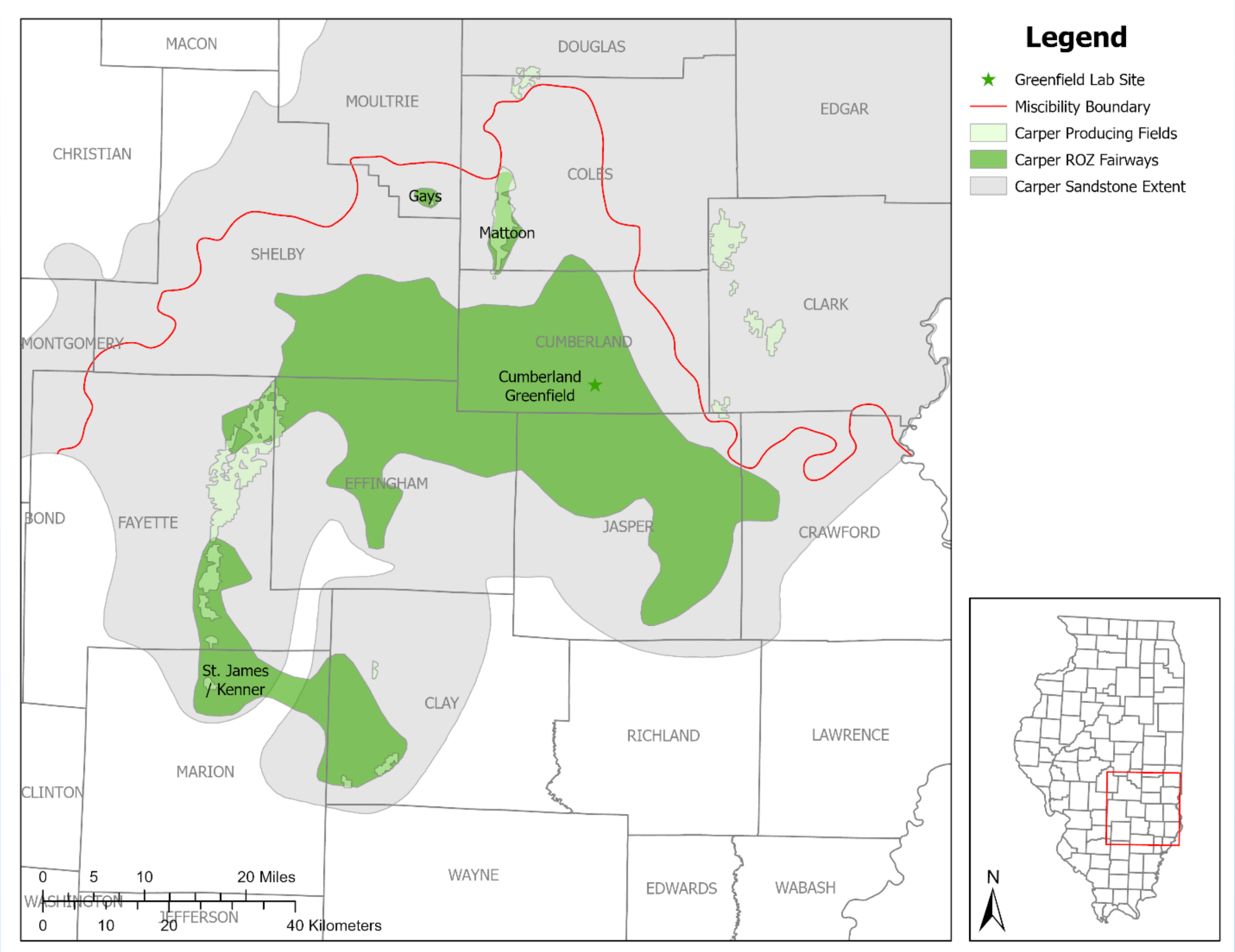
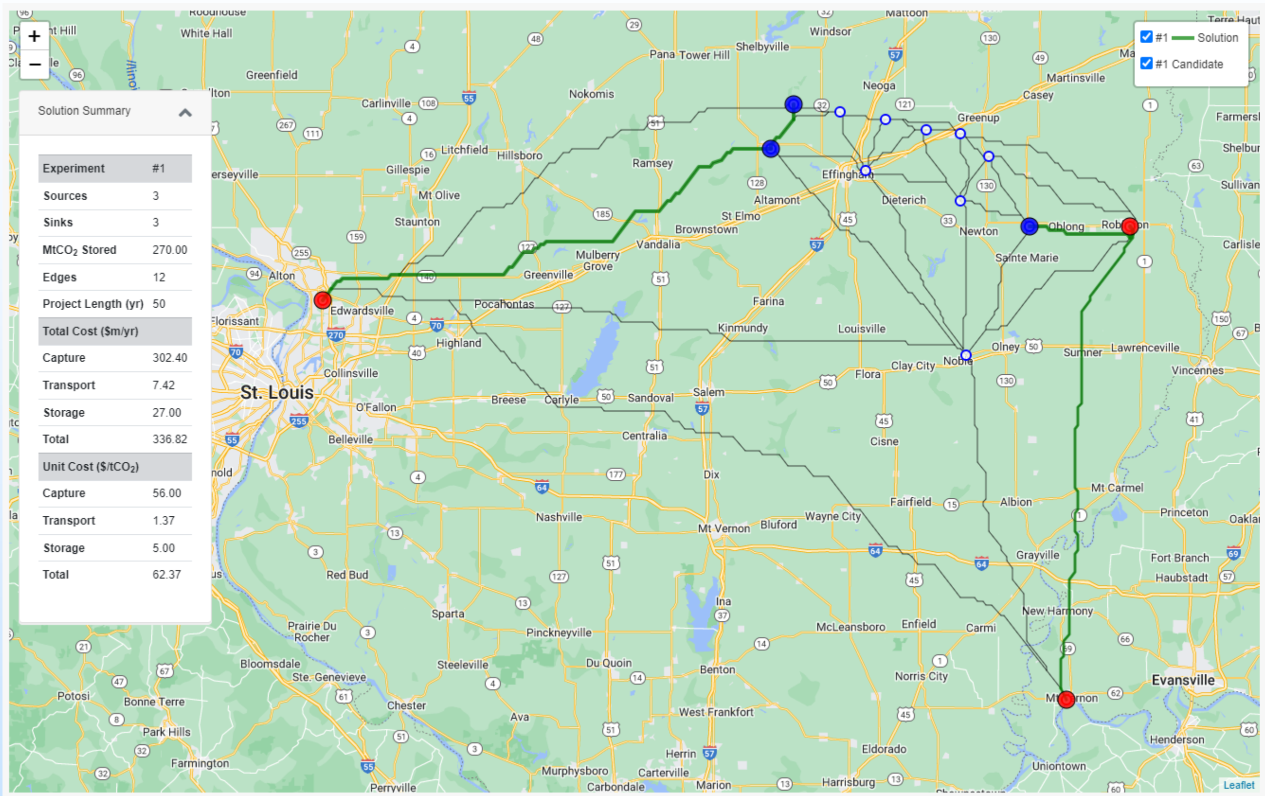
Resource Assessment

- Example Fairway map of Carper ROZ
  - ROZ bounded by thickness and depth (miscibility) cutoffs
- Fairway maps for other formations indicate opportunities for stacker ROZ potential in many areas of Illinois



CCS System Modeling



Potential pipeline corridors (grey lines) and preferred/most efficient pipeline corridors (green lines) that link Ethanol plant CO_2 sources with sinks in the Cumberland Greenfield

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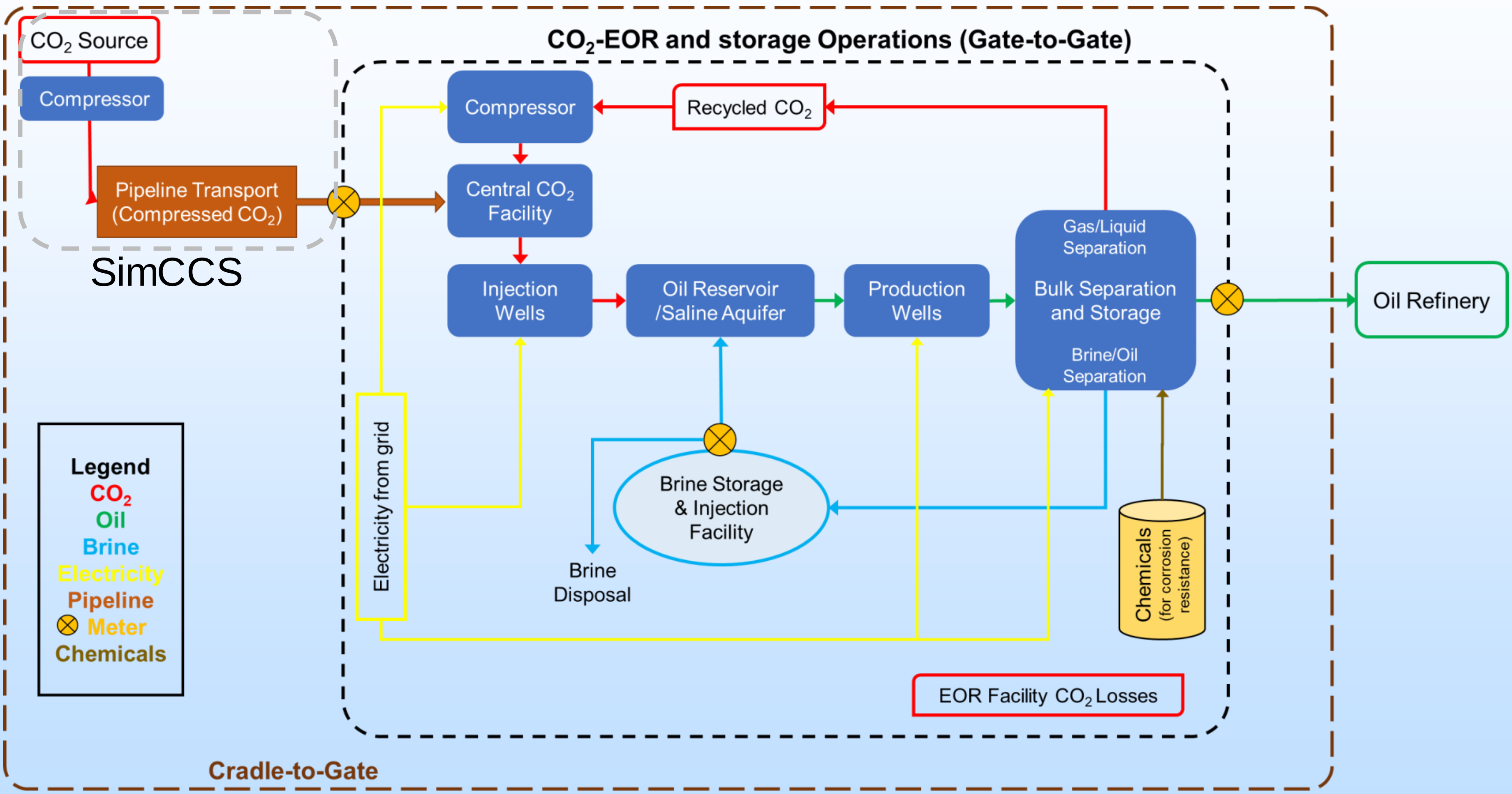
Life Cycle Analysis



Project summary

Key Findings

- Greenfield Lab Site is a potential associated storage resource
  - Carper HnP test allowed for evolved characterization and improved reservoir simulations
    - EOR likely to perform better with line drive flood with excellent associated storage potential
  - Geneva likely provides additional EOR and storage target
- Brownfield Lab Site is prototypical ROZ/depleted reservoir stacked storage target in the Illinois Basin
  - Reservoir simulations currently determining the magnitude of EOR and Storage potential
  - Various development strategies create flexibility for operators in prioritizing or co-optimizing EOR and storage depending on market conditions

Project summary

Lessons Learned

- Field laboratory research is unpredictable and requires extra attention to detail
- Stacked reservoir models require prioritization of important parameters to balance detail with computational efficiency

Next Steps

- Integrating co-optimized simulation results into LCA, CCUS systems analysis
- Final classification of stacked CO_2-EOR and storage resources

Acknowledgments

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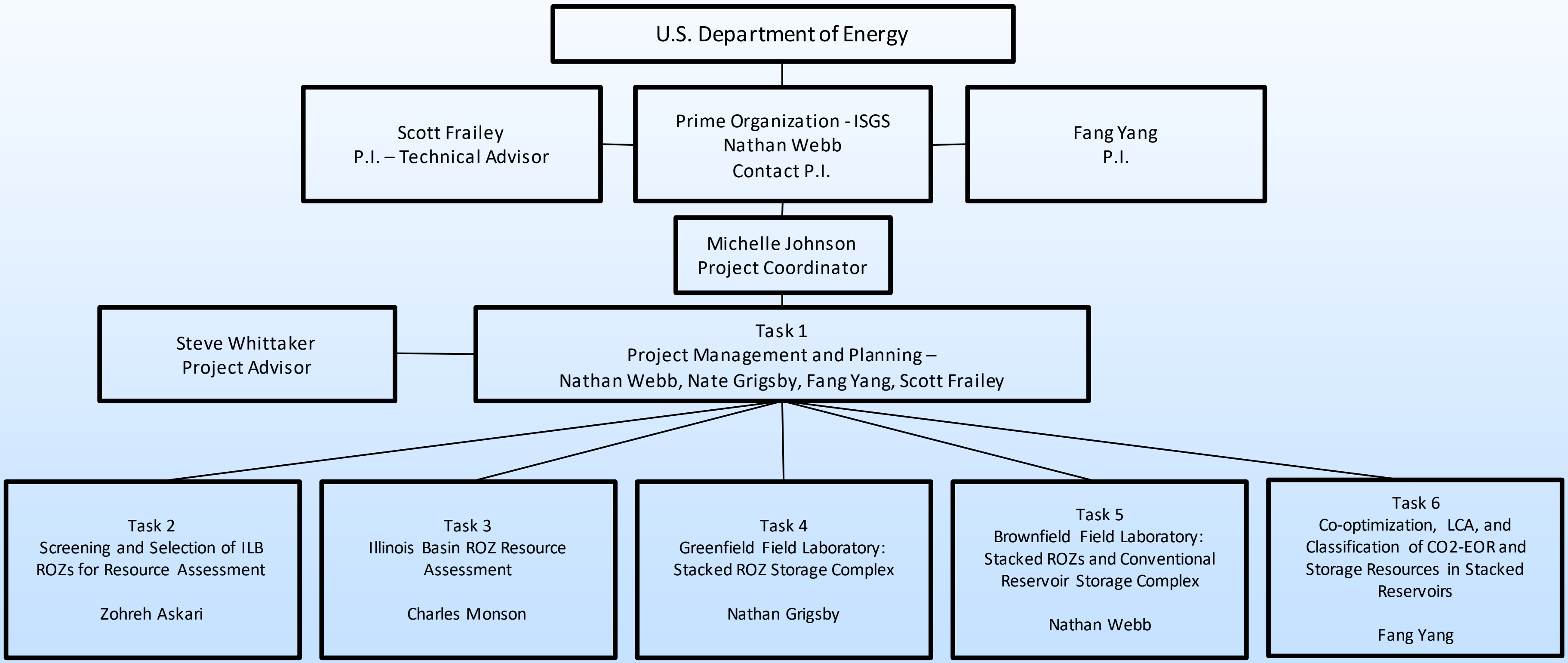
- Through a university grant program, IHS Petra, Geovariences Isatis, and Landmark Software were used for the geologic, geocellular, and reservoir modeling, respectively
- For project information, including reports and presentations, please visit:

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

Appendix: Organization chart



Appendix: Gantt chart