27th Annual CO_2 Conference

CO_2 Induced Oil Swelling and Results from a Huff & Puff in a Greenfield ROZ, Carper (SS) Illinois

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- For project information, including reports and presentations, please visit:

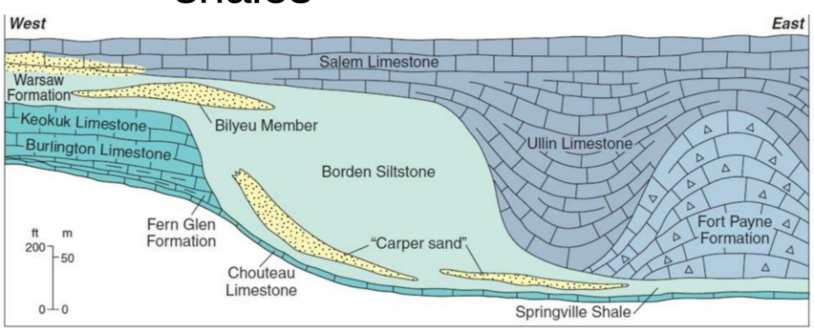
http://www.isgs.illinois.edu/research/ERD/NCO2EOR

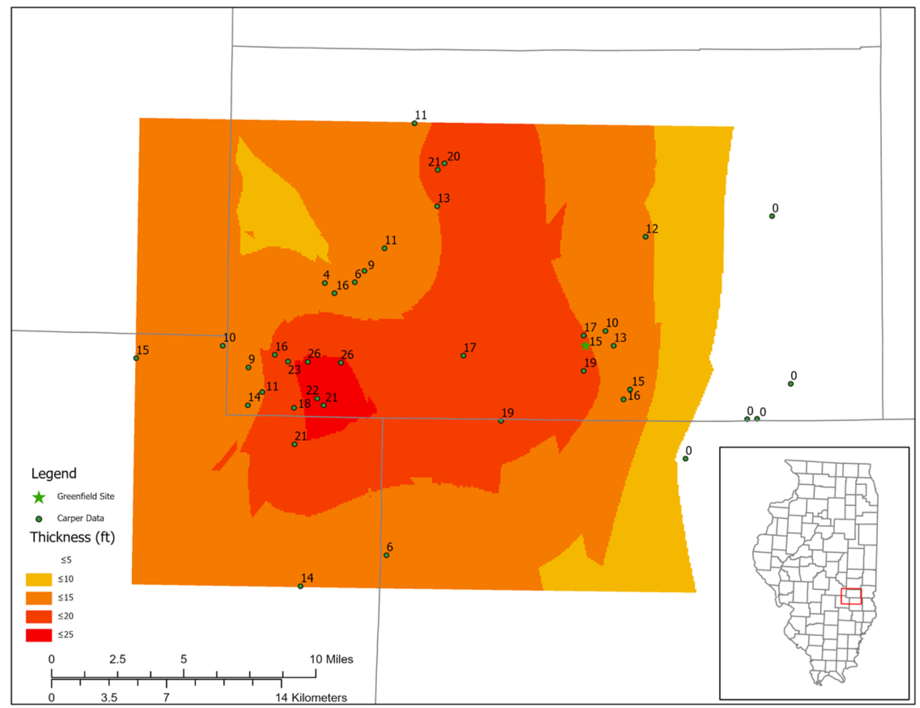
Objectives

- DOE objectives
  - Develop specific subsurface engineering approaches leveraging CO_2 injection field tests and applied R&D, that address research needs critical for advancing CCS to commercial scale
- ISGS project objectives
  - Screen for ROZs using analysis of empirical data and basin evolution modeling
  - Characterize stacked brownfield/greenfield siliciclastic ROZs at field lab sites
  - Conduct injection tests and collect and analyze core and logs at field lab sites
  - Use calibrated simulation models and LCA to identify development strategies
- **ISGS field pilot objectives**
  - **Characterize geology and fluids in ROZ**
  - **Demonstrate the efficacy of CO_2 EOR and storage in a siliciclastic ROZ**

Pre-Test Characterization: Carper and Borden (Caprock) ILB ROZ

- Mississippian (Osagean) deposits
- Carper sandstone encased in the basal Borden Siltstone
  - Overlain by middle-Miss limestones
  - Secondary seals in Chesterian shales

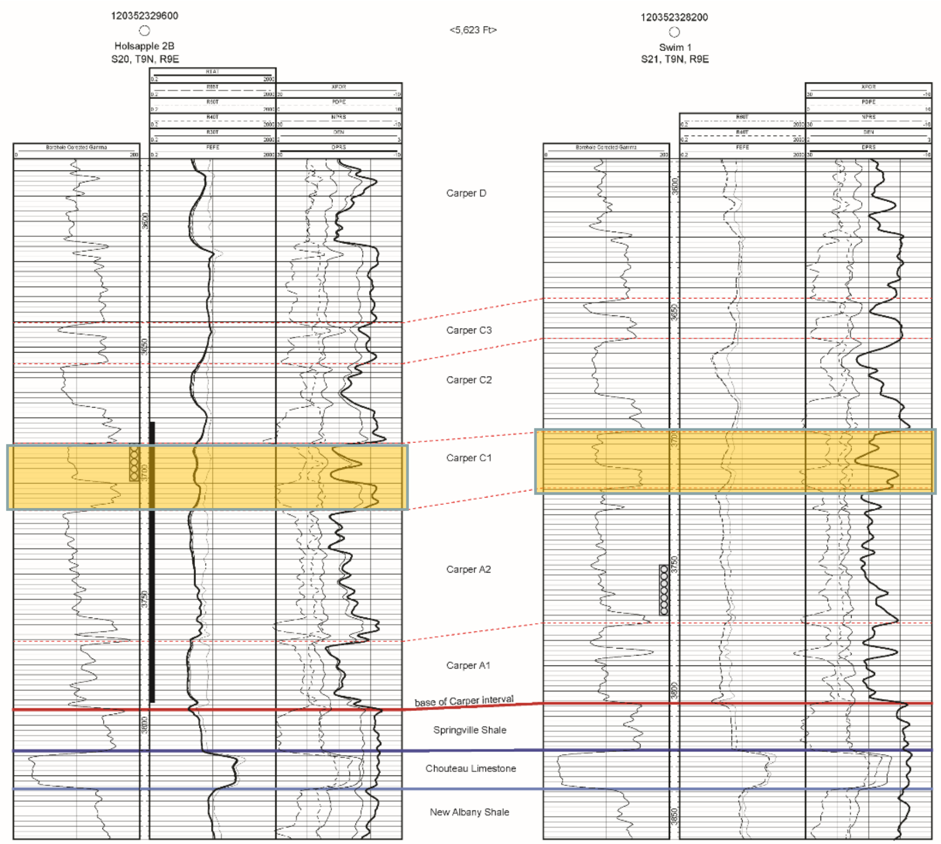




From Kolata and Nimz, 2010

Pre-Test Characterization: Test Well Geology

- Drilled in 2016
- Targeting 15-foot interval
  - 3690-3705
  - Very fine-grained sandstone with thin shale laminations in middle
  - 15-foot shale above and below
- ~100 feet of core (target and underlying units)
  - Low porosity and permeability
  - Core porosity matches DPHI
  - Submitted for detailed petrography, XRD, core flood testing



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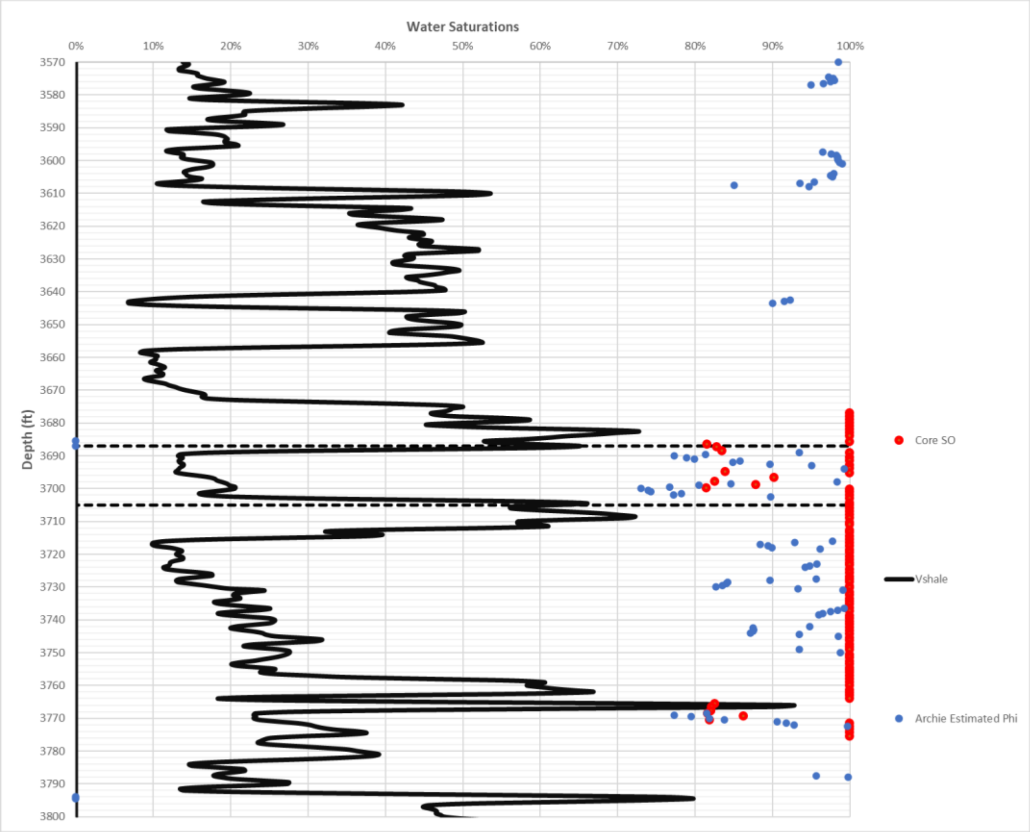
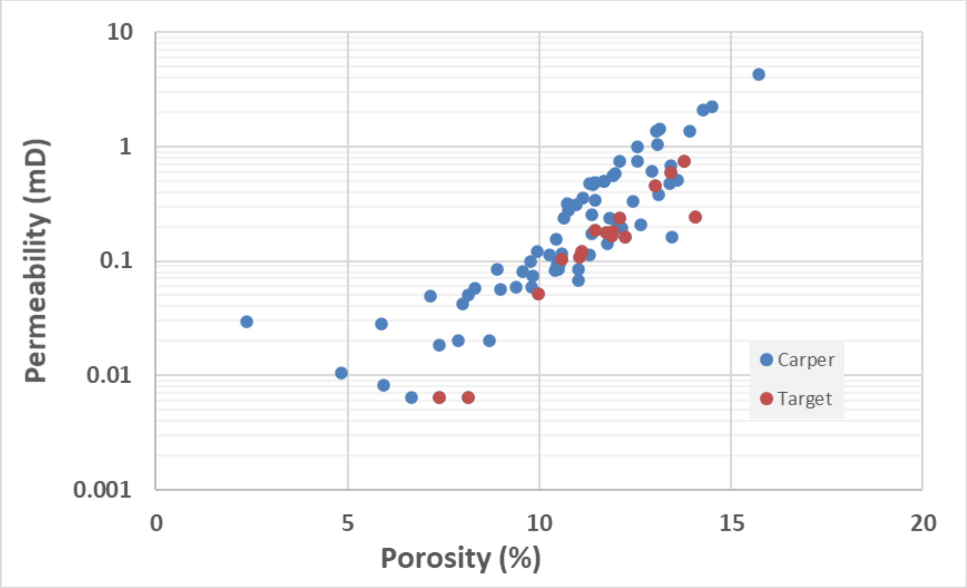
Pre-Test Characterization: Test Well S_O

- Target has oil saturation
  - Core has oil in target sandstone bed and thin zone in a deeper sandstone bed
  - Target sandstone bed has oil shows in nearby wells
  - S_O calculated ~25% via log analyses
- This oil is immobile in the presence of water
  - 6 months of pumping with no oil production
  - Interpretation: Greenfield ROZ
    - 15 miles from Carper production
    - Nearby wells have oil shows but no production



Pre-Test: Natural Fracture Network

- Core perm too low to produce 250 bbls fluid/day)
  - Need 3 orders of magnitude higher perm
- Effective permeability validated by pressure transient tests, baseline production, and CO_2 injection tests



Permeability (md)	Thickness (ft)	Rate at 2 months (stb/day)	Permeability - Thickness (md-ft)
20	15	248	300
15	15	192	225
10	15	134	150
1	150	182	150
0.2	750	234	150

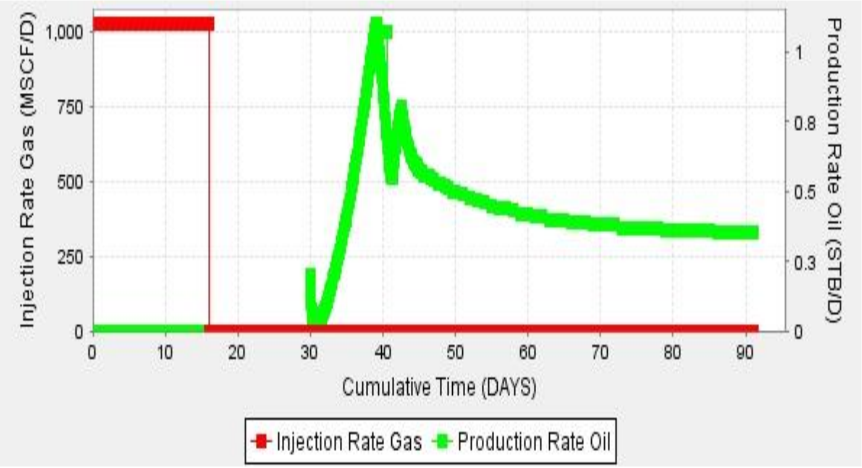
Pre-Test: HnP Simulation

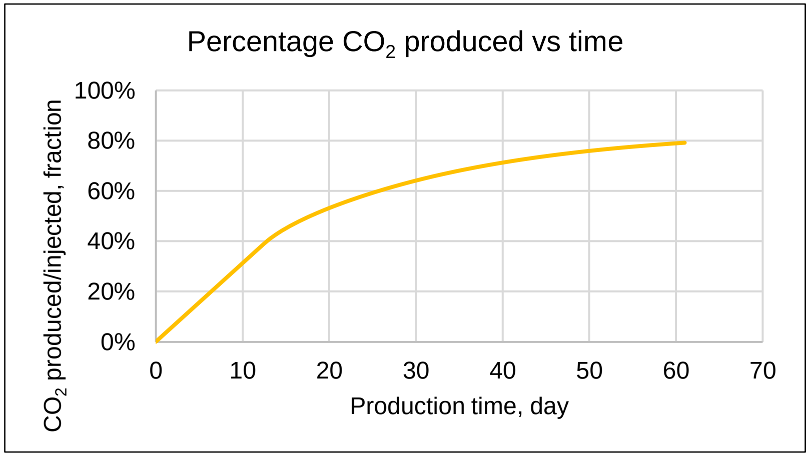
Input

- Matrix: 0.2 mD, 11% porosity, Soi=25%
- Natural fractures tuned to match historical production (Soi=2%)
- CO_2 injection at 60 t/d for 16 days, soak 14 days, then produce liquid at 400 stb/d

Findings

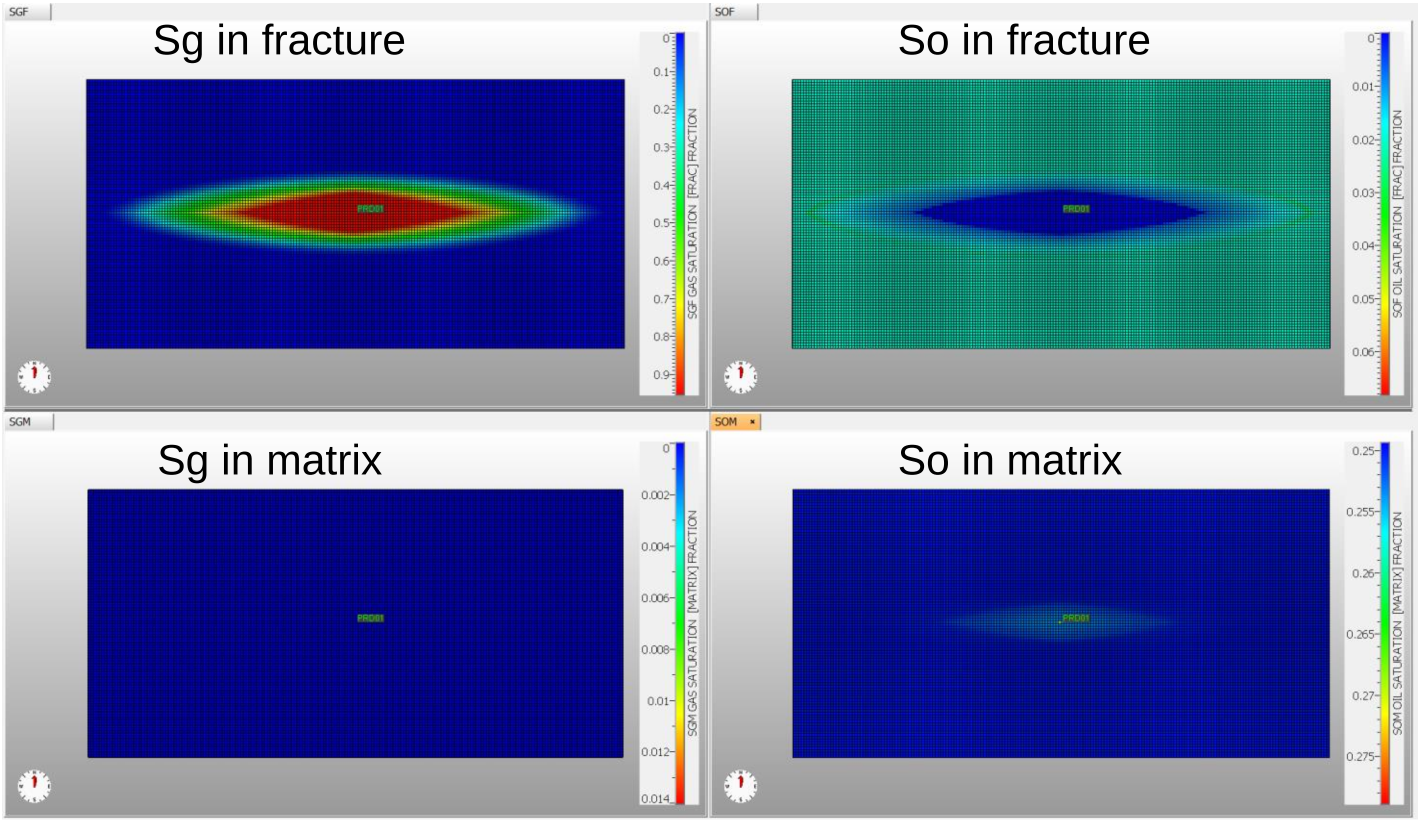
- Oil production
  - 1.1 stb/d peak rate
  - Total 15 stb at the end of first month
- CO_2 production
  - 64% at 1-month production
  - 80% at 2-month production





Pre-Test: HnP Simulation con't

- Low porosity matrix and natural fracture network results in CO_2 staying in fractures and having limited contact with matrix



Top view of gas and oil saturation at the end of CO_2 injection

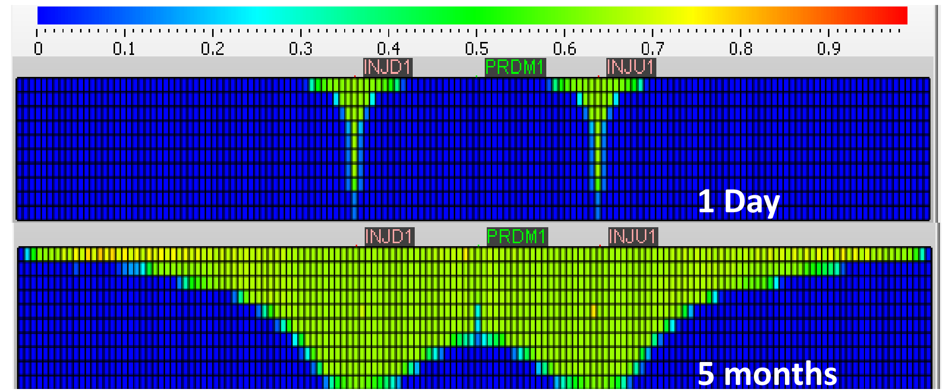
Pre-Test: Line Drive Simulations

Direct line drive

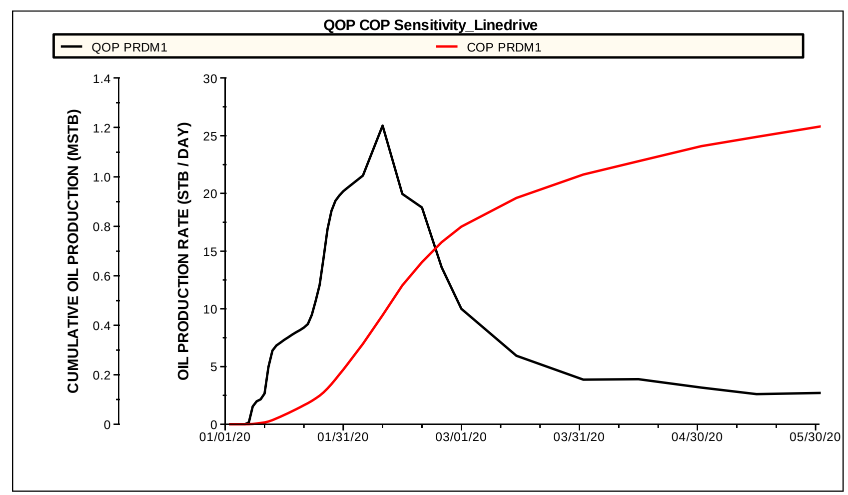
- 20-acre pattern
- CO_2 inj rate: 200 ton/d (3.4 MMscf/day)
- Results:

– Single pattern
  - Peak oil rate: 26 stb/day
  - 1,200-1,300 stb

– Metrics after 5-months:
  - Oil recovery = 1.6% OOIP
  - Net utilization = 56 Mscf/stb (3.4 ton/stb)
  - Gross utilization = 428 Mscf/stb (25 ton/stb)



Gas saturation in fracture (side view of middle wells)



HnP: Pilot Results

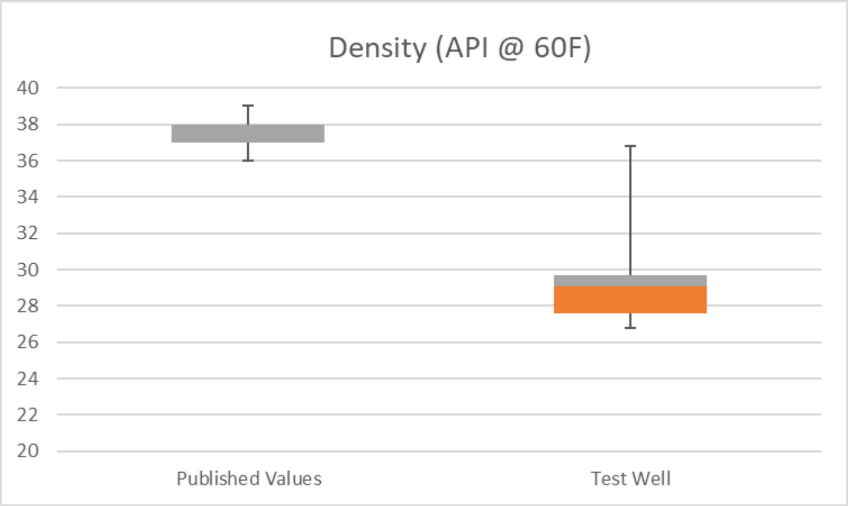
Results

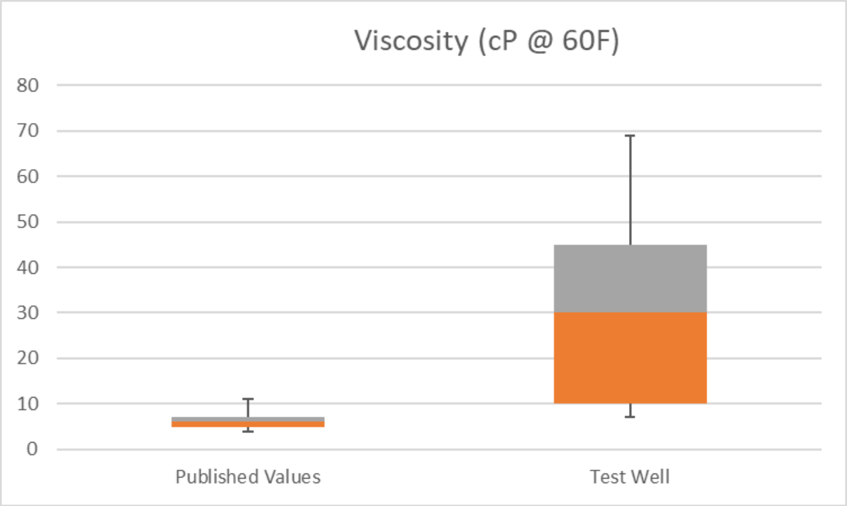
- Injected
  - 1,000 tons of CO_2
  - 25 days
- Produced
  - 14,000 bbls water
    - 1 month flowing
    - 5 months pumping
  - 360 tons of CO_2
    - 640 tons stored
  - 65 bbls oil
    - 5 months of pumping
    - Still 0.5 bbls/day when shut in
    - Includes 15 bbls of measurement error

Suppressed oil response

- Operational
  - Sand in well forced pump to be placed ~150 ft above perforations
  - Equipment limited production rate (size of gas/liquid and gunbarrel separators)
- Measurement error
  - Oil in brine tank/disposal meter

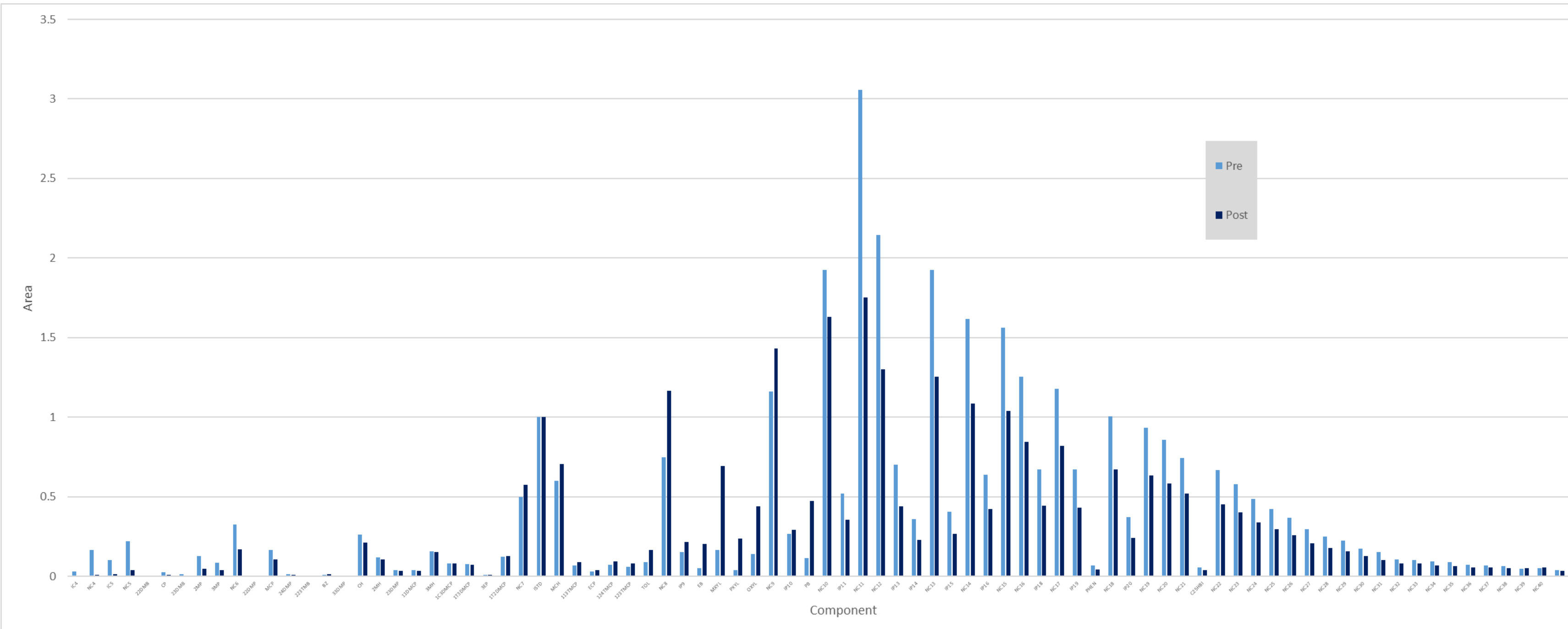
Post Test Interpretation: Oil Properties





- 9 samples taken from test well over course of testing
- Oil in test well is significantly denser and more viscous than published values

Post Test Interpretation: Oil Properties

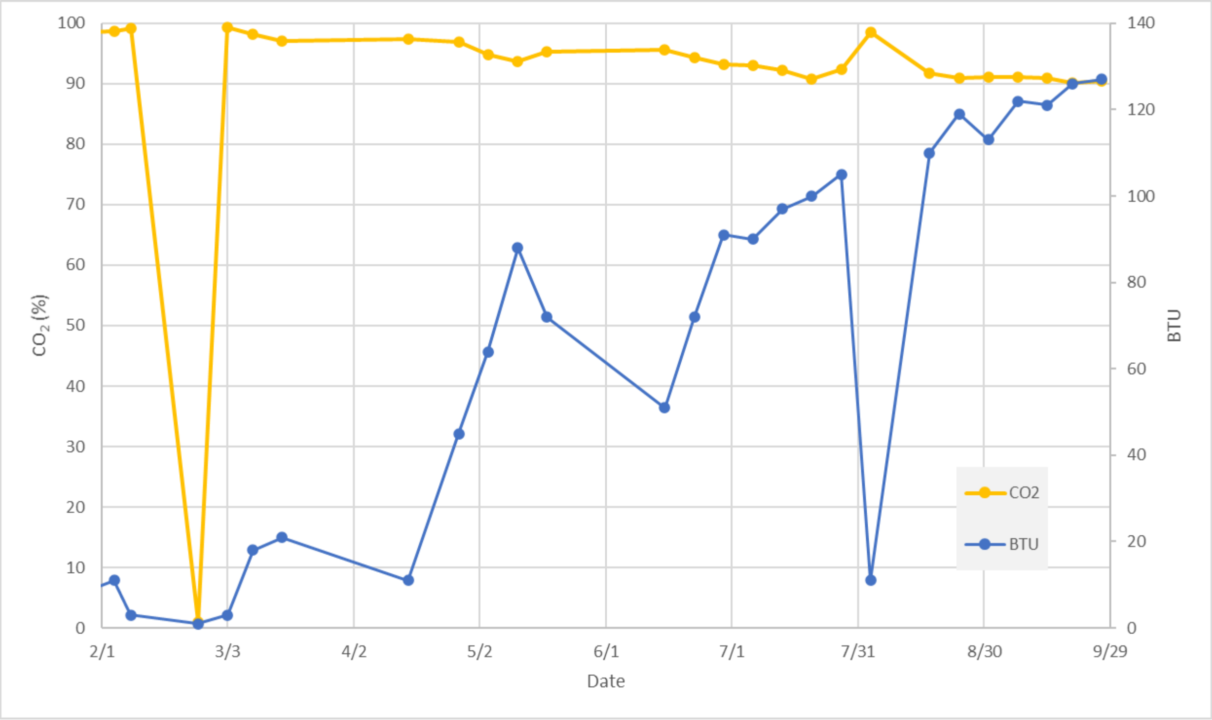


- GC analysis of oil samples before and after CO_2 injection
- Light ends were stripped before CO_2 injection. They appear to be slightly more attenuated after CO_2 injection

Post Test Interpretation: Core Flood

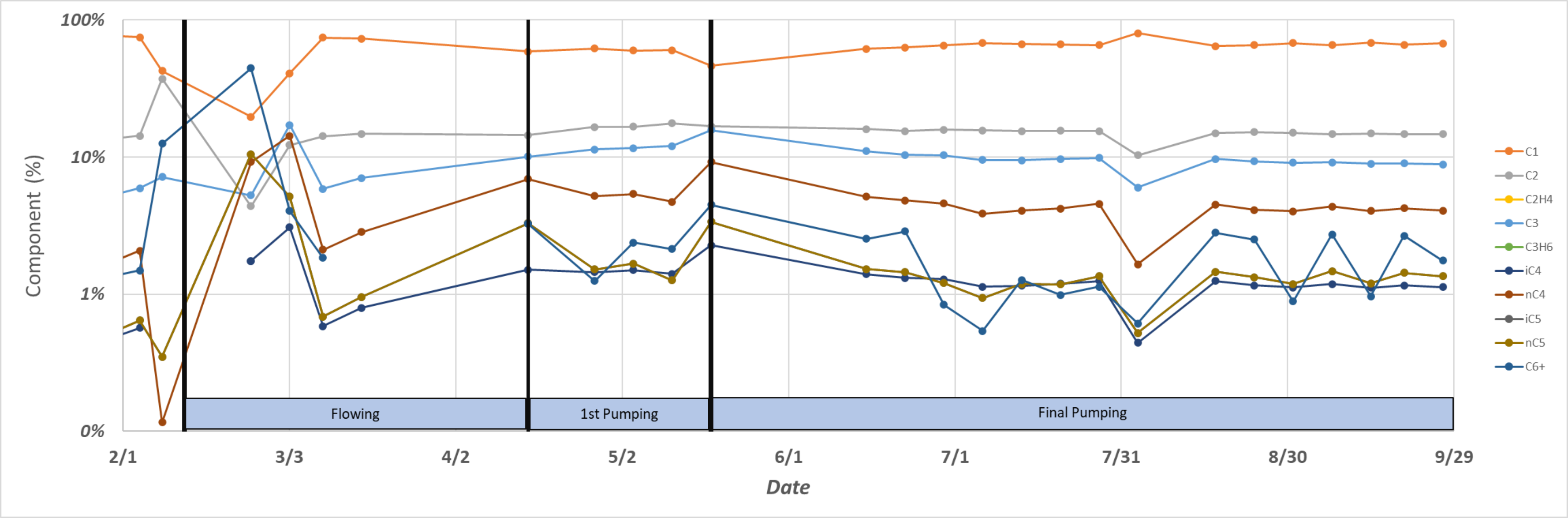
- 30 cP oil
- Waterflood: Residual oil saturation (S_{ORW}) = 60%
- CO_2 flood: Residual oil saturation (S_{ORCO2})= 16%
- Interpretation
  - S_O = 25% from well log analysis
    - S_{oi} <<<<S_{ORW}?
    - CO_2 flood of matrix would require 25% S_{Oi} to swell to 60% for Darcy flow
  - CO_2 can mobilize 30 cP oil from matrix

Post Test Interpretation: Gas Properties



- CO_2 in vented gas reduces from 100% to 90% at end of pumping. This is accompanied by an increase in hydrocarbons

Post Test Interpretation: Gas Properties



- Evaluating hydrocarbons and comparing them to oil samples to determine if they represent CO_2/oil mixing

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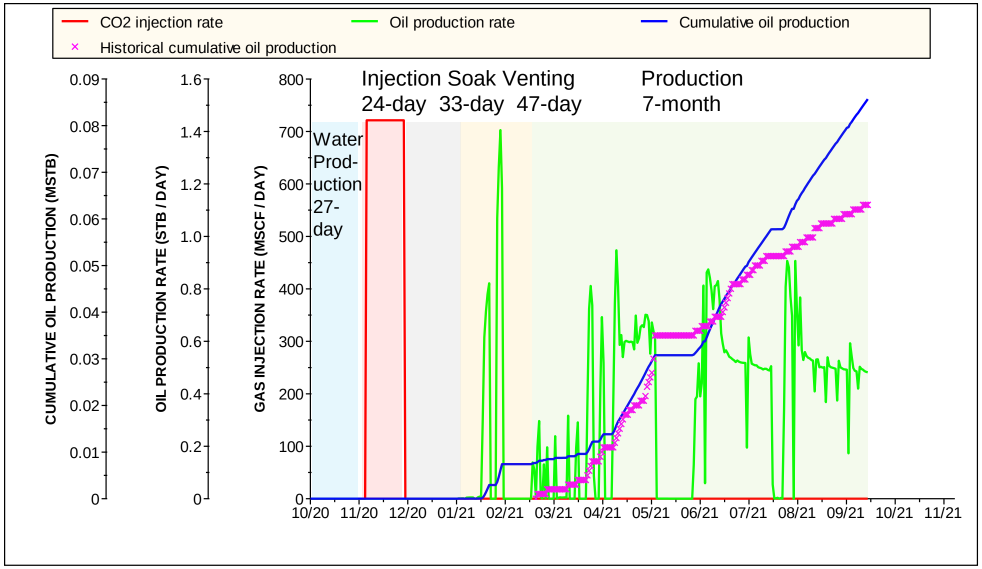
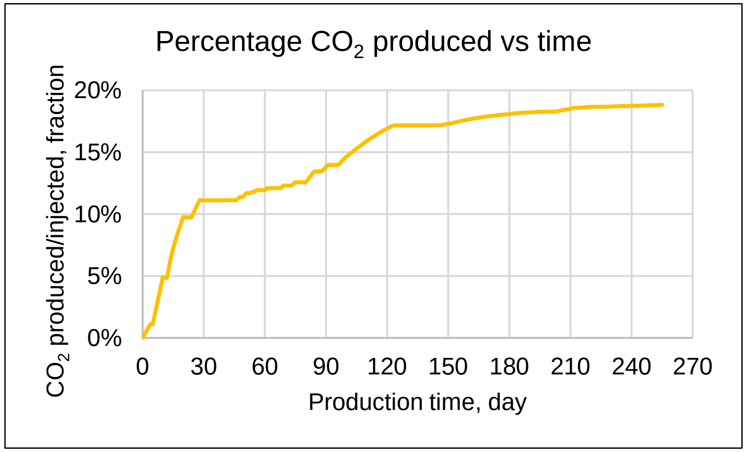
Post Test Interpretation: HnP Simulation

- Calibrated reservoir model to water injection and multi-rate tests; tuned EOS data to measured data (29 API and 30 cP at 60 °F); adjusted Soi and Sor in both matrix and fracture trying to match oil production
- CO_2 venting constrained by gas rate, and production constrained by water production rate
- Simulated peak rate 1.4 stb/d (measured 2.5 stb/d, which is affected by operation rather than following natural decline trend), simulated total oil production at 7 month 86 stb (measured 63 stb).
- Soi in fracture needs to be 15% to match cumulative oil production.



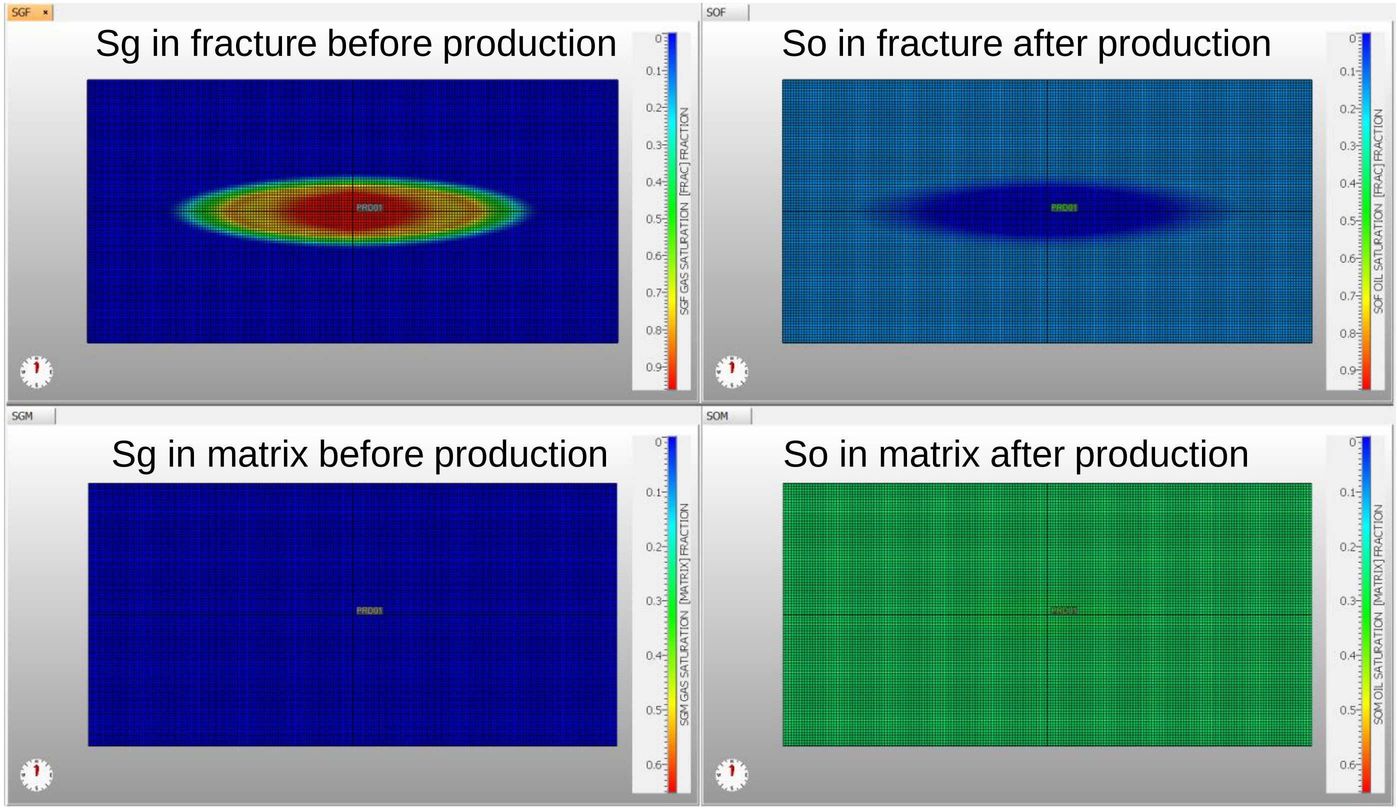


CO_2 production:

11% after venting
19% at 7-month production

Post Test Interpretation: HnP Simulation

- CO_2 stays in fracture, cannot move the 30cP oil in matrix
- Oil is produced from the fracture



Top view of gas and oil saturation in fracture and matrix

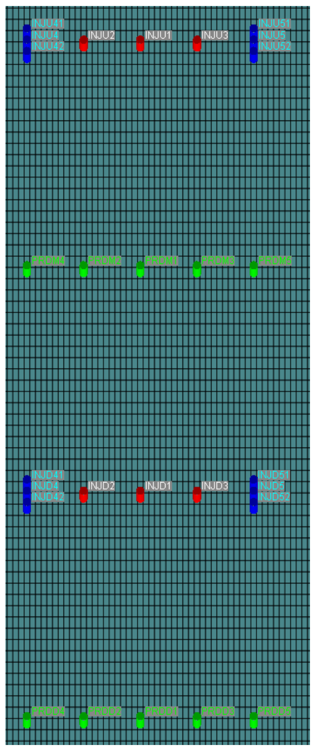
Post Test Interpretation: EOR and Storage

- How did CO_2 enhance 30 cP oil recovery?
  - Natural fractures (likely)
    - Residual oil in fractures produced via Darcy flow (near wellbore CO_2 expansion)
    - Swelling residual oil in fractures (plus produced light hydrocarbons in gas)
  - Matrix (less likely)
    - Darcy Flow: CO_2 would displace mobile water instead of oil if it entered very small water wet pores
    - Swelling: 25% S_{Oi} would not swell to 60% S_{ORW} to mobilize oil
- How was CO_2 stored?
  - Stayed in fractures, moved far enough away that it didn't get produced
  - Hydraulic fracture breached seal, CO_2 is in upper Carper
  - Entered matrix

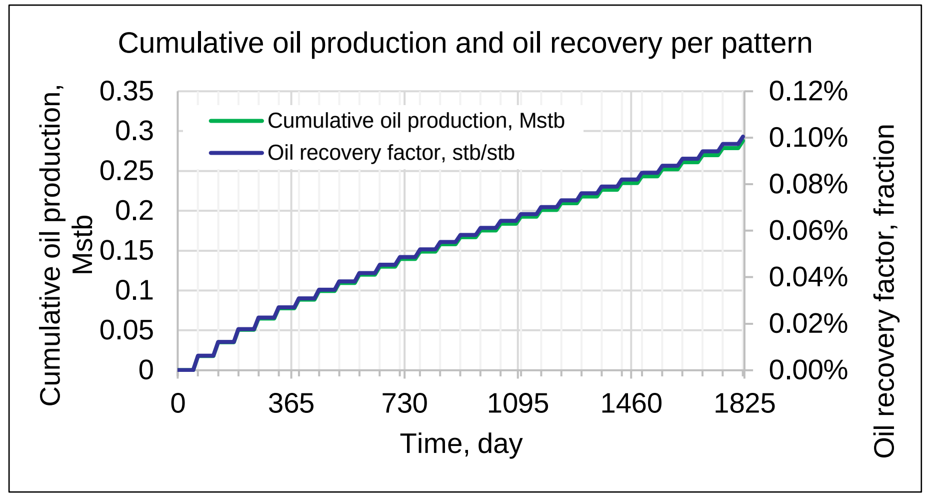
Post Test Interpretation: Calibrated Line Drive

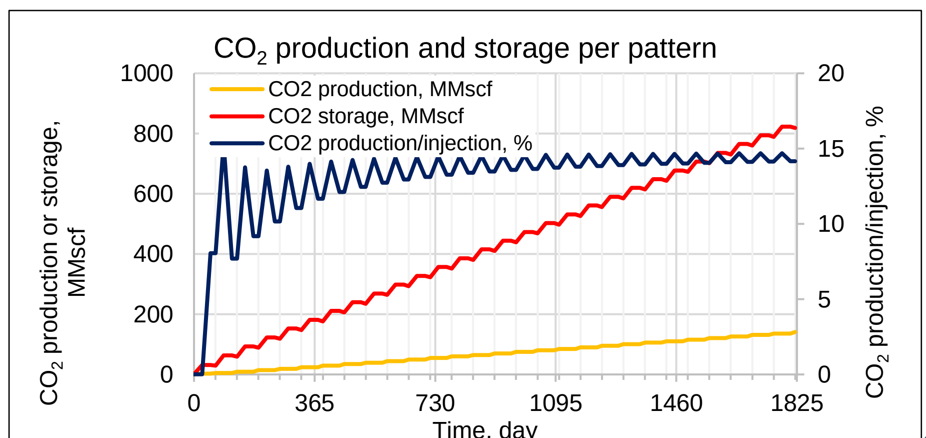
- Line drive showed low oil recovery factor but great storage potential

- Direct line drive CO_2 EOR in 80-acre pattern with a pattern width to length ratio of 1:8 (660 ft :5280 ft)
- SAG to slow CO_2 breakthrough and enhance CO_2 interaction with matrix
- Inject 25 days: CO_2 at 40 t/d/w and water at 200 stb/d/w; soak for 25 days; produce for 15 days at maximum gas rate of 20 t/d/w. Repeat for 5 years



Pattern inner well placement: a row of injectors followed by a row of producers, except the side injectors are converted to water injectors, and more water injectors are added above and below to keep CO_2 in the pattern.





About 14% injected CO_2 was produced, 86% stored.

Conclusions

- Demonstrate CO_2-EOR and storage
  - HnP exceeded pretest expectations
  - Calibrated line drive simulations show low oil recovery factor but high CO_2 storage
- Characterize rock and fluid properties of ROZ
  - 30 cP oil
  - Natural fractures within low permeability matrix exerting large influence