Advanced Recovery in Unconventional Reservoirs

Luncheon Keynote by

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Montana Tech

25th Annual CO_2 Conference

Thursday Dec 12th, 2019

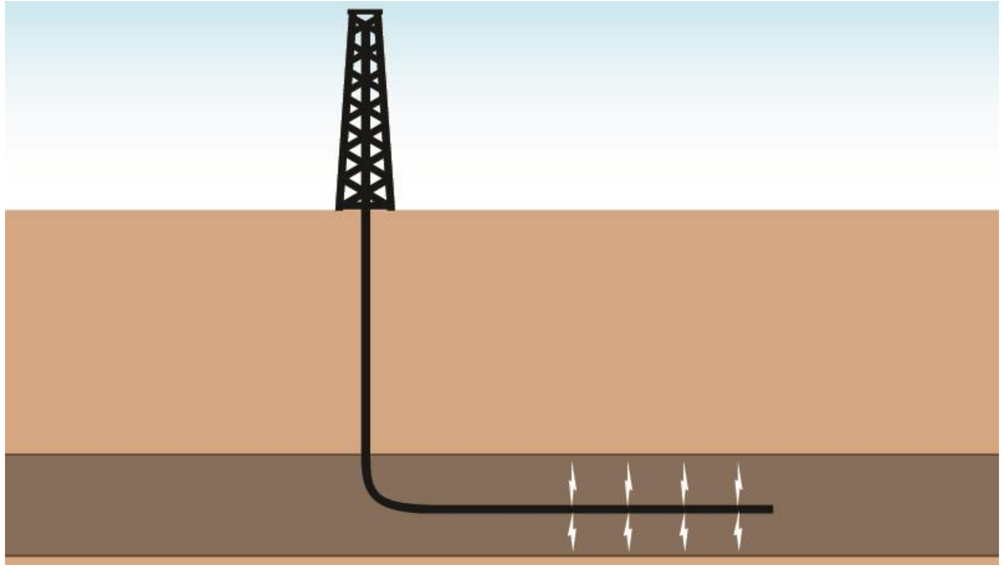
Outline

- Overview of EOR in Unconventional Reservoirs
- Potential Issues/Pitfalls – Things to consider
- Economics & Investments

Unconventional Reservoirs

also known as (aka)

- Shale Oil / Shale Gas
- Resource Reservoirs
- Source Rock Reservoirs
- Light Tight Oil (LTO)



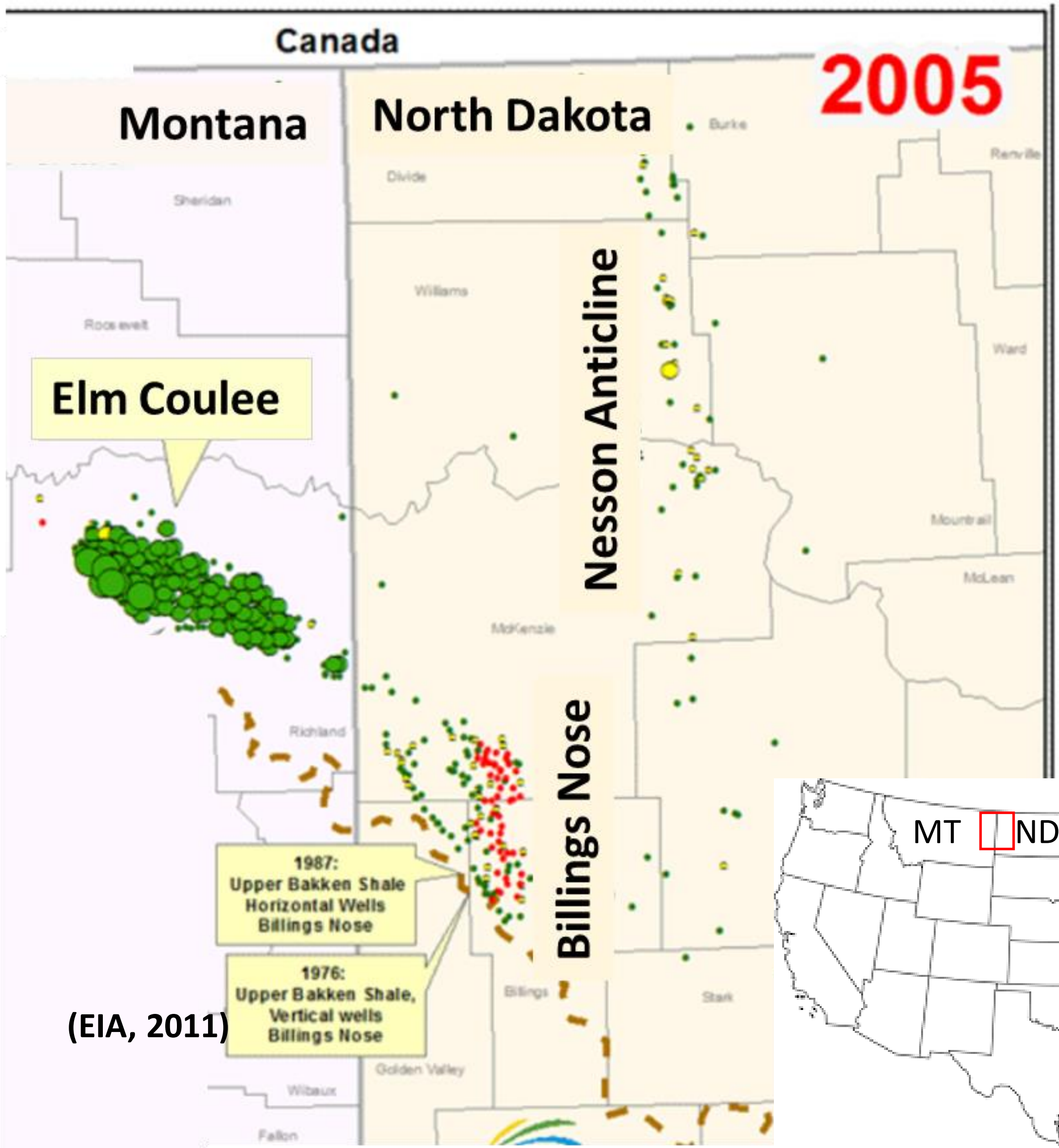
Characteristics

– Source rock & reservoir rock are the same or nearby

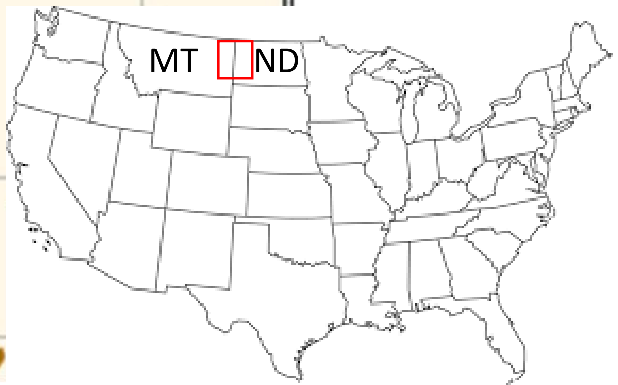
– Extremely low permeability

– Requires long horizontal wells and multi-stage hydraulic fracturing

Elm Coulee Bakken (Montana)

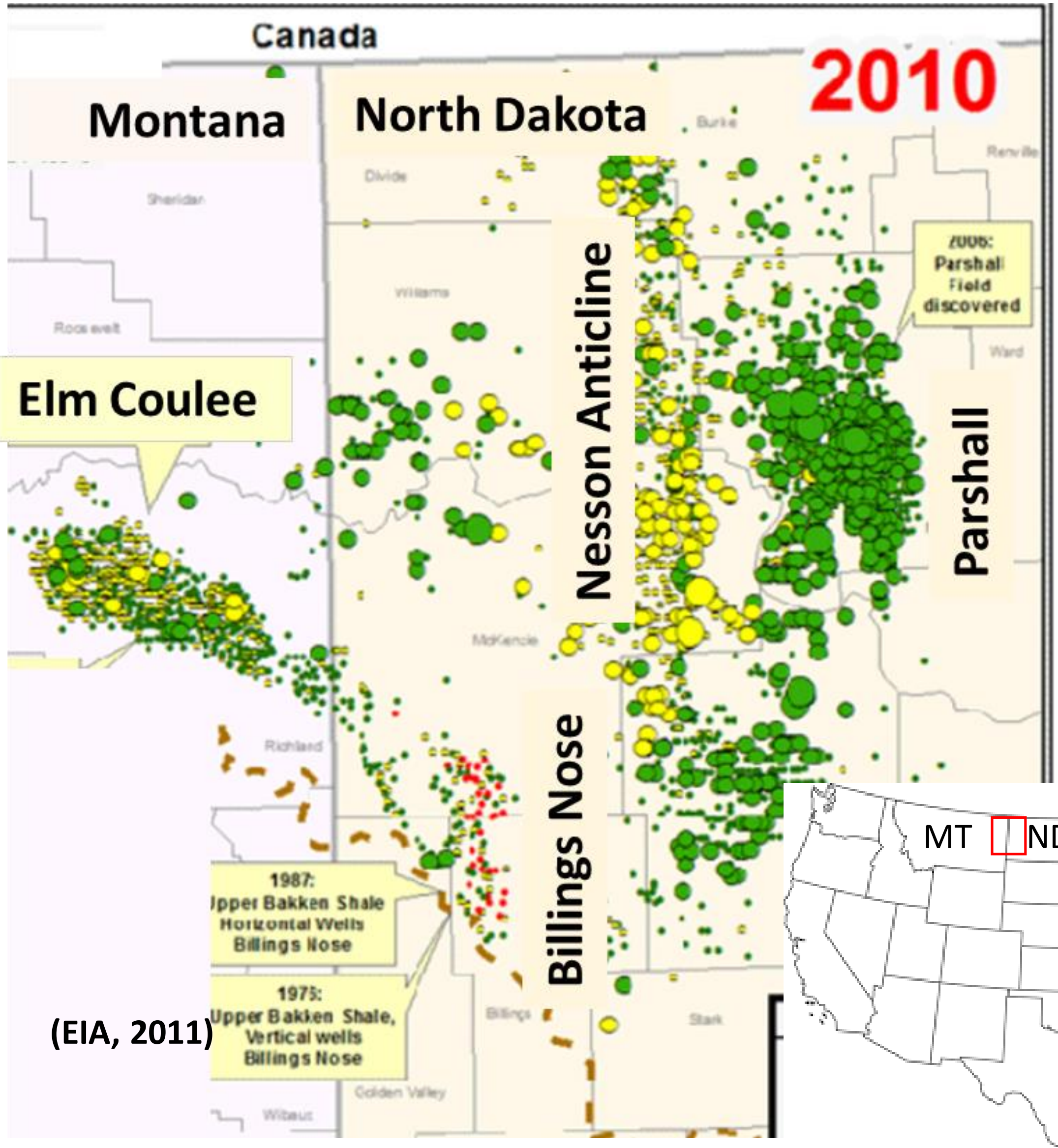


(EIA, 2011)

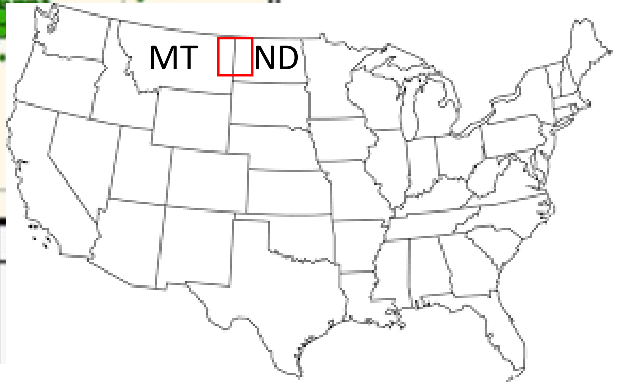


- R. Findley & Lyco Energy drilled first unconventional oil wells in Elm Coulee in late 1999 - fractured in 2000

Bakken – Expanded Development

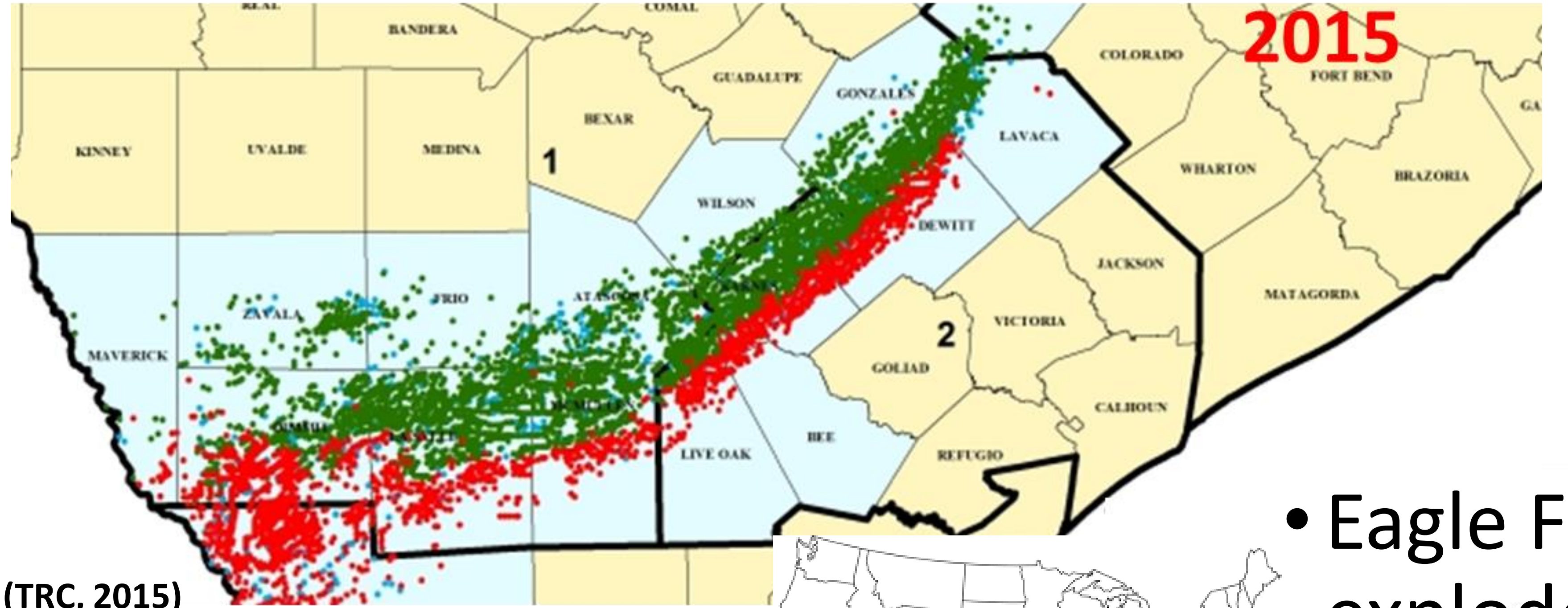


(EIA, 2011)



- In late 2000's, development expanded to North Dakota side of the Bakken

Eagle Ford - Development

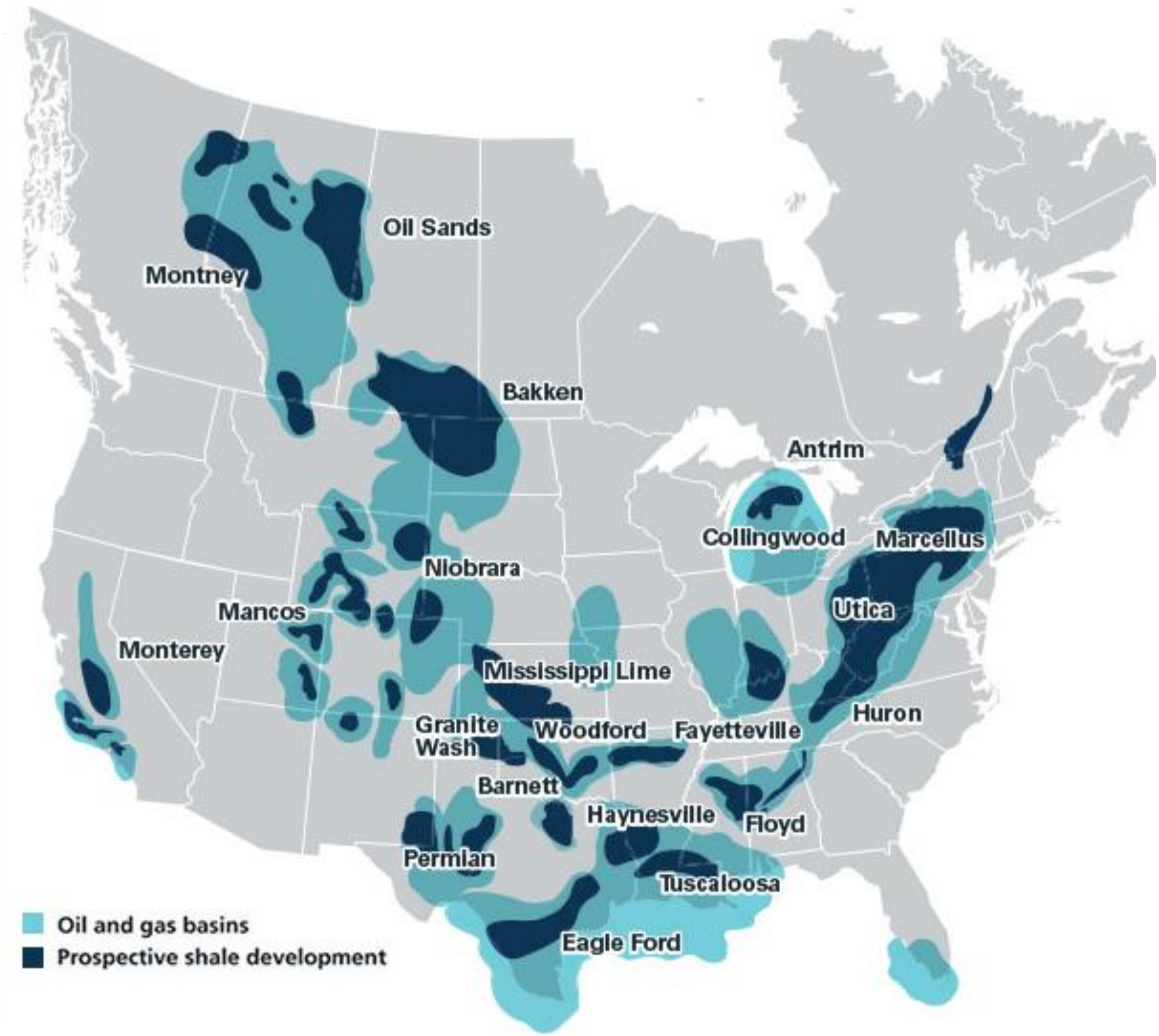


(TRC, 2015)

- Oil Wells
- Gas Wells
- Permitted Wells

- Eagle Ford development exploded in early 2010’s

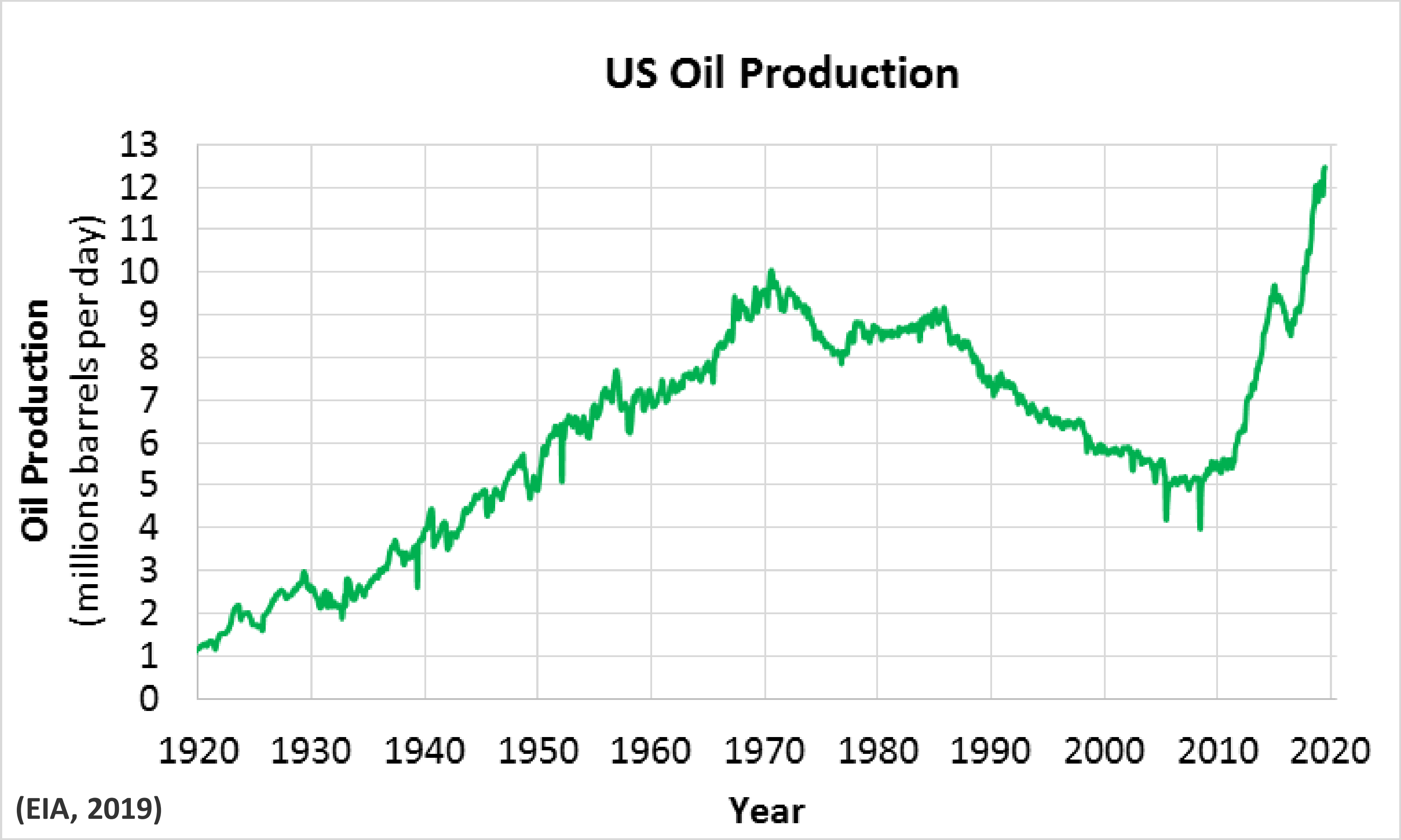
Unconventional Oil Reservoirs



North America Formations

- Bakken
- Eagle Ford
- Niobrara/Codell
- Utica
- Montney
- Permian
- STACK/SCOOP
- Duvernay
- others …

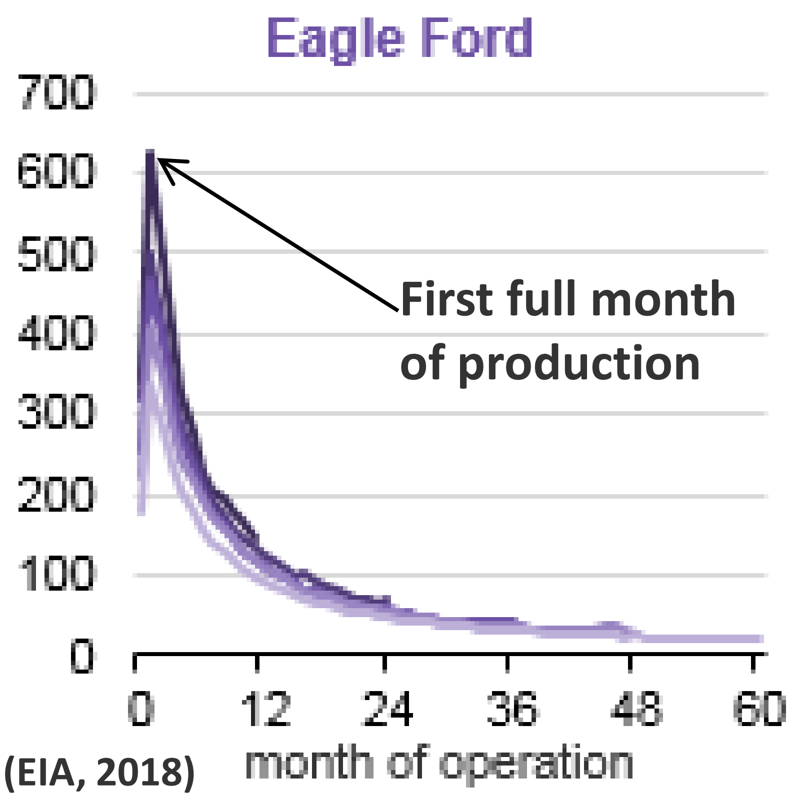
Unconventional Oil Success - US



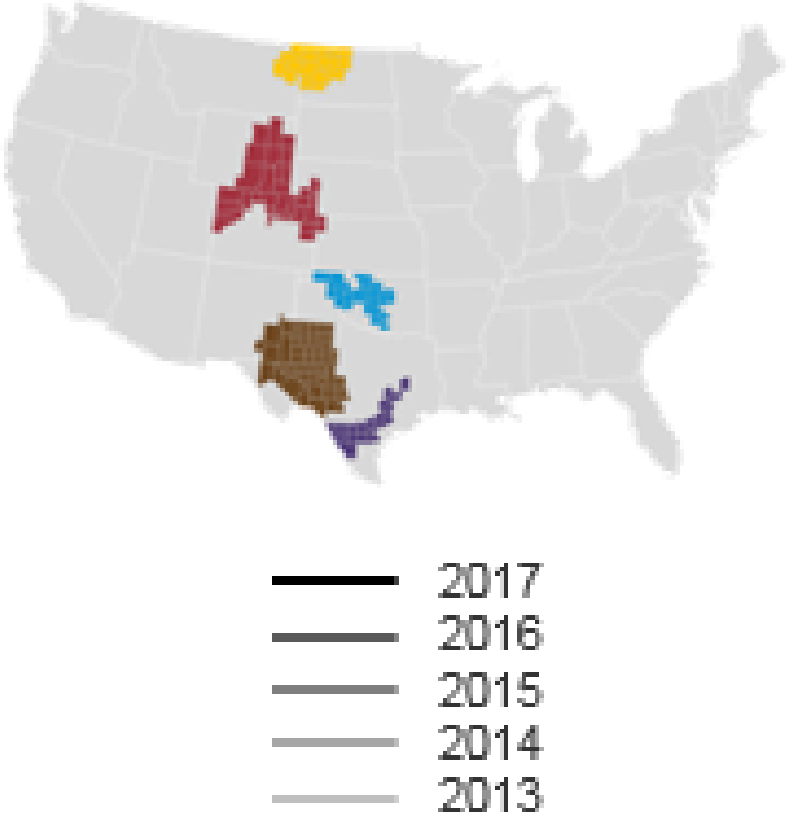
- Increased oil rate in the US is from unconventional oil reservoirs
- Trillions of barrels of oil resource in unconventional reservoirs

Unconventional Oil Opportunities

Average Eagle Ford Oil Production



(EIA, 2018)



- **High initial rates, but rapid decline**
- **Low recovery factors (5-10%)**

- **Need for EOR in unconventionals is apparent**

Options for EOR in Unconventionals

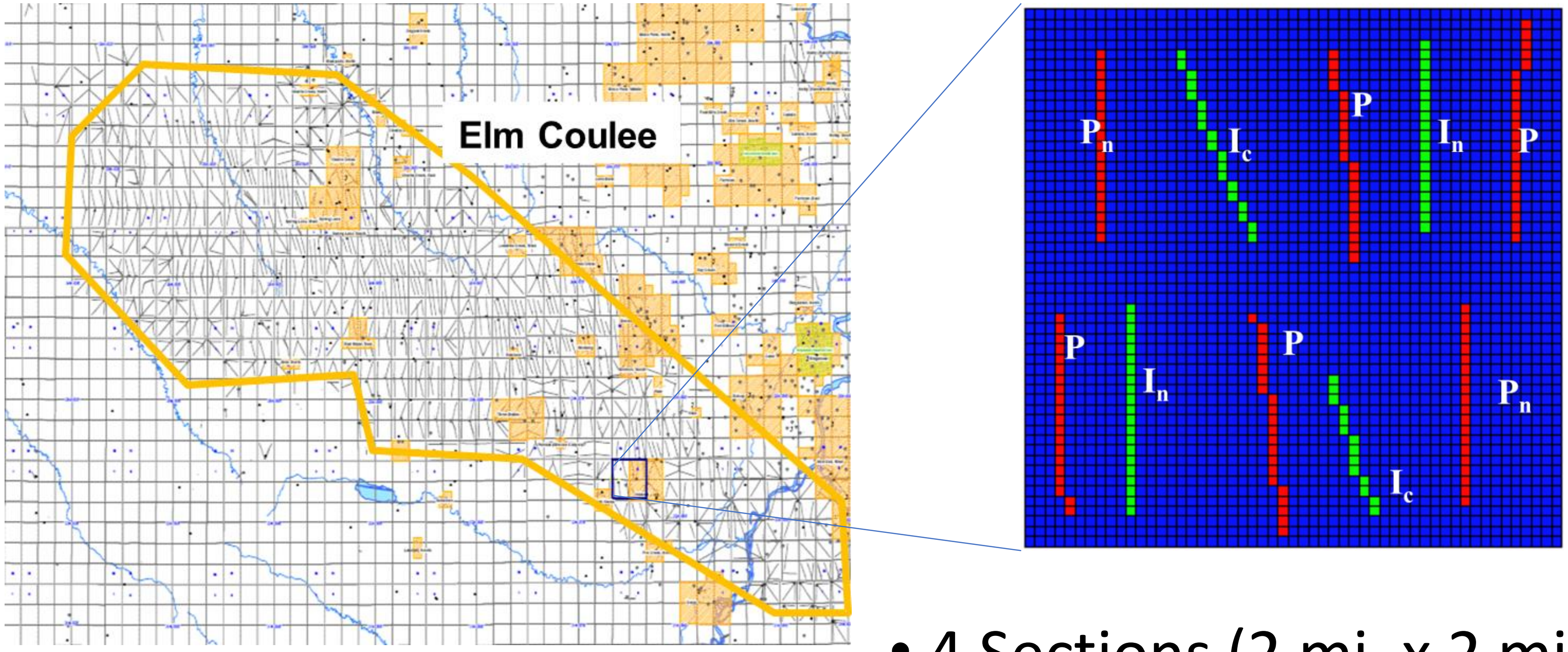
Gas

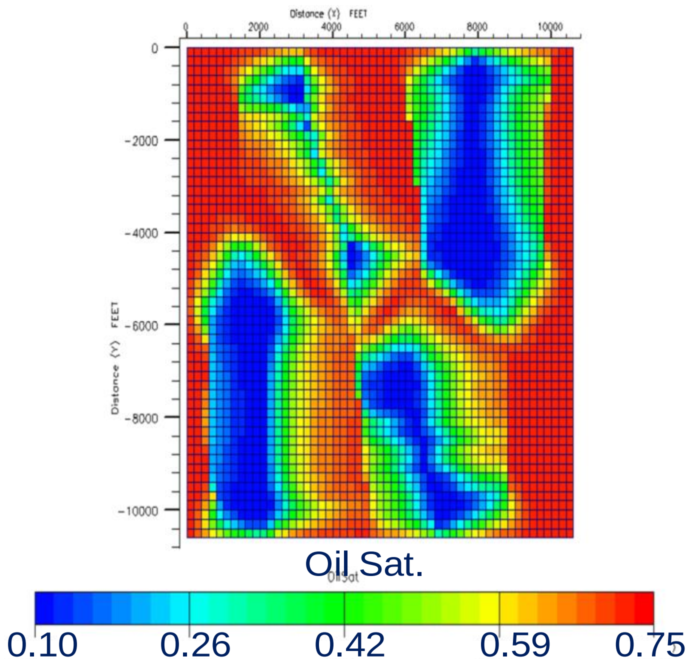
- CO_2
  - Source may be issue
- Rich natural gas
  - 60% C_1, 40% C_2+
  - Behaves similar to CO_2
- Lean natural gas
  - 90+% C_1, <10% C_2+
  - Vapor extraction
- Miscible / Immiscible

Water / Surfactants

- Injectivity doesn't appear to be a concern
- Matrix imbibition
- Surfactants may help
  - Change wettability
  - Find low cost option?
- Low salinity

Initial Simulation Study - Bakken





- **Grad student at Montana Tech**
- **Summer intern at Continental**

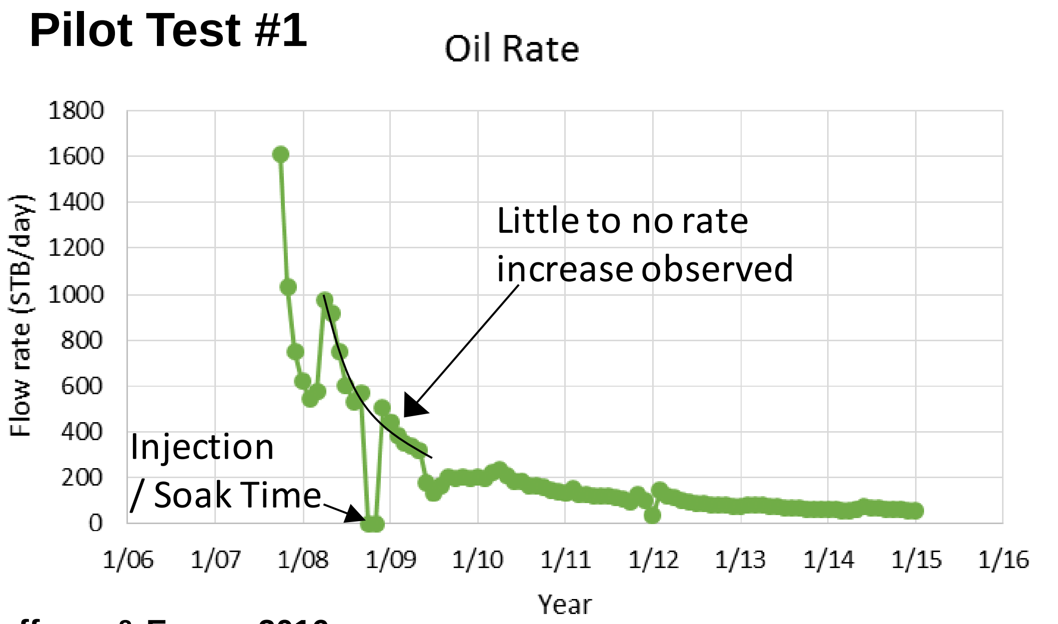
(Shoaib, 2009) SPE 123176

- 4 Sections (2 mi. x 2 mi.)
- 8 layers including upper shale and middle member
- Multiple CO_2 injection cases

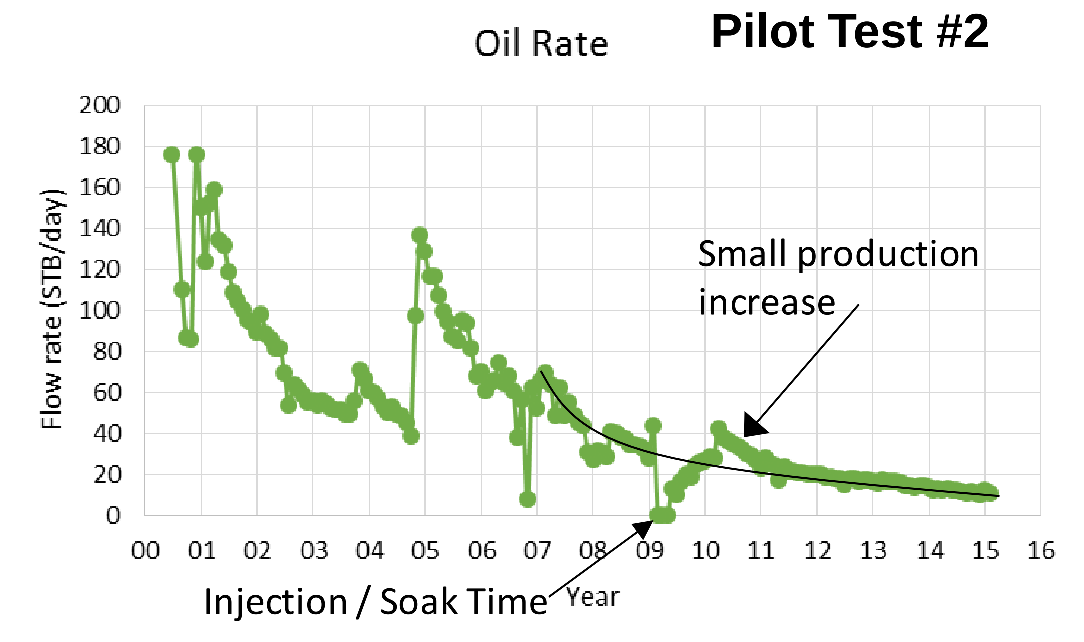
- Simple model
- Indicates added recovery

Early Pilots - CO_2 Injectivity - Bakken

- **2 Pilot tests (one in MT and one in ND)**
- **Injection rates / pressures**
  - ~1500 Mscf/day @ 2000-3000 psi
  - 30-45 days inj., 10-20 days soak, ~ 3 months prod.

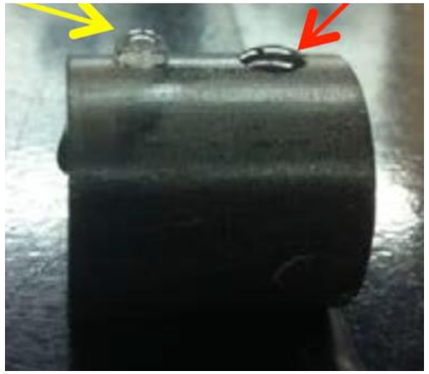


Hoffman & Evans, 2016



EOR in UR - Research

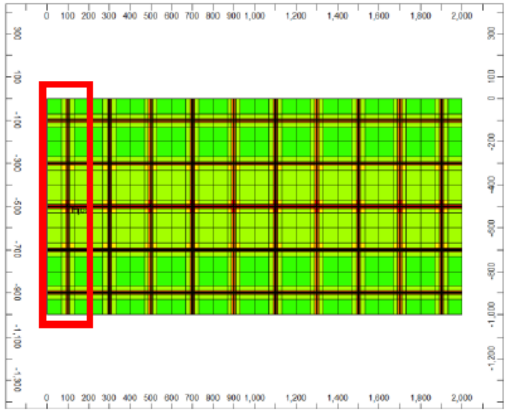
- Laboratory / Experiments
  - Gas Injection
  - Surfactants
- Analytical Analysis
- Reservoir Modeling / Flow Simulation
  - Generally, models showed success
  - Capturing true EOR response?



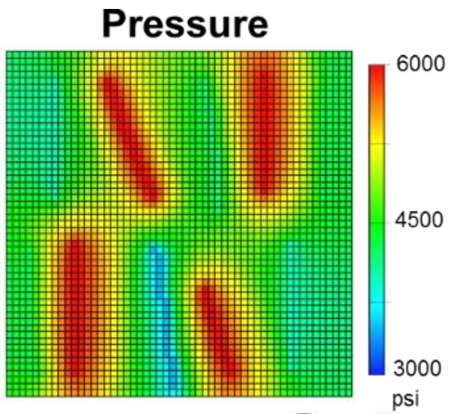
Nguyen et al, 2014

Adekunle et al, 2013

Kurtoglu, 2013

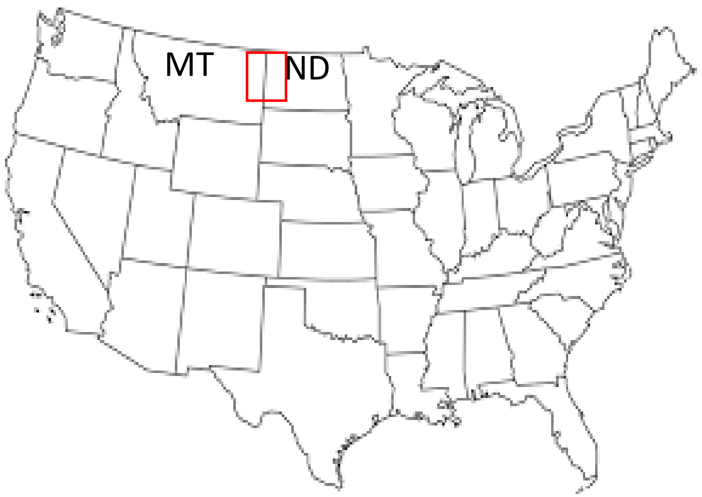


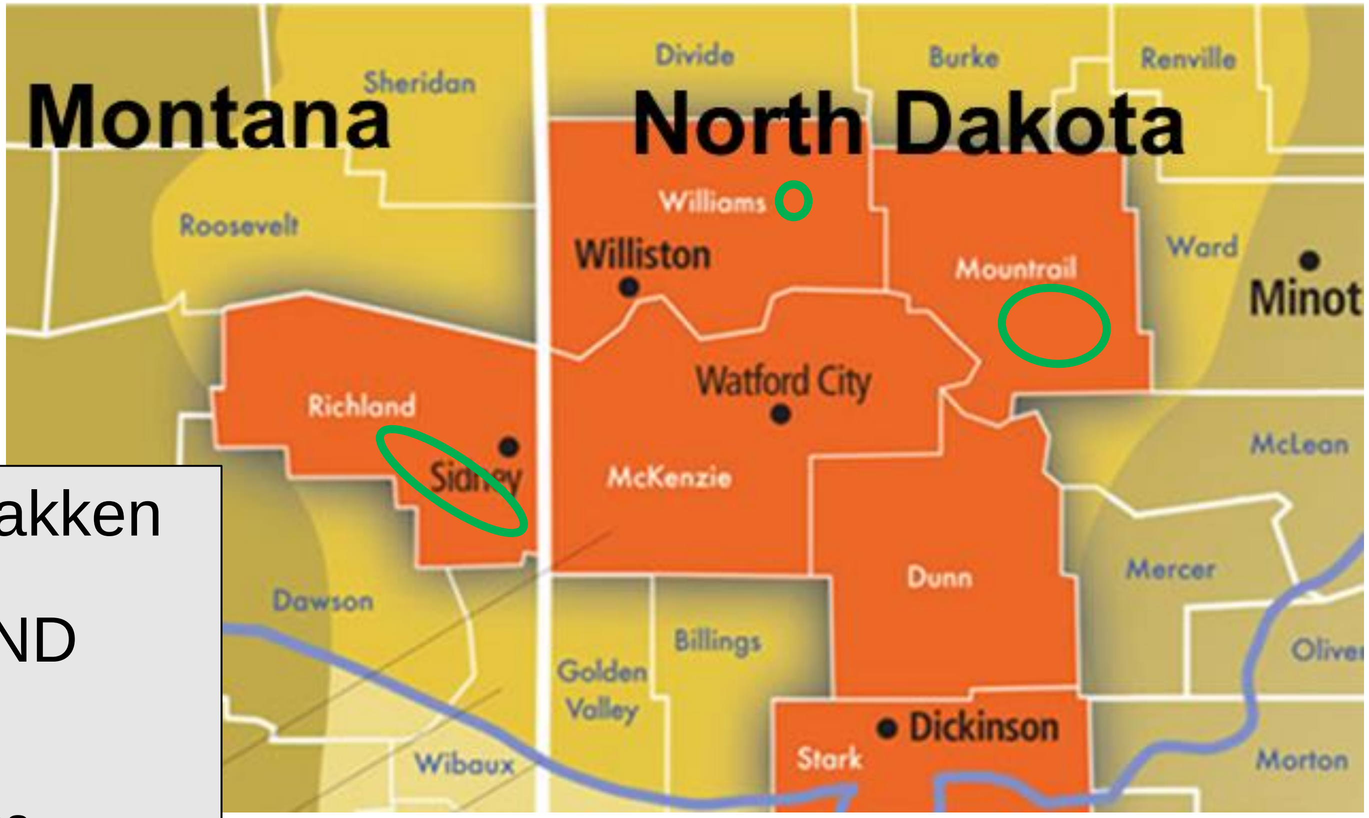
Wan et al, 2013



Hoffman, 2011

EOR Pilots in the Bakken





9 pilots in MT/ND Bakken

- 3 in MT and 6 in ND

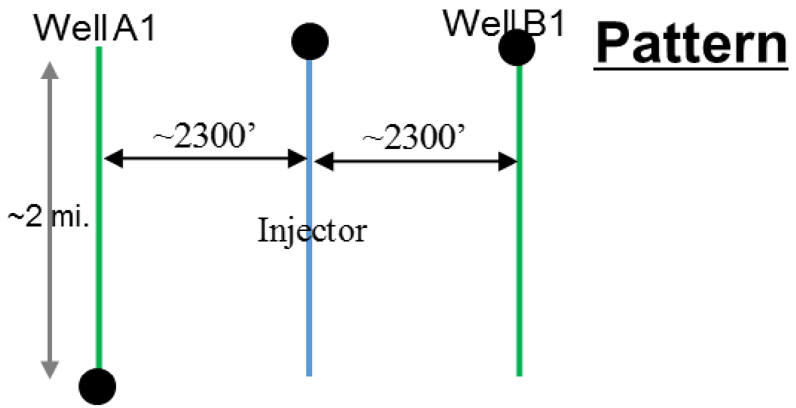
5 Gas → 3 CO_2, 2 Natural Gas

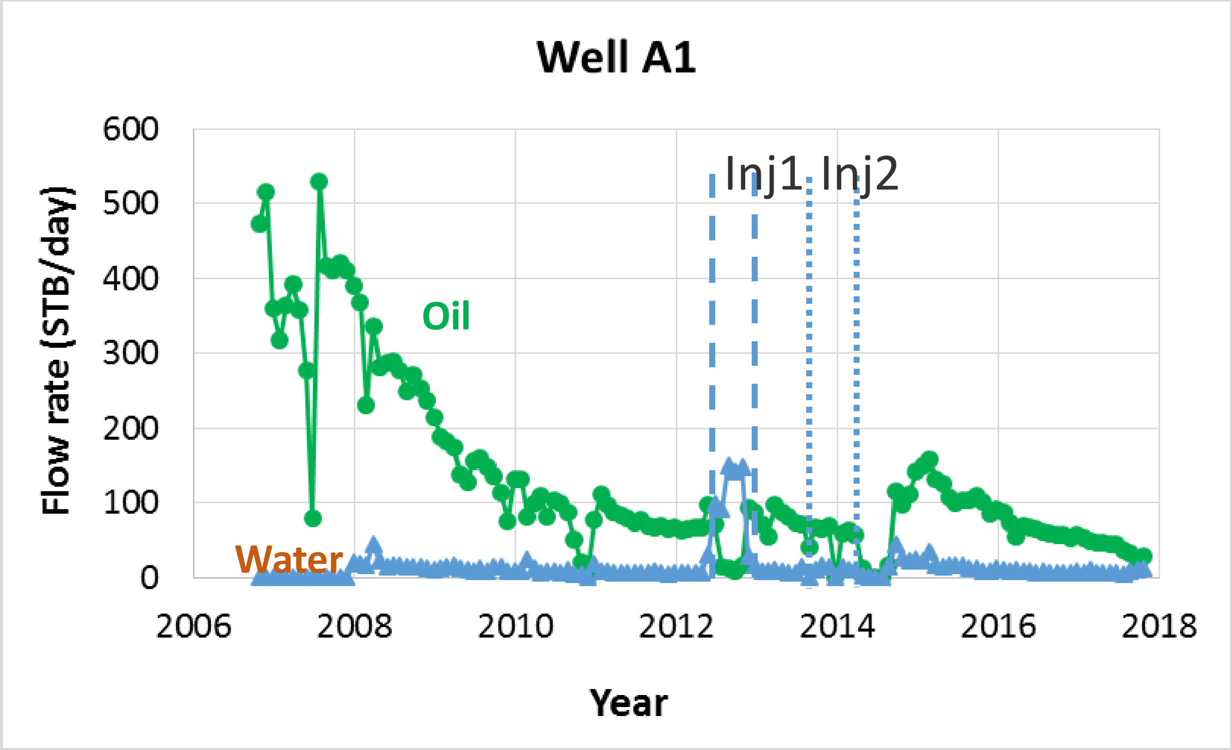
4 Water (1 with surfactants)

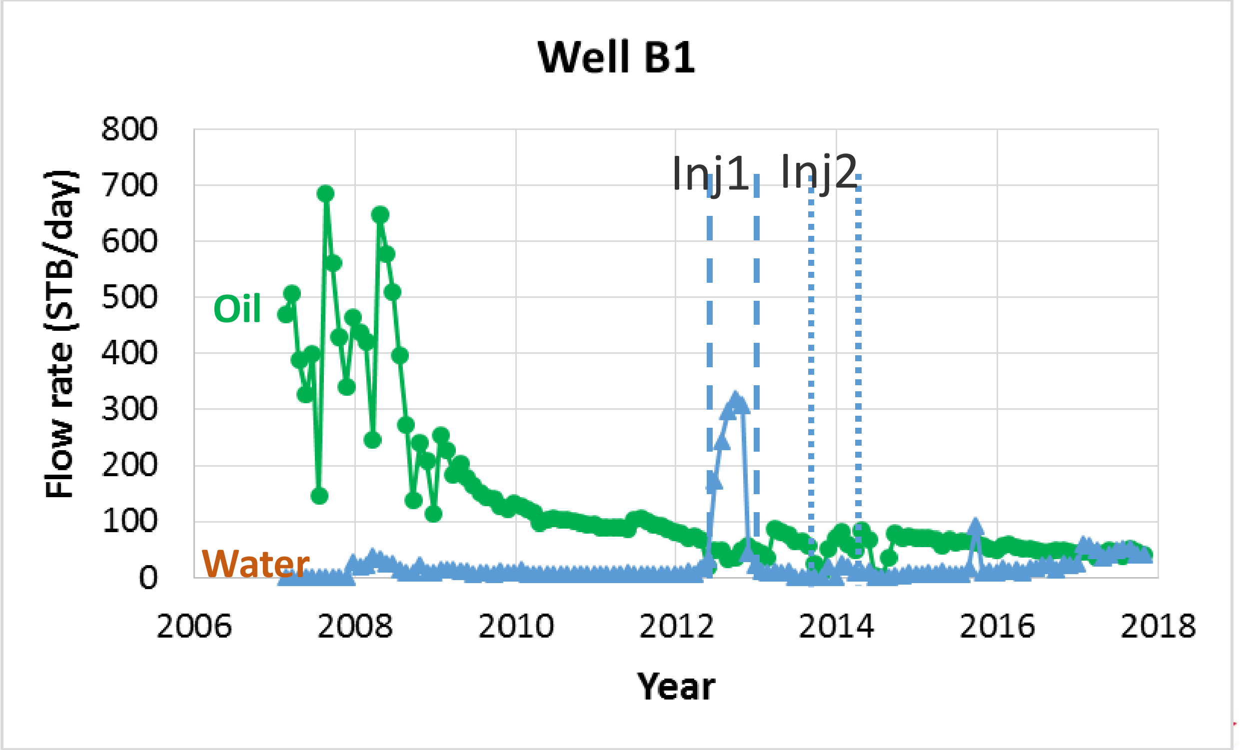
SPE 180270

Continuous Water Injection – Bakken Pilot

- **Injection rates**
  - ~1350 bbl/day for 8 months
  - then shut in for 6 months
  - ~380 bbl/day for 8 months



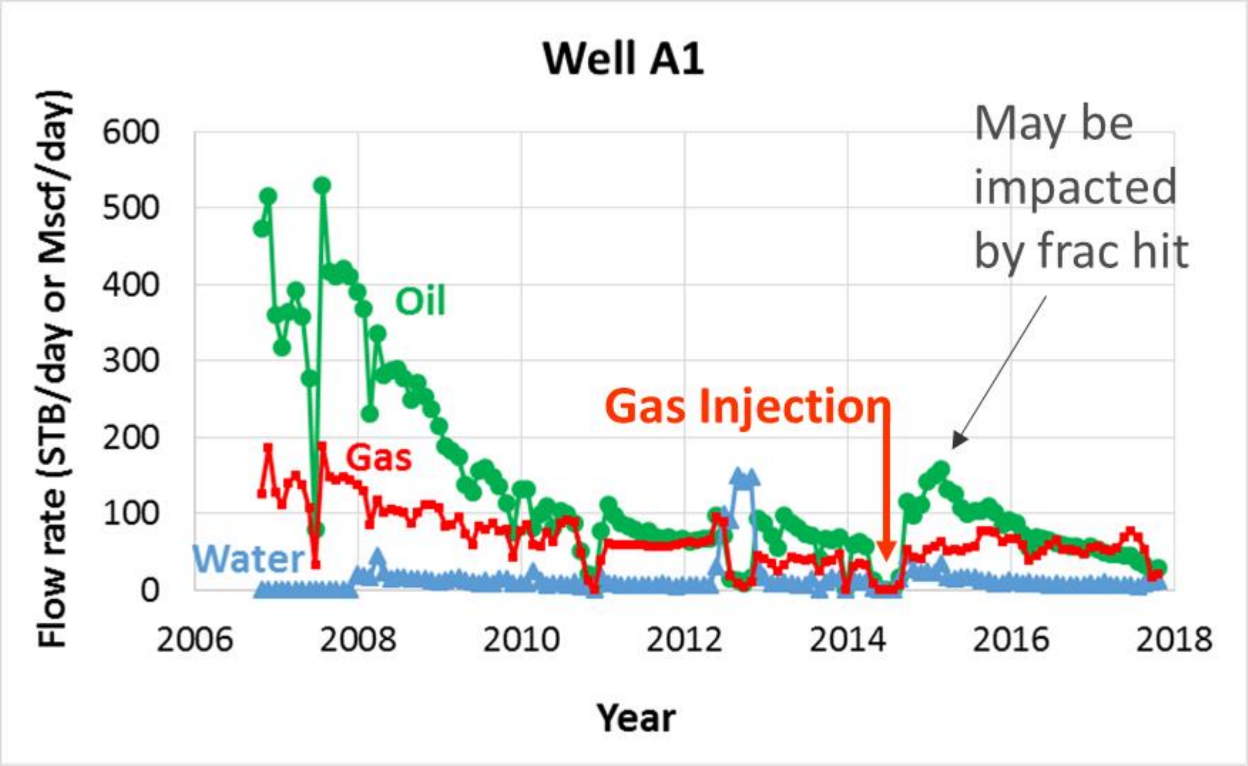


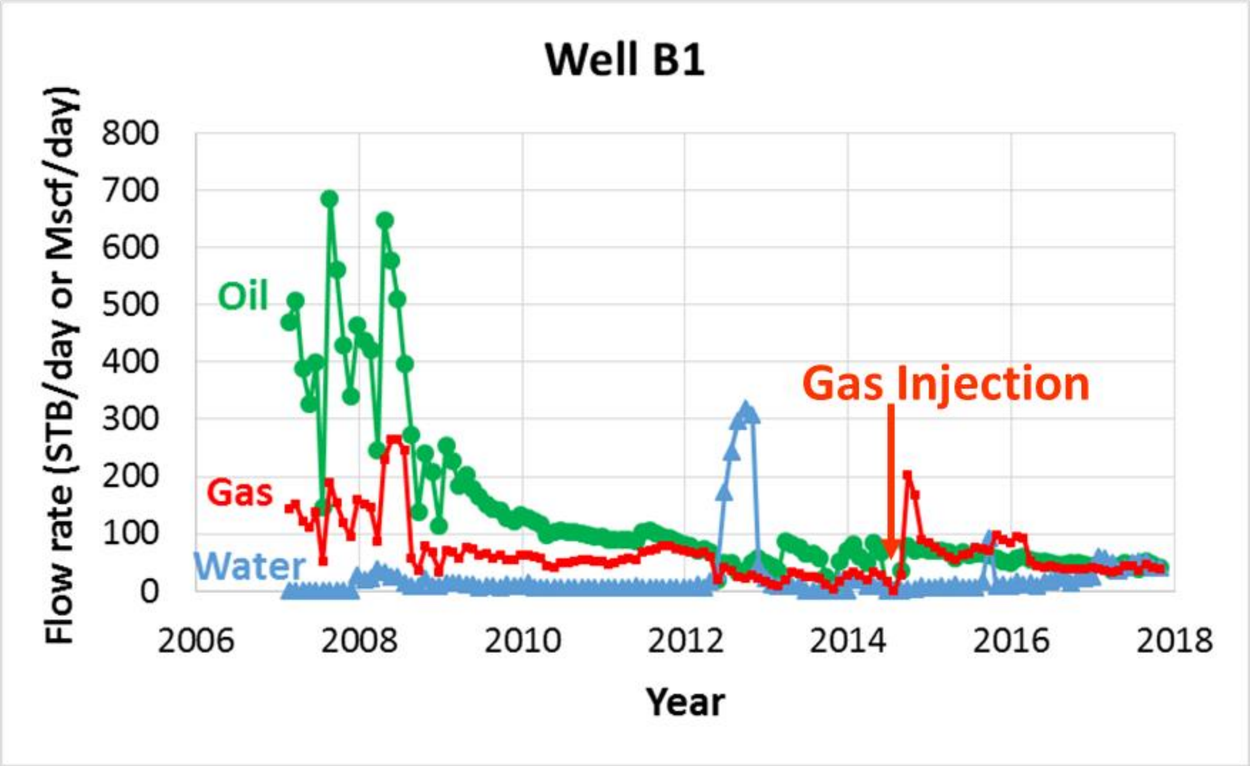


Continuous Natural Gas Injection - Pilot

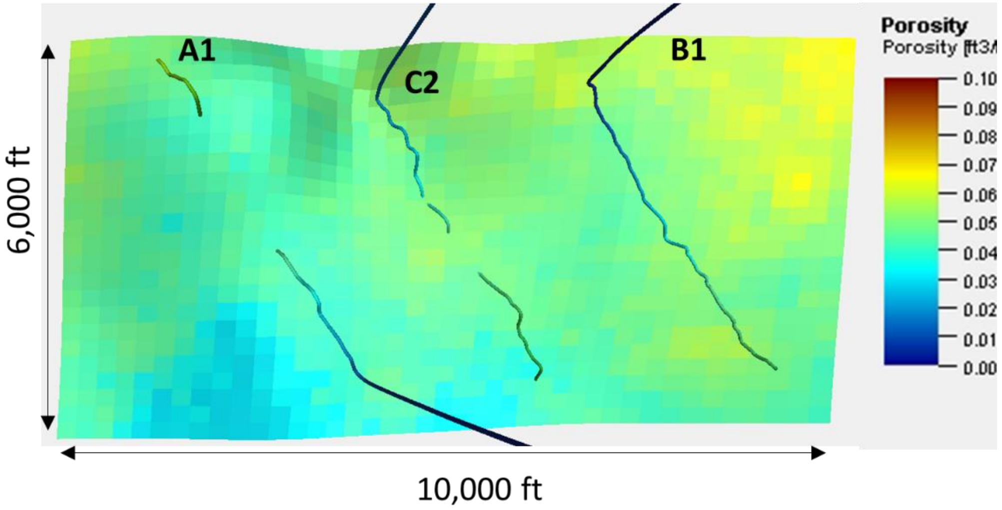
- **Injection rates**
  - ~1700 Mscf/day for 2 months
- **Most encouraging of Bakken pilots**
  - All wells have increased oil production (2 wells complicated by frac hits)

Also looked at offset wells North and South of injection well





Injection Pilot - Flow Simulation Model



Average properties

H = 33 ft $\qquad k_H$ = 0.023 md

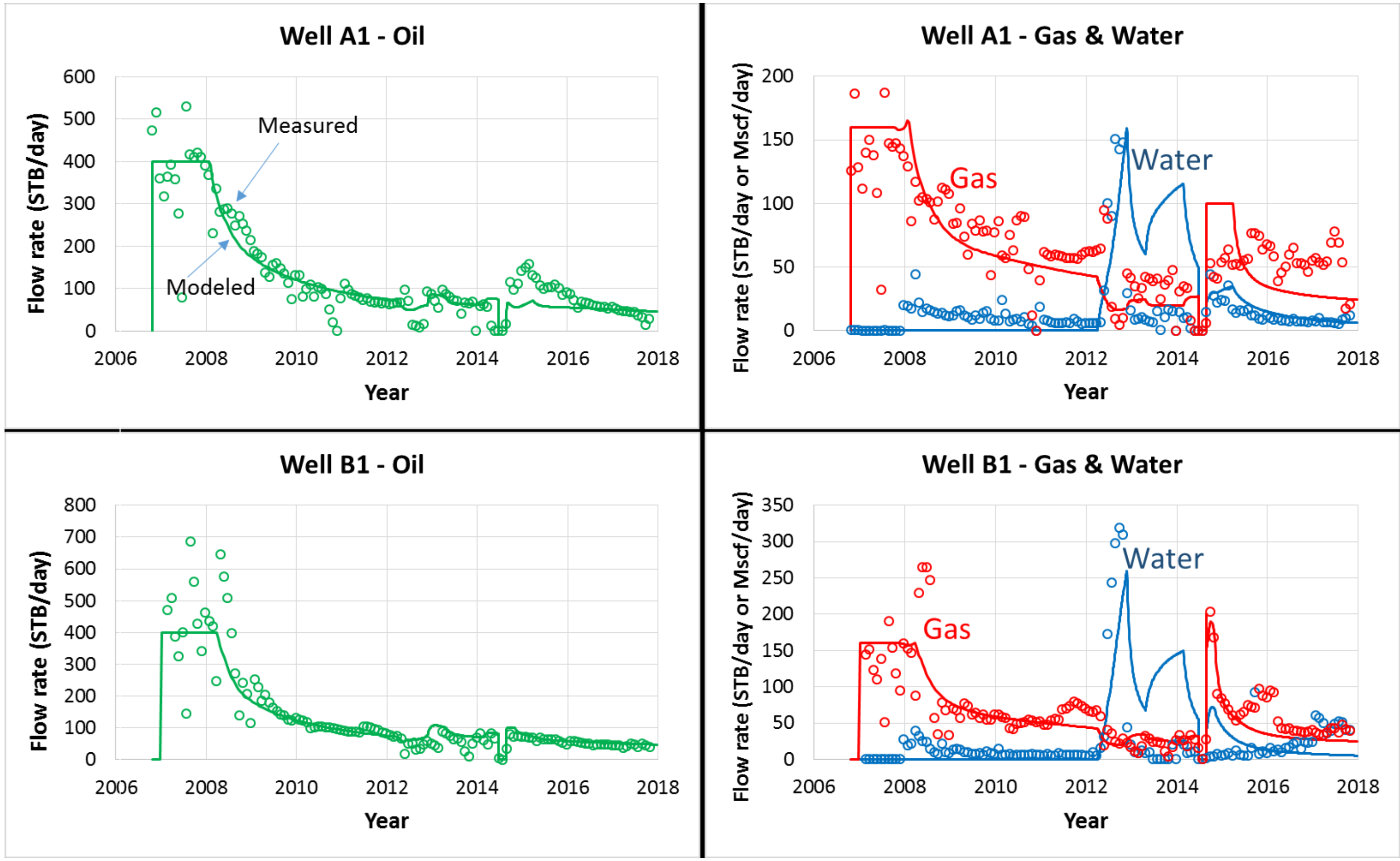
ϕ = 4.3 % $\qquad k_V$ = 0.023 md

- Hydraulic fractures modeled in dual porosity grid

ϕ_f = 0.01 % $\qquad k_f$ = 50 md

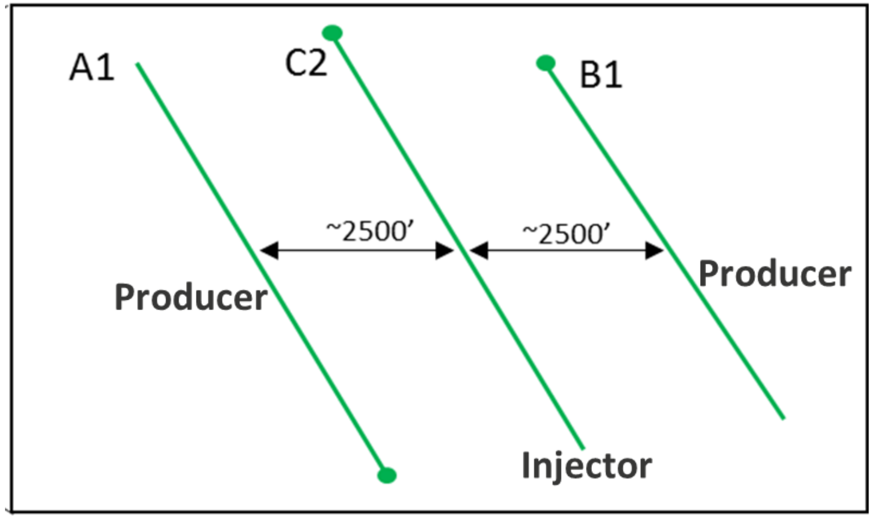
➢ History Matching Results

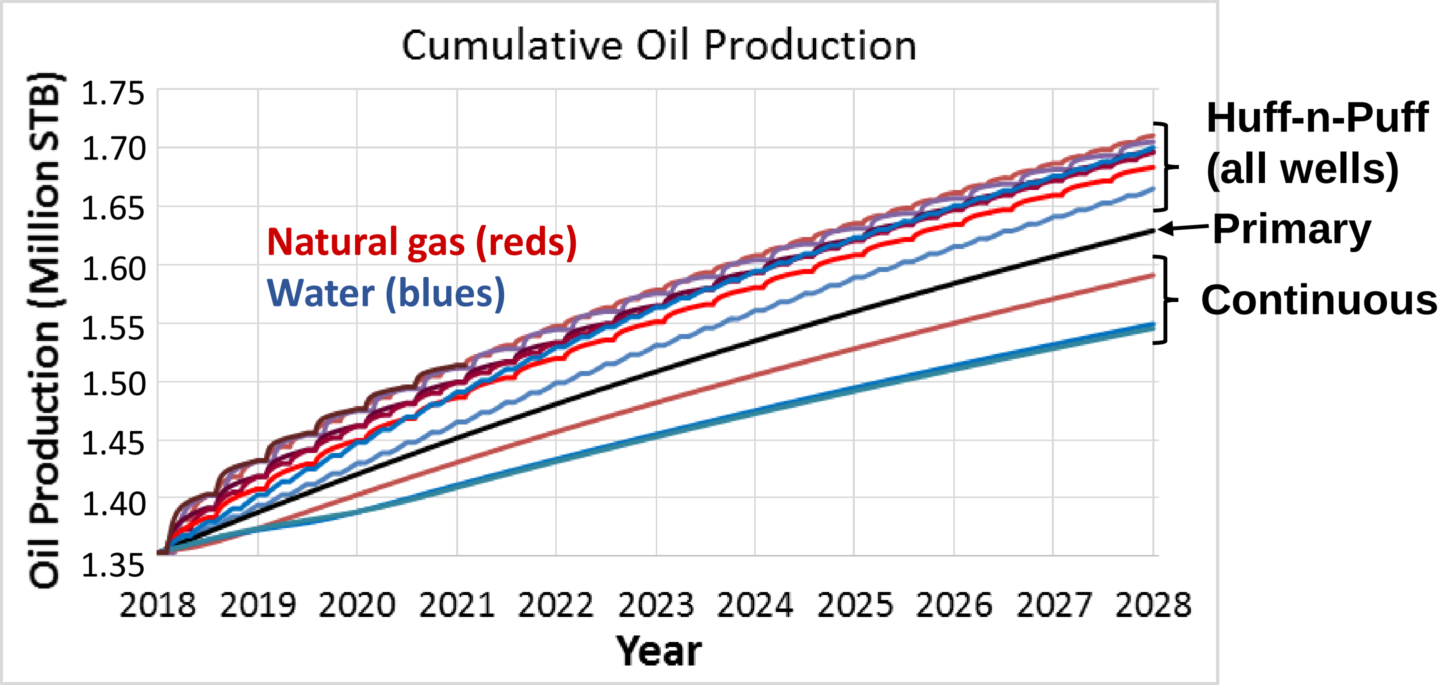
Individual Wells



Injection Pilot - Prediction Cases

- **Continuous vs. Huff-n-Puff**
- **Water vs. Natural Gas**
- **Injection Rate Sensitivity**
- **Cycle Change Frequency**



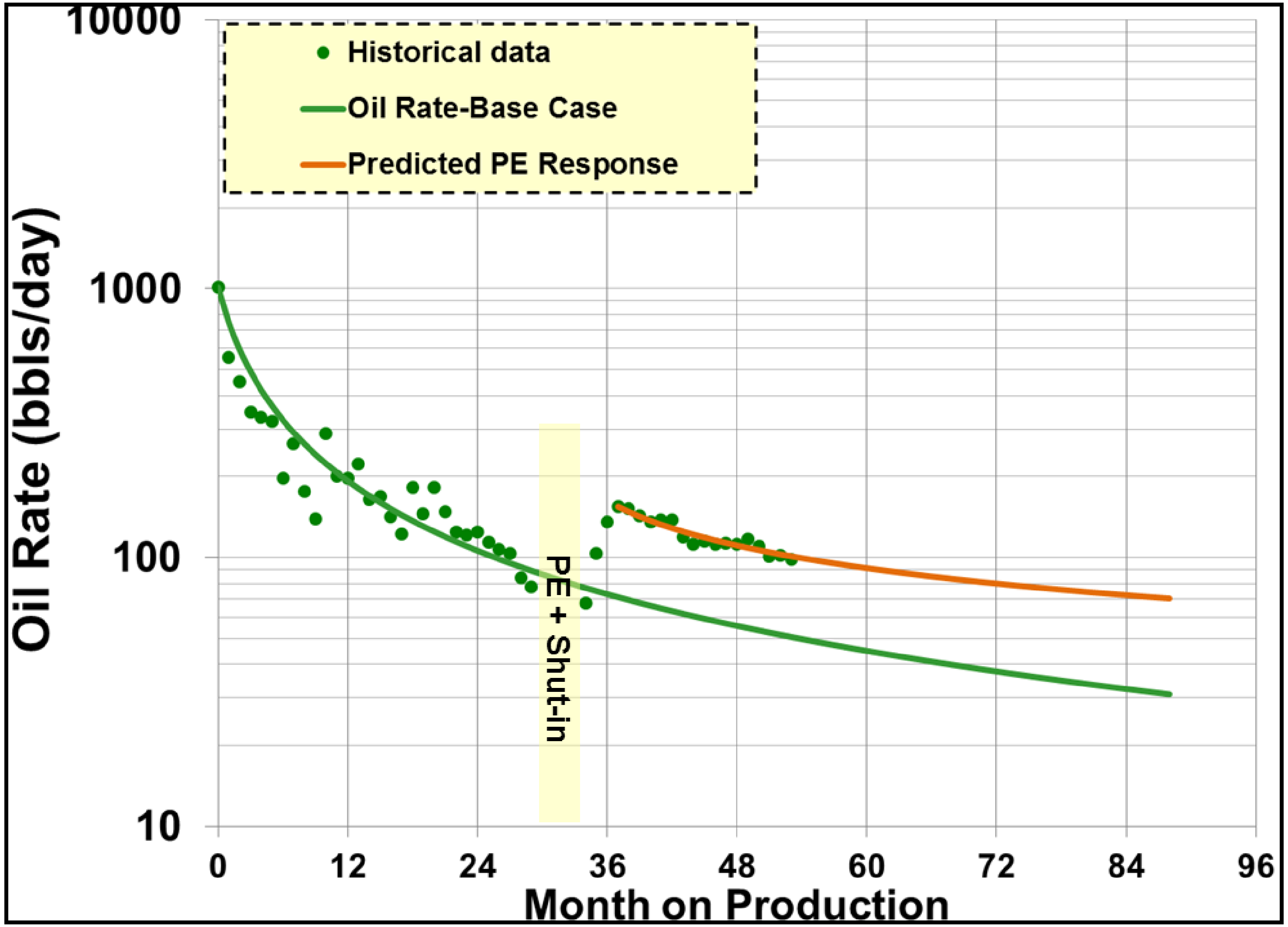


Huff-n-Puff :: ~20% better than primary

Continuous :: ~20% worse than primary

SPE 190221

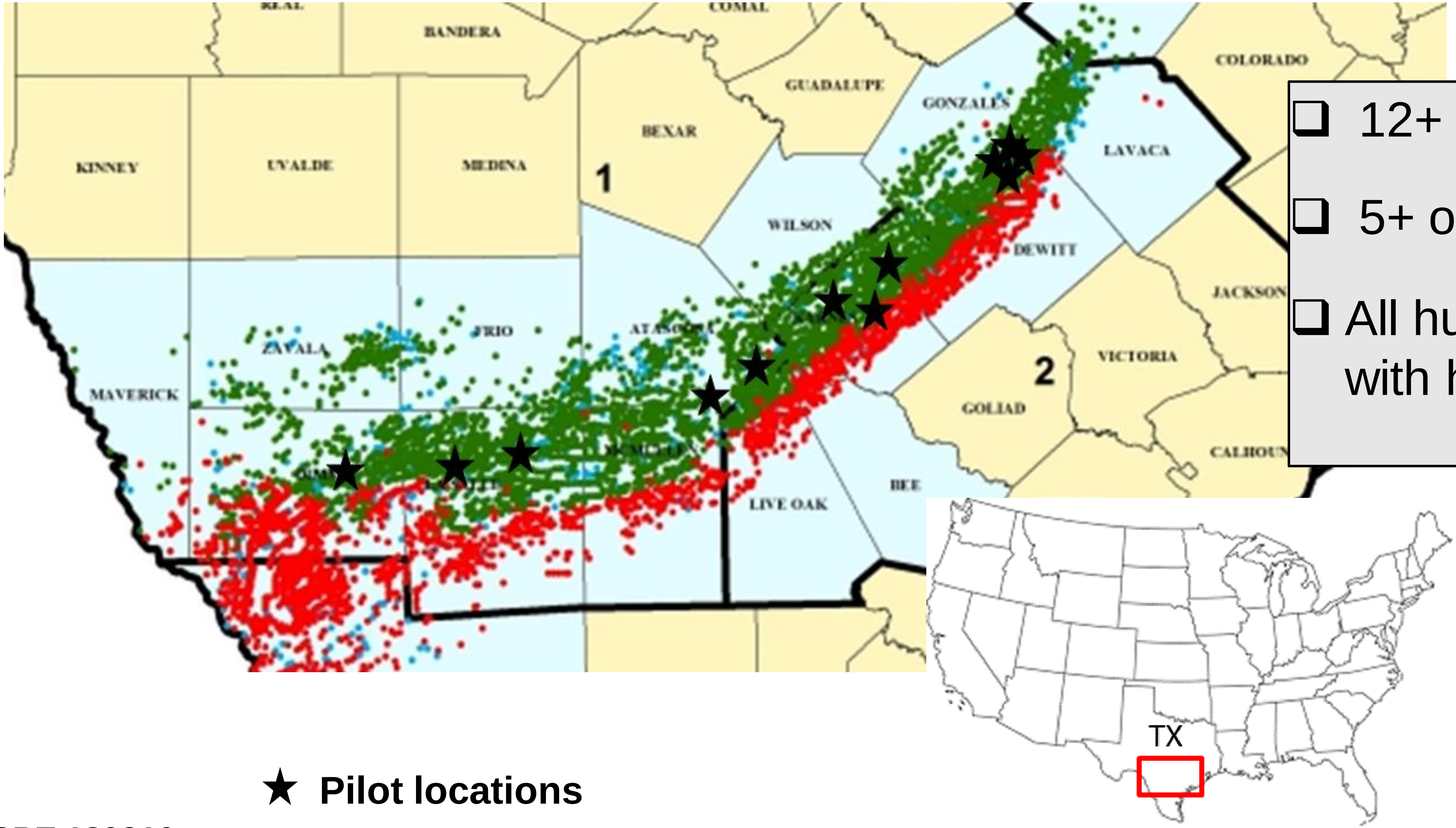
Injection Pilot - Surfactants



- ➢ **Surfactant Concentration**
  - ~1500 ppm
  - Low salinity brine
- ➢ **2 weeks of injection**
- ➢ **4 months shut in (soak)**

- ➢ **Oil rate increased from ~80 bbl/d to 180 bbl/d**
- ➢ **Sustained for 1.5 years so far …**
- ➢ **Increase EUR by 25%**

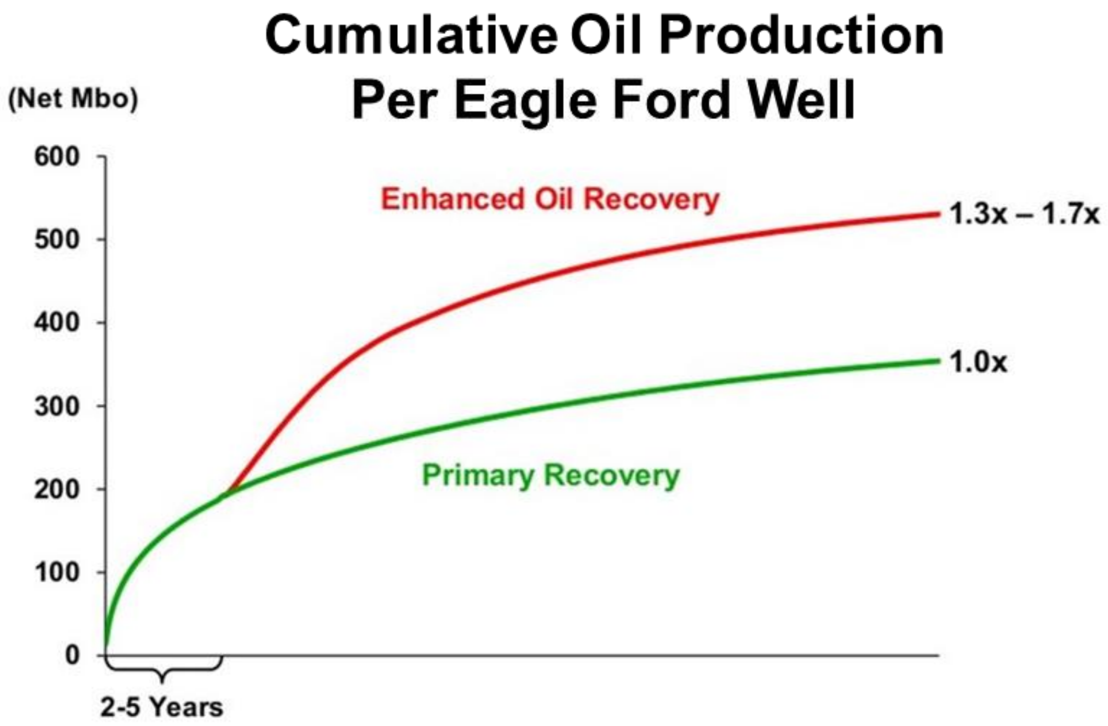
EOR Pilot Tests - Eagle Ford

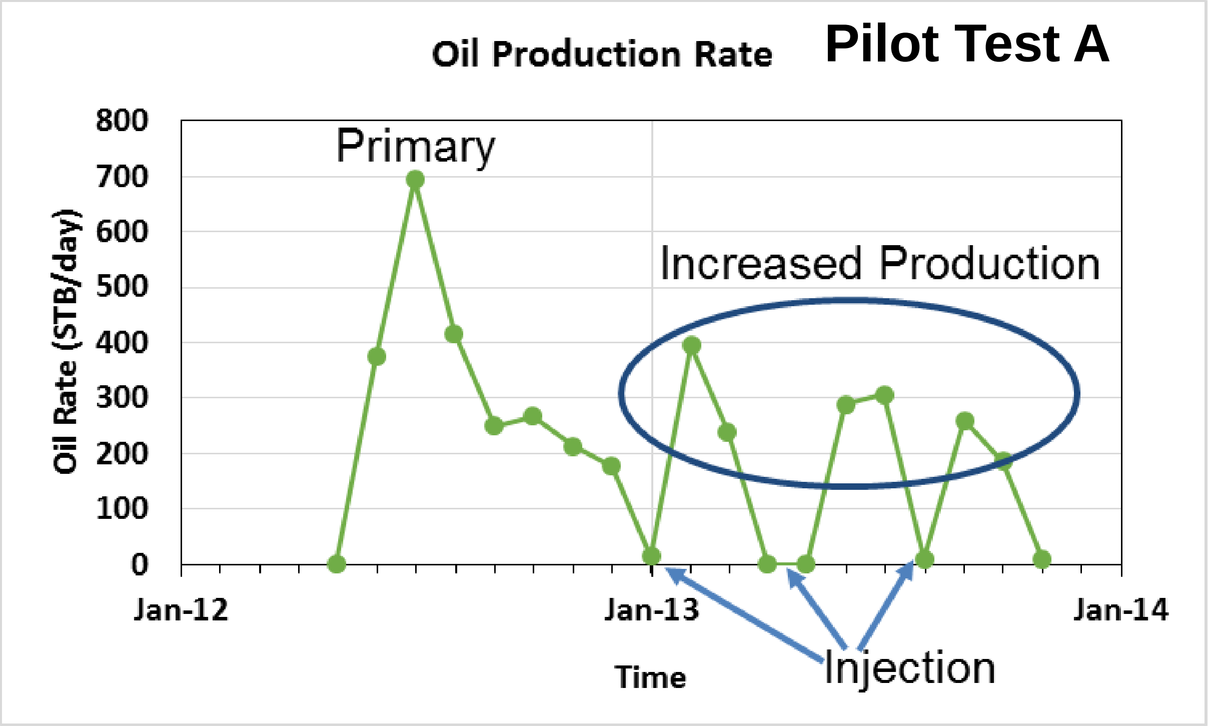


- 12+ pilots in Eagle Ford
- 5+ operators
- All huff-n-puff operations with hydrocarbon gas inj.

★ **Pilot locations**

Eagle Ford - Huff-n-Puff EOR

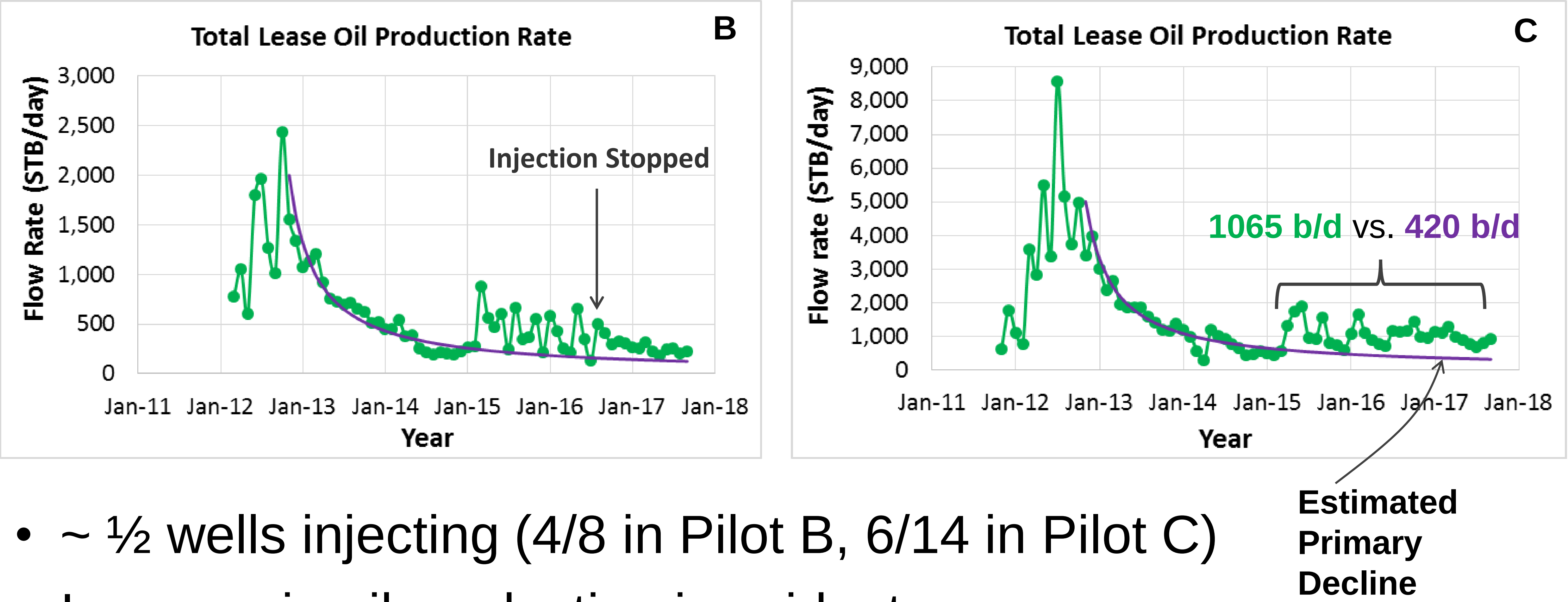




- Reported in investor relations presentation
- But no data presented

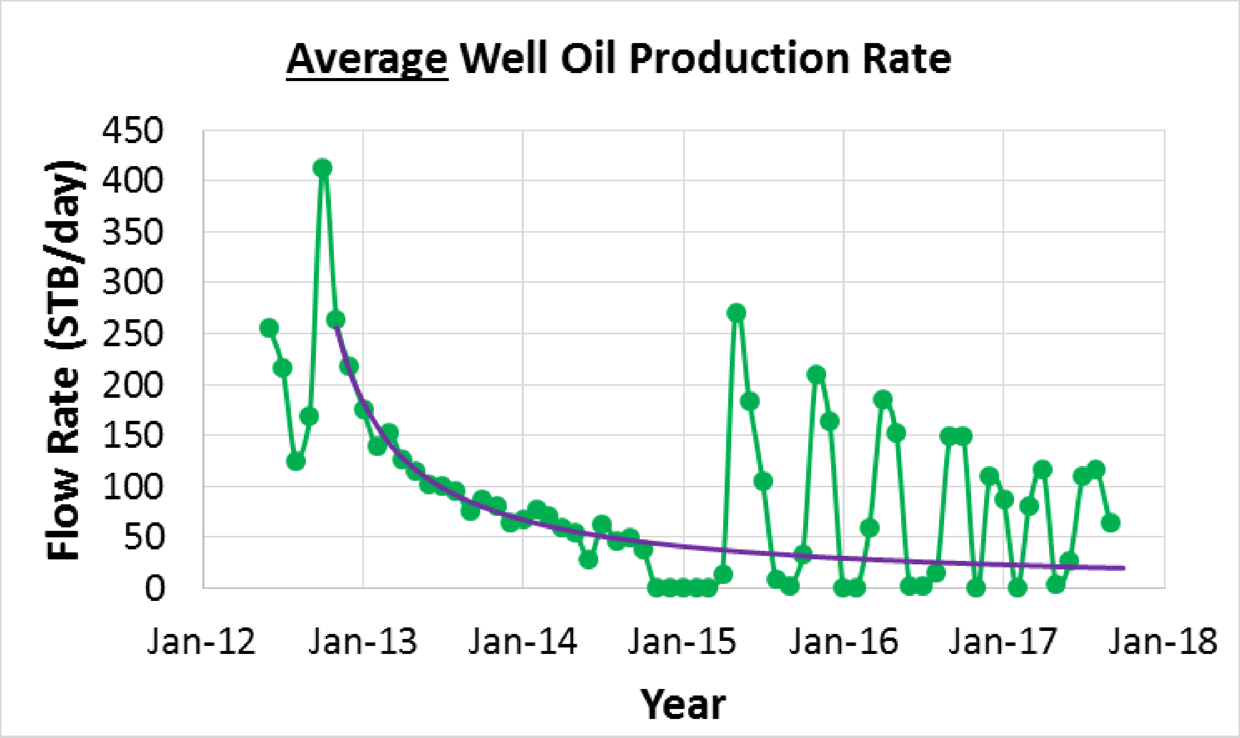
- Started at end of 2012
- Lean gas Inj. (90-95% C_1)
- 3 cycles in 2013

Multi-Well - Huff-n-Puff EOR

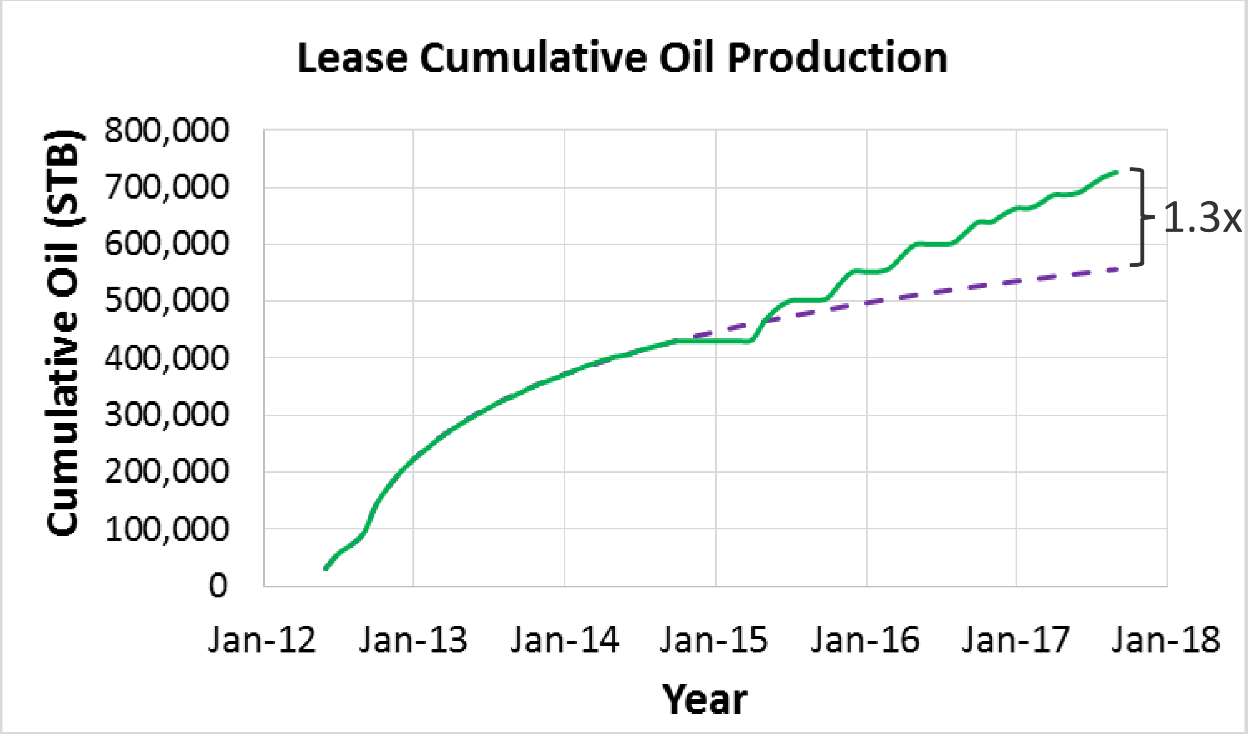


- ~ ½ wells injecting (4/8 in Pilot B, 6/14 in Pilot C)
- Increase in oil production is evident

Eagle Ford Huff-n-Puff Pilot D: 4 Wells



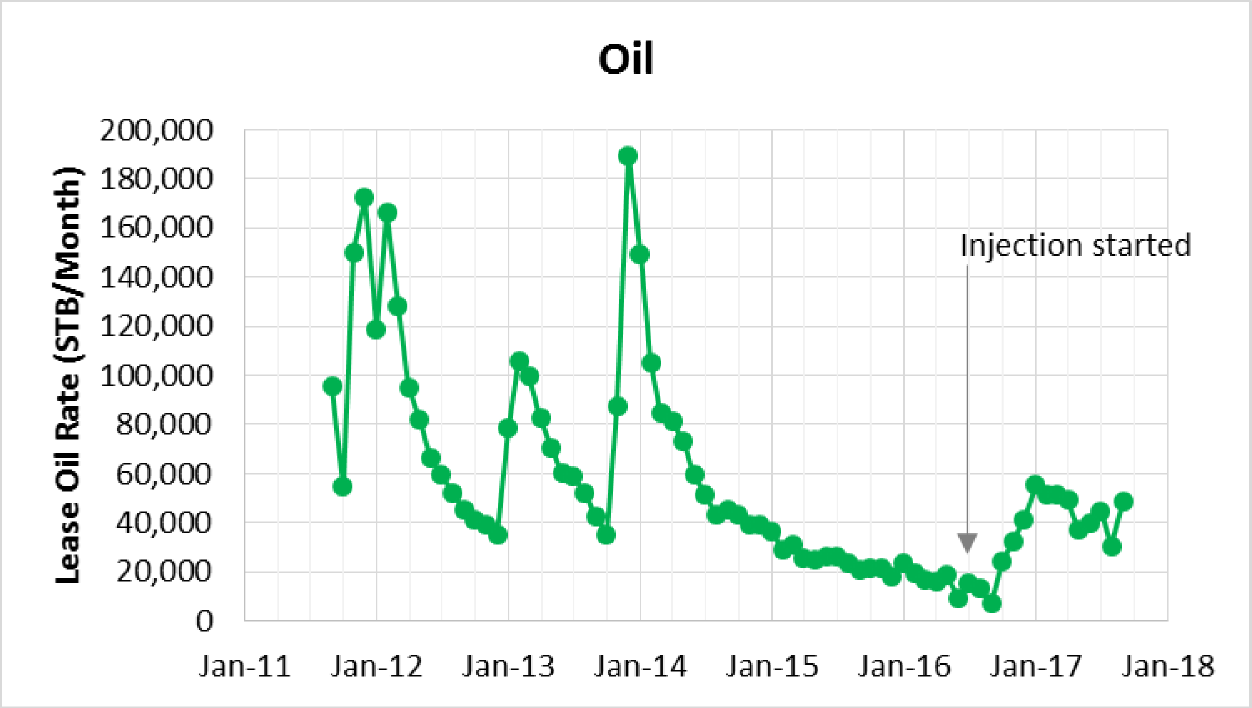
- 4 isolated wells
  - injecting/producing in all
- Cleanest indication of improved recovery

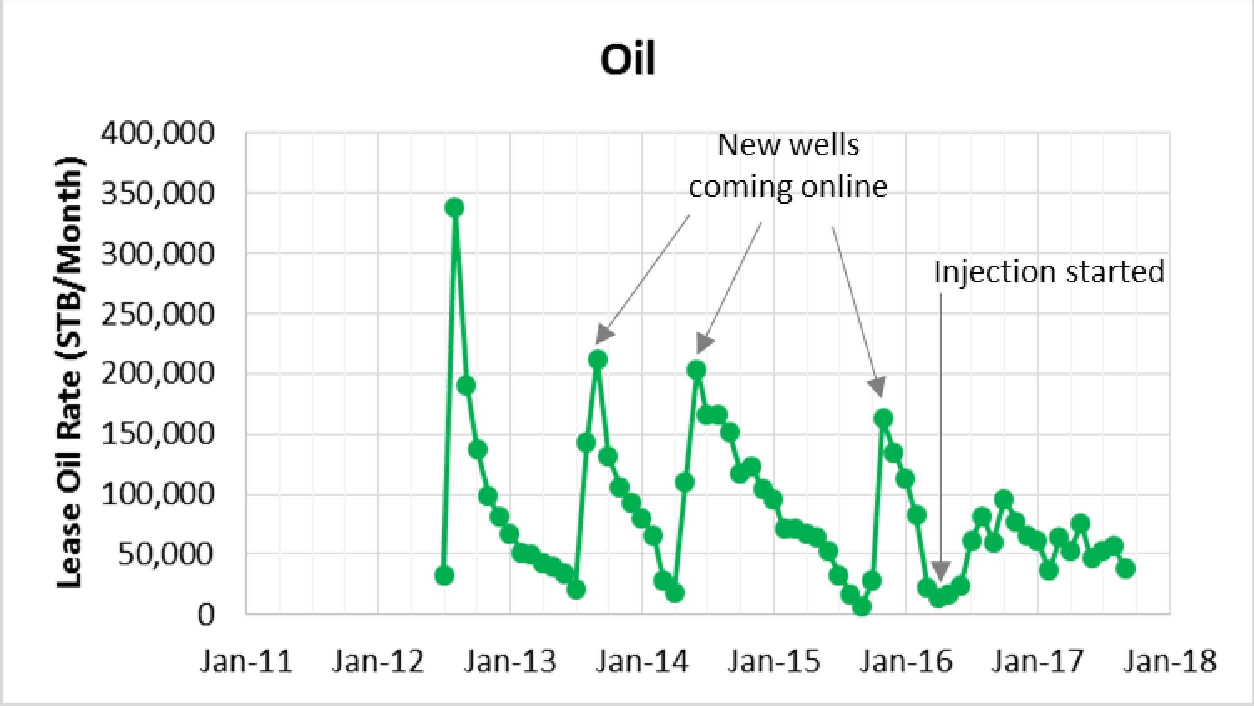


- After 3 years of injection, recovery is more than 30% greater than primary

Eagle Ford Summary

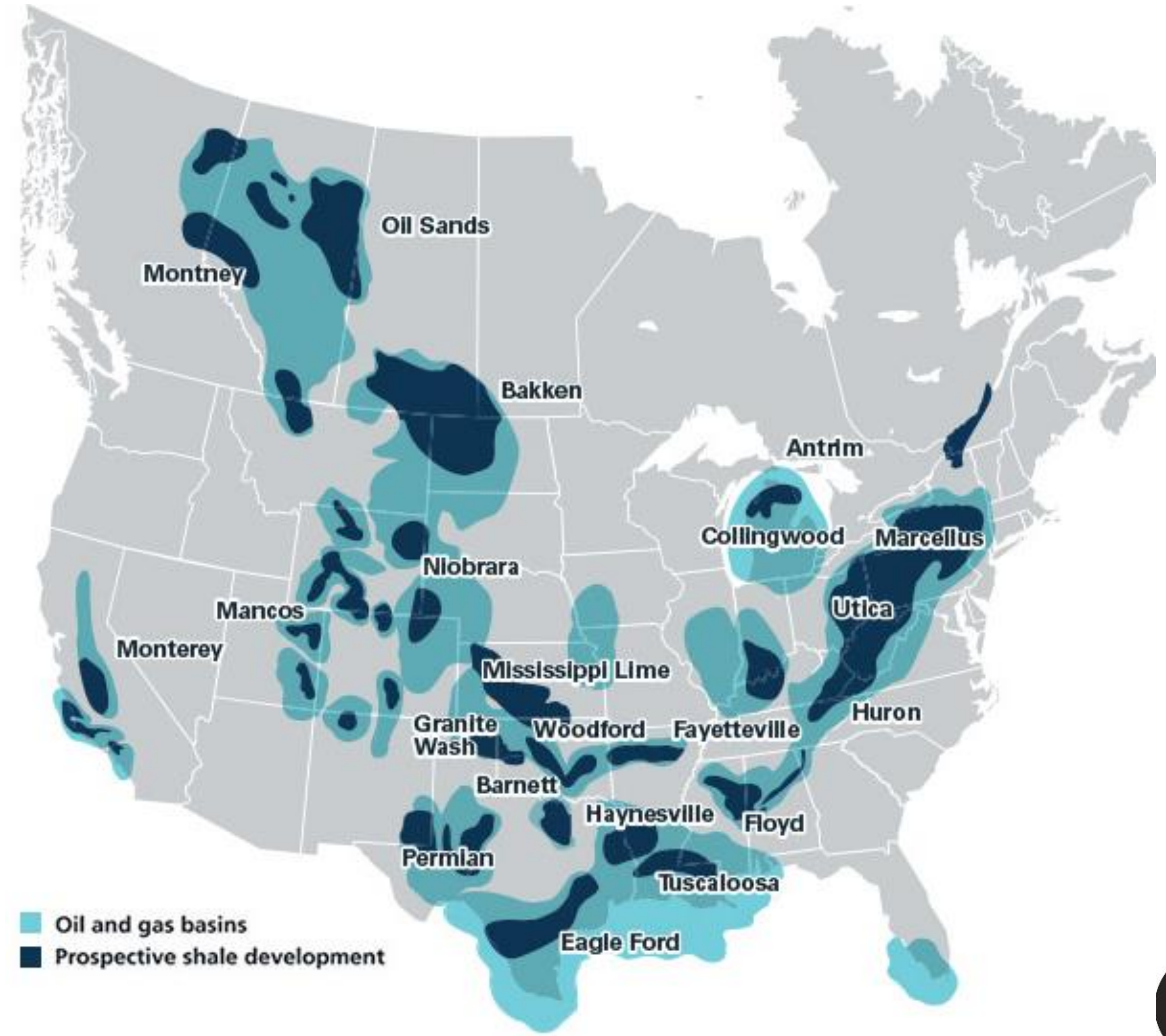
- EOG is at 150+ wells with Huff-n-puff gas injection
- At least 4 other companies have injected in EF, and many more are planning pilots
- Early indications look promising, but issues? …





Other Basins

- **DJ Basin / Niobrara**
- **SCOOP in OK**
- **Montney (future?)**
- **Others…**
- **Permian** (next slide)

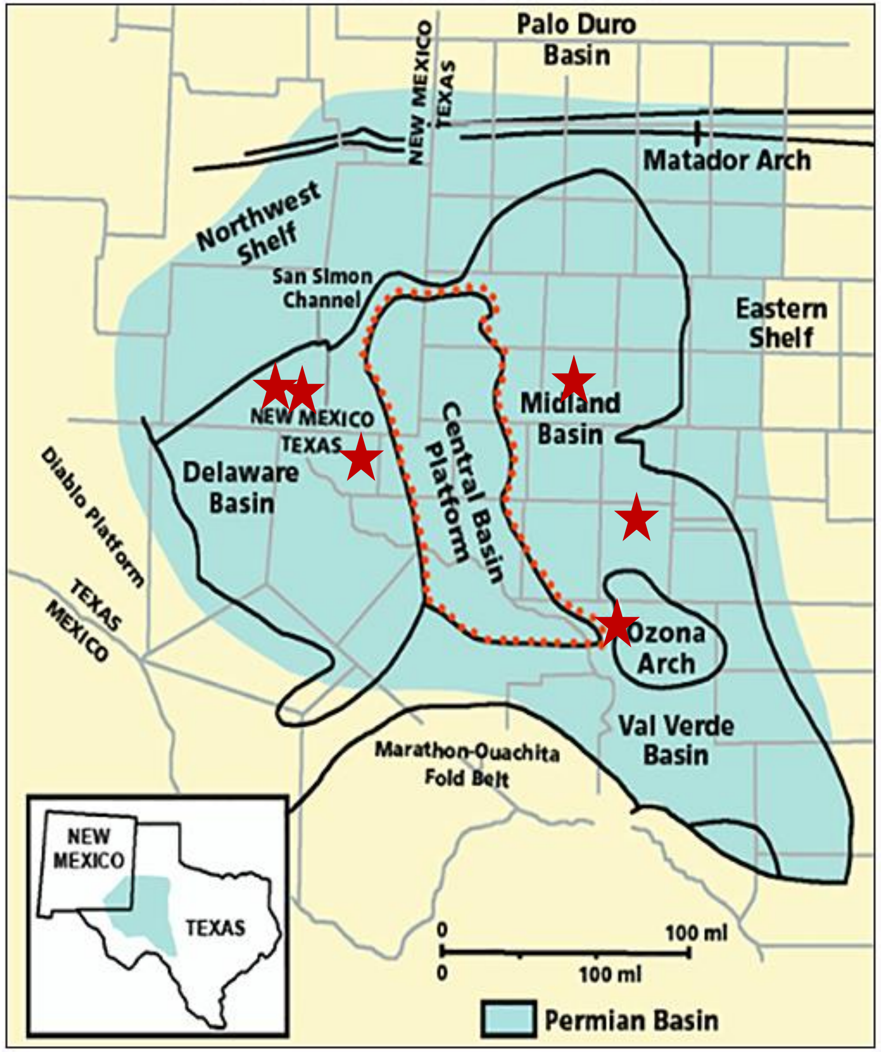


Permian

- **Permian**
  - **Chevron**
  - **Laredo / GTI**
  - **EP Energy**
  - **Oxy**
    - **Delaware Basin (2 NM)**
    - **Midland Basin**

★ **Pilot locations**

Map Of Central Basin Platform & Other Permian Sub-Basins



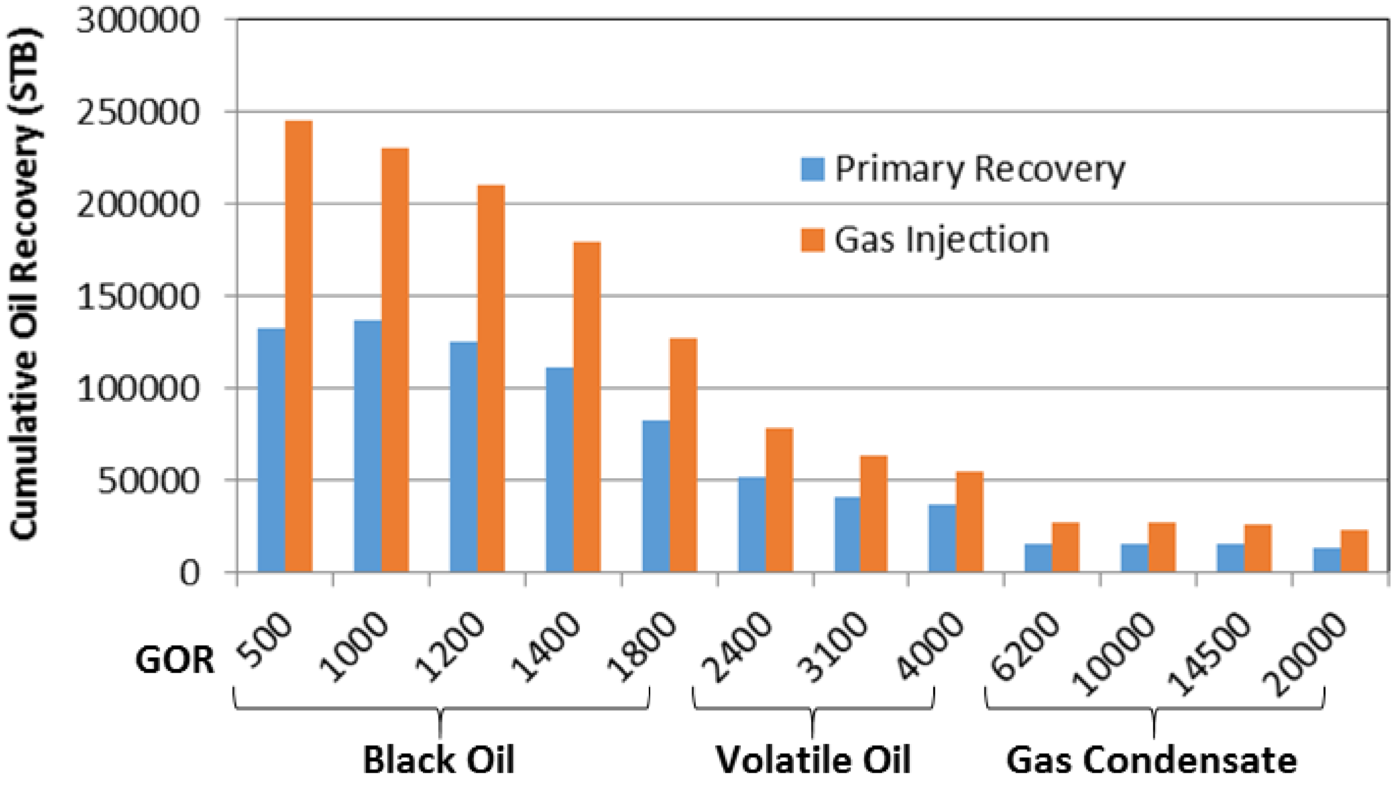
Source: Ring Energy

Potential Issues/Pitfalls – Lessons Learned

- Conformance Control
  - Building Pressure
  - Shutting off ‘Big Water’
- Importance of the Primary Completion
- Compressors/Equipment
- Access to Gas
- Land Issues
- Injection Implementation

Building Pressure

- Force gas to go back into solution
  - Miscibility Pressure (kind of…)



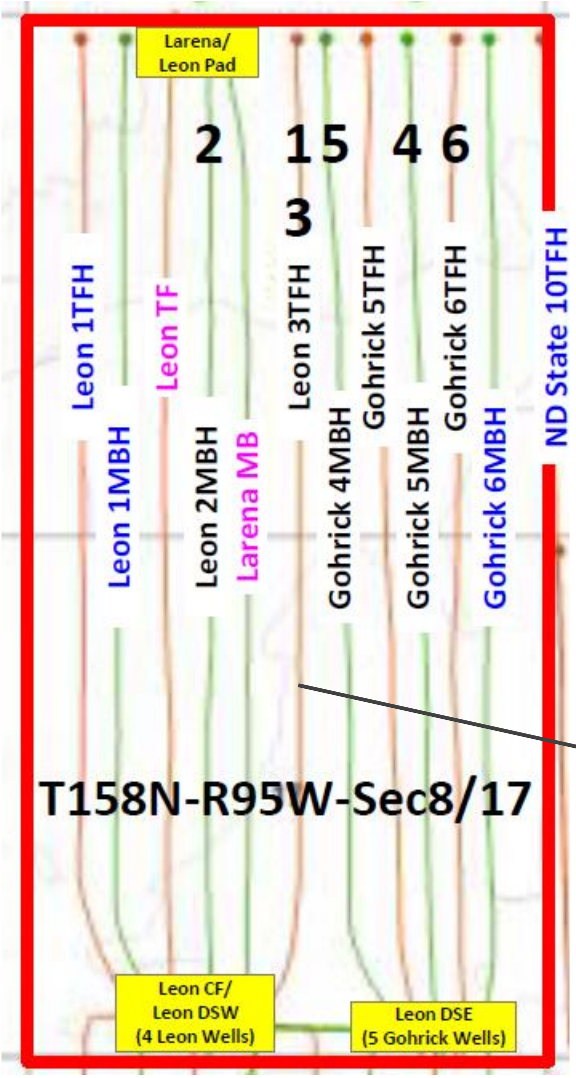
Aside

- Black Oil v.
  Gas Condensate

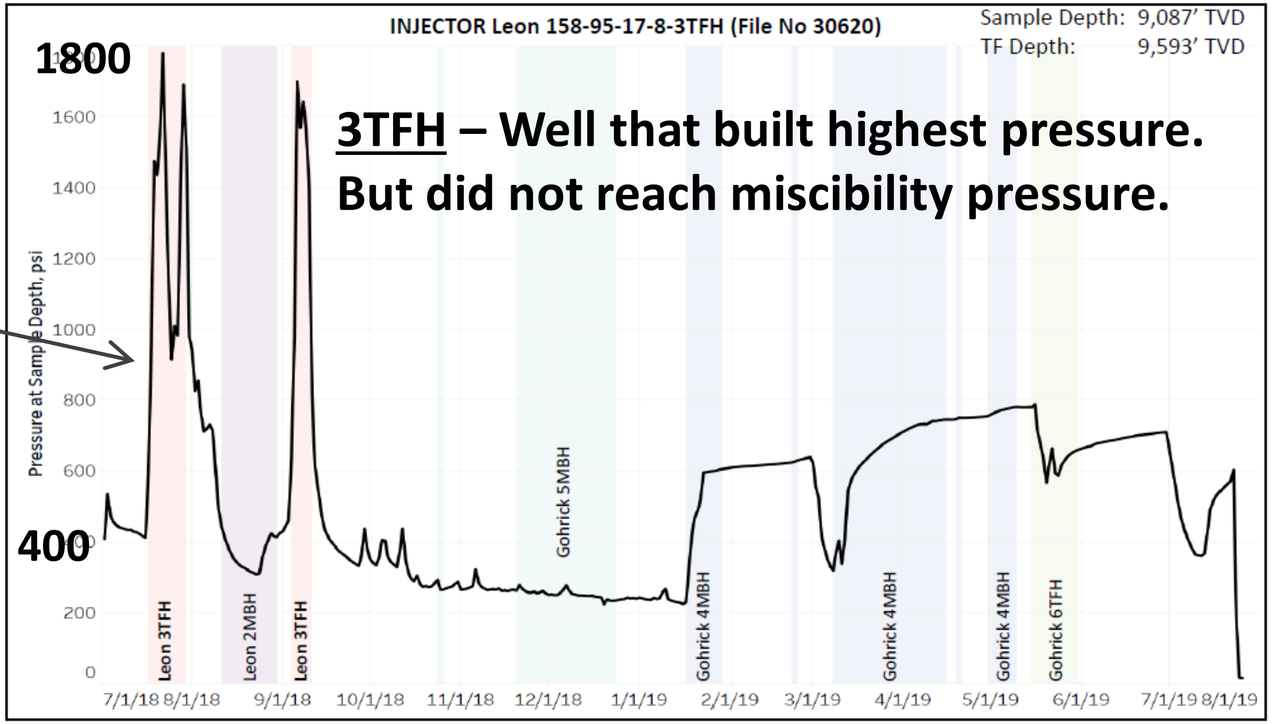
Conformance Control – Bakken

MB: Middle Bakken

UTF: Upper Three Forks

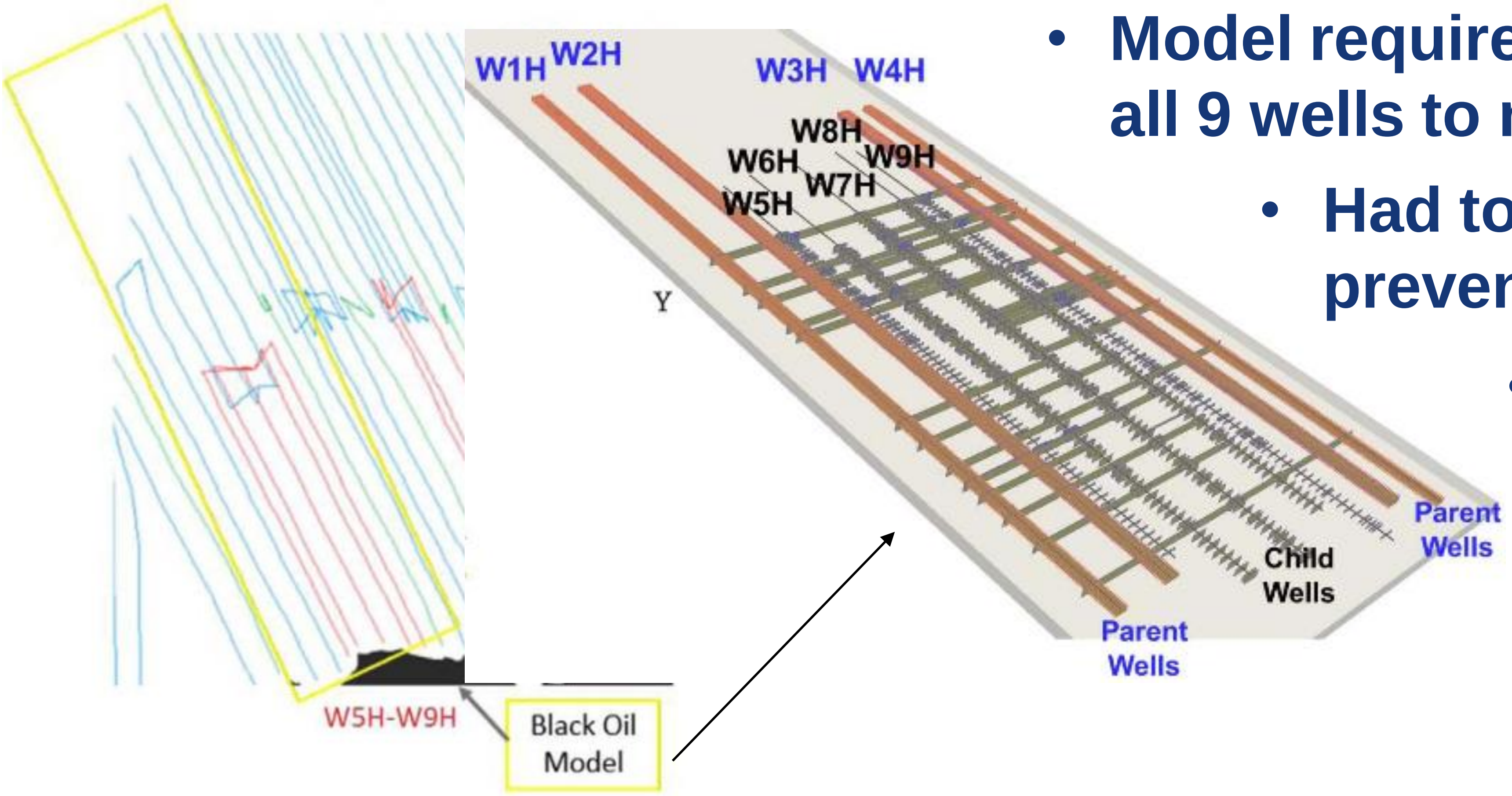


- Difficult to build pressure
- Initial compressor too small
- Wells had low pressure (depleted)
- Pressure leaked off to offset wells



(NDIC, 2019)

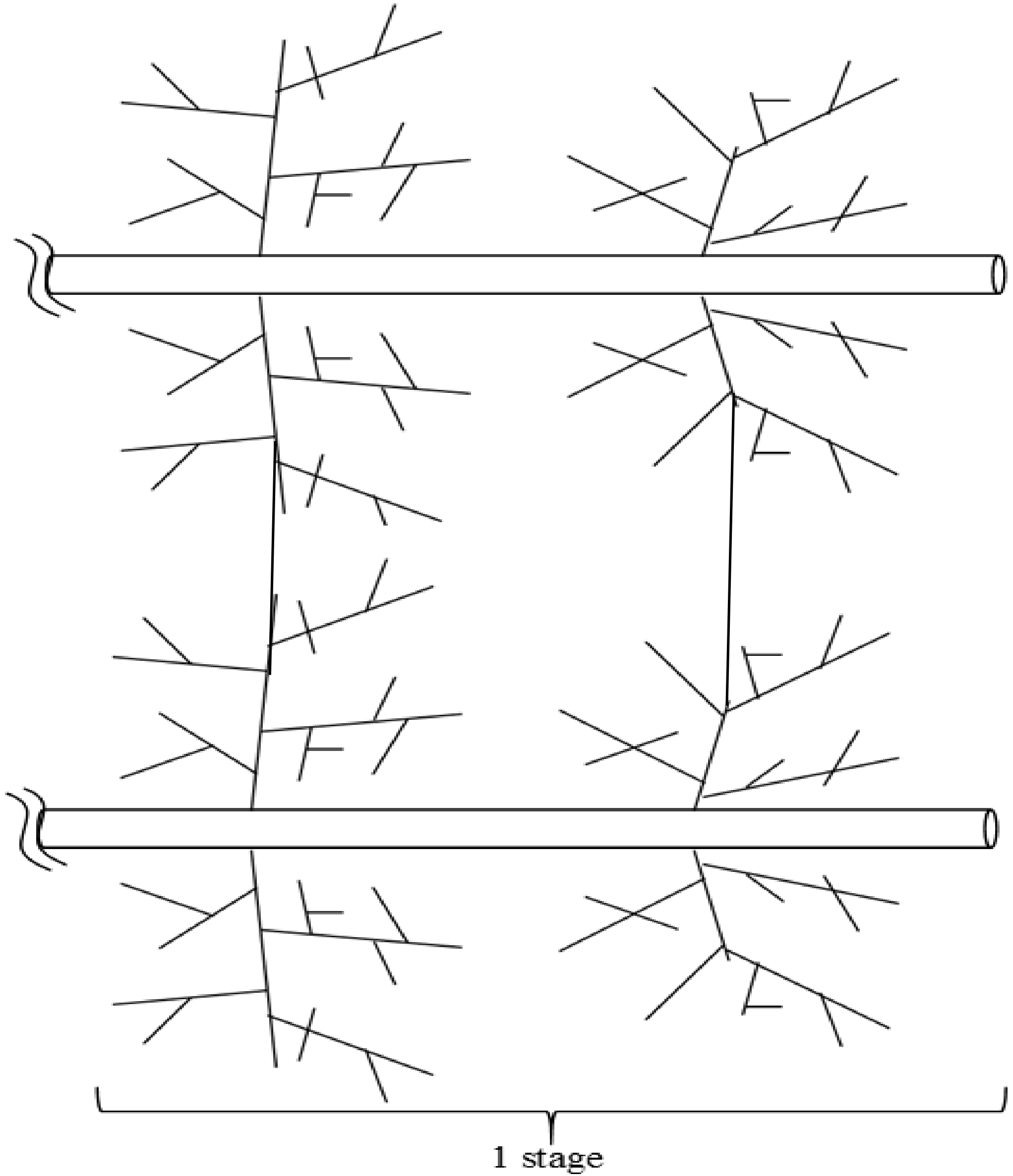
Conformance Control – Eagle Ford



- Model required fractures crossing all 9 wells to match breakthrough
  - Had to shut wells in to prevent gas breakthrough
    - Gas leakage was a major issue

- **Possible Solutions: Isolate cluster of wells, pressure containment strategies.**

Importance of Primary Completion



1. Lots of surface area (10-100 million ft^2)

- Better for primary, too

2. Not intersecting with offset wells

Compressors

Eagle Ford : Pilot Test A

Jan. 2014

Jan. 2015

- **Get the most amount of gas in the ground with shortest shut-in times, above miscibility pressure**

Compressors & Equipment

Compressors

- **Huge Machines**
  - 6000-9000 psi outlet pressure
  - 5-15 Million SCF/day outputs
- **Largest Expense**
  - Multi-million dollars
  - Maximize usage (>1 pattern)
- **Delivery Date**
  - 6-9 months out (coming down)

Other Equipment

- **Wellhead (5K enough)**
- **Gas-tight tubing connections**
- **Packers, etc.**
- **Gas handling**
  - Existing equipment sizes
  - Sour gas

Access to Gas / Land Issues

Gas

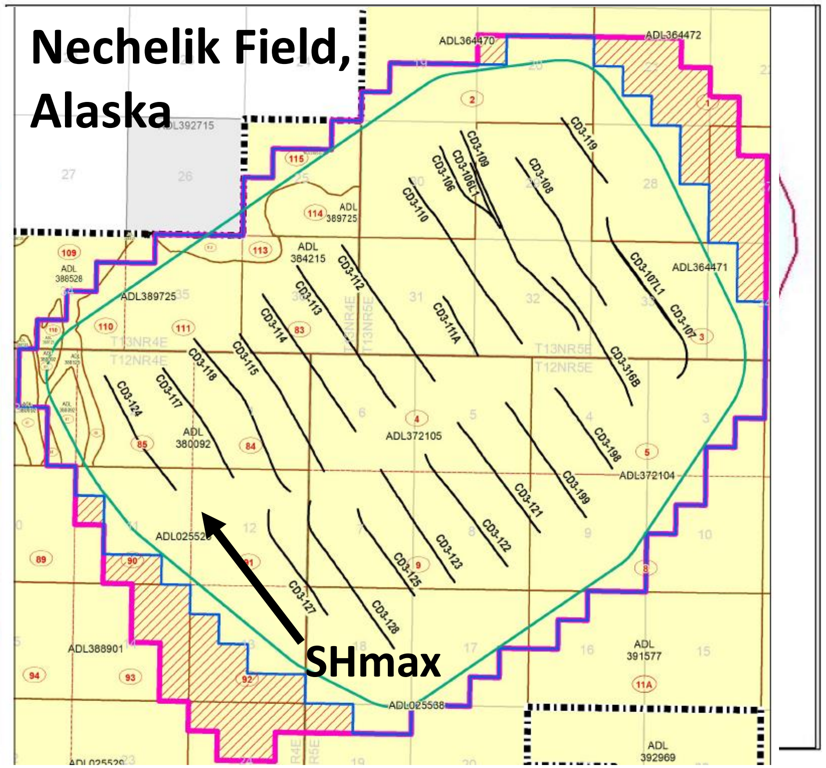
- **Slowed and stopped projects**
- **Produced gas often is not enough**
- **Compressors need 1000 psi suction pressure**
  - Booster compressor or line pressure

Land

- **Slowed and stopped projects**
- **Need buy-in from royalty owners, lease partners, & offset acreage operators**
- **Allocate gas: state for taxes & royalty owners**
  - Need industry consistency

Injection Implementation

- **CO_2 vs. Natural Gas vs. Water**
- **Continuous vs. Cyclic (Huff-n-Puff)**

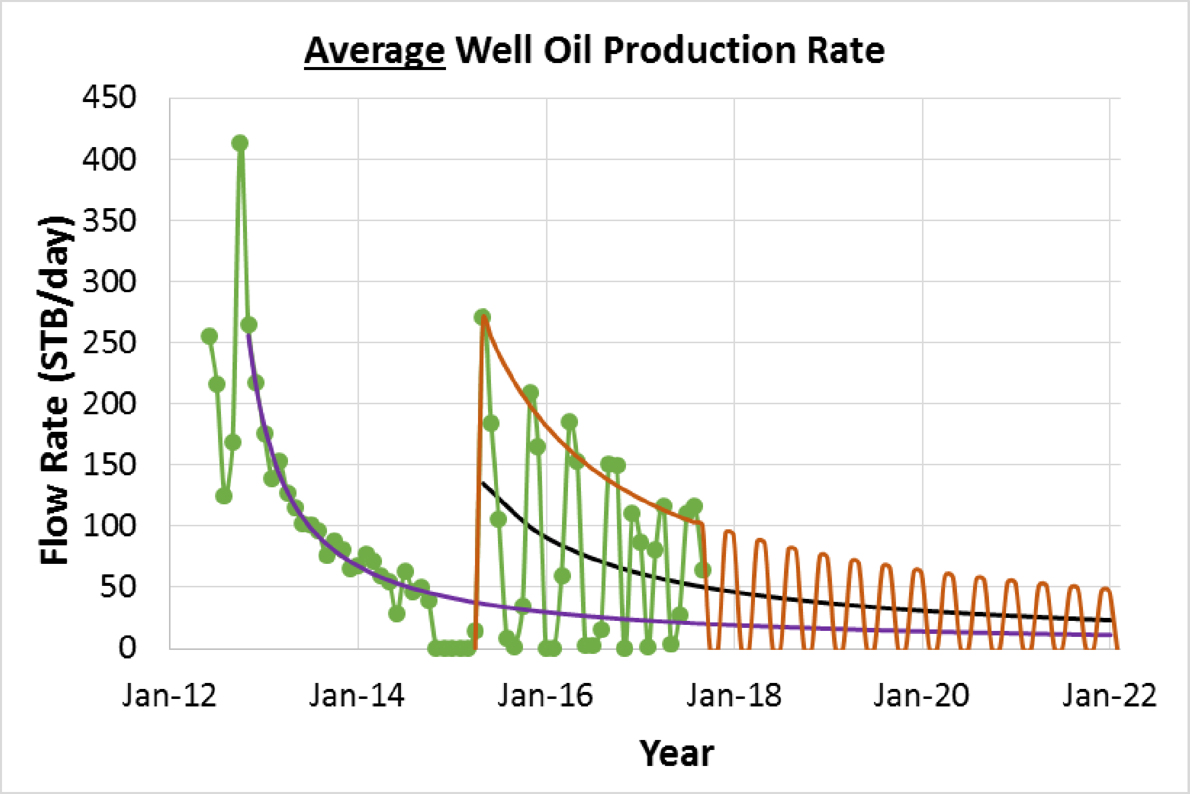


- **Longitudinal Fracs**
- **Perm. ~0.1 - 1 md**
- **Continuous WAG Injection Scheme**

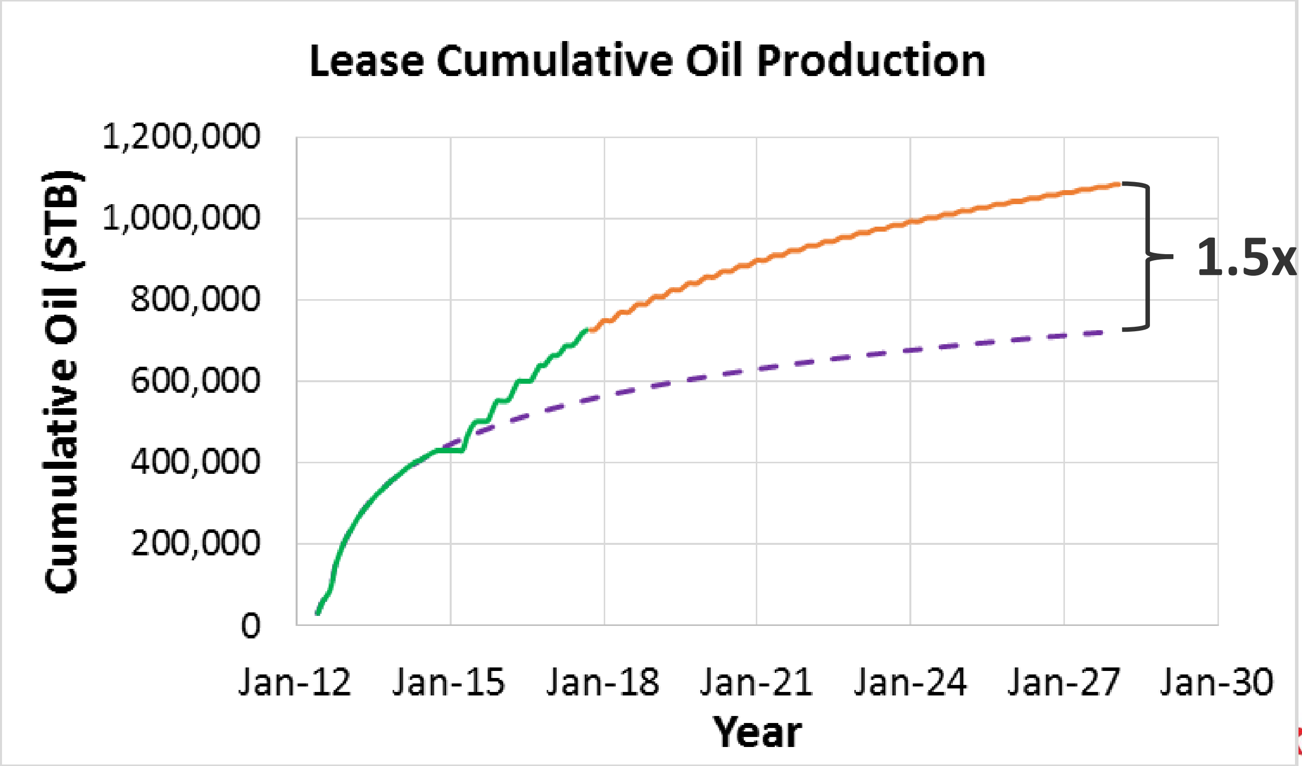
Economic Analysis and Investments

- **Eagle Ford Economic Example**
- **Added Value**
- **Comments**

Eagle Ford Economic Analysis



- Predictions are based on extrapolating decline curves
- Inject 2 months; produce 2 mo.

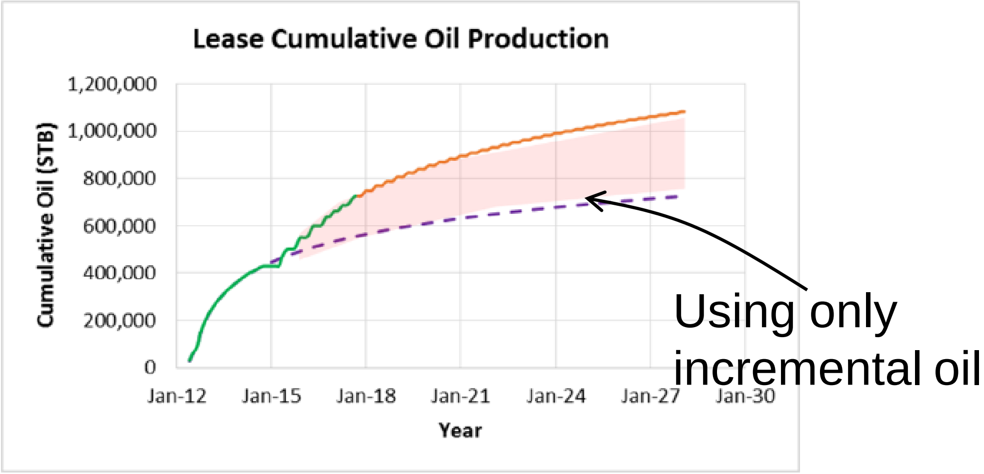


- Predicted out for 20 years
- Similar to reported expected recoveries (1.3x - 1.7x)

Eagle Ford Economic Analysis

Inputs

- CapEx: $1 million/well
  - compressors, flowlines, workovers, etc.
- Injection rate: 2 million scf/day ($2.50/Mscf)
  - 3 month fill up time
  - 20% make up gas during injection time
- OpEx: 10% of injected gas – compressor fuel
- 20 year predictions - Discount rate: 15%



Results

Oil Price	$35	$50	$65
NPV	-$1,300,000	$1,700,000	$4,700,000
IRR	-- %	28.1 %	44.1 %
Payback	-- yrs	1.8 yrs	1.2 yrs

Comments

- Marginally economic
- More than half of the cost is gas fill up
- Efficiency gains should be realized over time

Upside Potential

Lifecycle of Unconventional Wells

1. Acreage costs: ~$1-4 million / well
2. Well construction costs: ~$5-8 million / well
3. Primary Production: if EUR is ~300,000 STB, ~$15-18 million, with opex and time value, marginal well
4. EOR Production: if EUR goes to ~450,000 STB for ~$1 million in capex and ~$1 million in gas costs, that can improve the economics*

*some companies in EF are adding EOR production in private equity proposals

Economics of EOR in Unconventionals

- Operational efficiencies will improve economics
- Start injection earlier, but after some depletion (~1 yr)
- May not be as economic as new drills in Tier 1 acreage (but on par with Tier 2 acreage)
- Other EOR methods may be more economic
- Knowledge from pilots is essential to increasing profitability

Conclusions

- Potential is Enormous for EOR in Unconventionals
  - Huge volumes in place; Low recovery factor
- Natural gas huff-n-puff works wells in Eagle Ford
  - Large scale field development is occurring
- Other basins still in testing period
  - e.g Permian, Bakken, SCOOP, Niobrara …
- Ultimately, other methods may prove to be better
  - Water, CO_2, surfactants, continuous injection, etc.
- Significant work to be done
  - Lab, modeling, and field trials

Questions/Comments

Thank you!

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