# Enhanced Oil Recovery (EOR) for Unconventional Reservoirs: The Next Big Thing?


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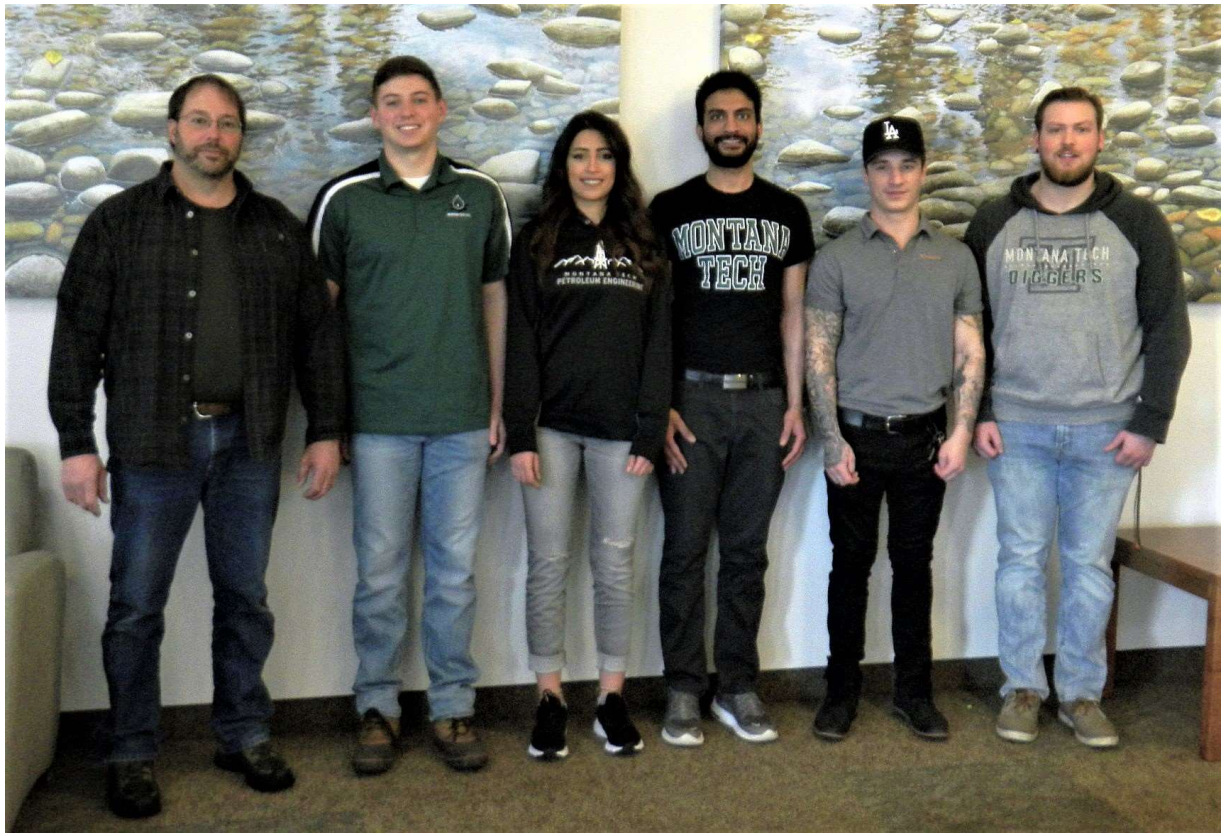
**Montana Tech**



Society of Petroleum Engineers
Distinguished Lecturer Program
www.spe.org/dl

# Thank You!!!





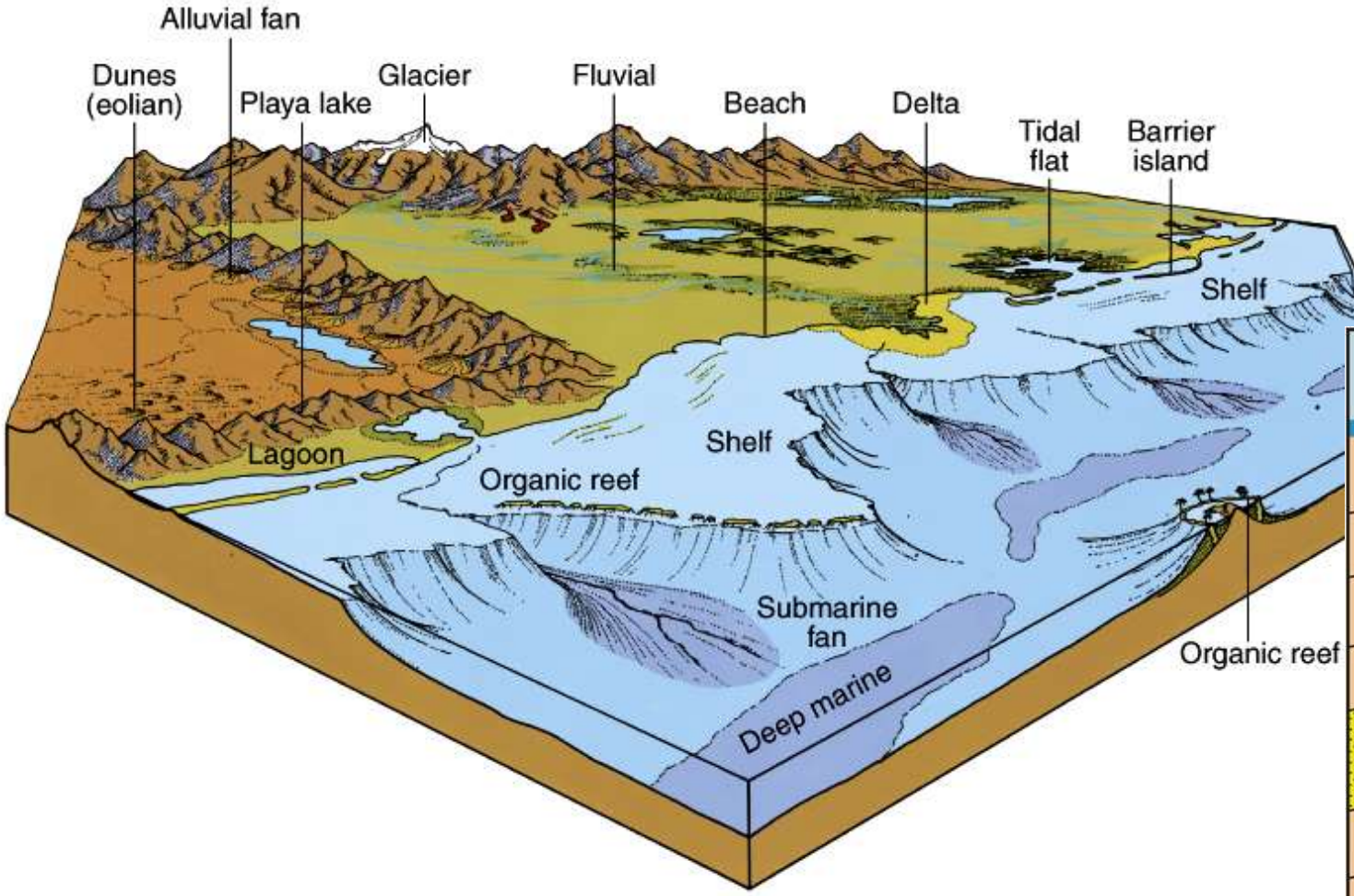

This year the Denver Chapter dispersed $50,000 in scholarship money for the 2019-2020 school year. This amount will be shared between 33 students from the Colorado School of Mines, Montana Tech, New Mexico Tech, University of North Dakota, and University of Wyoming.

# Outline

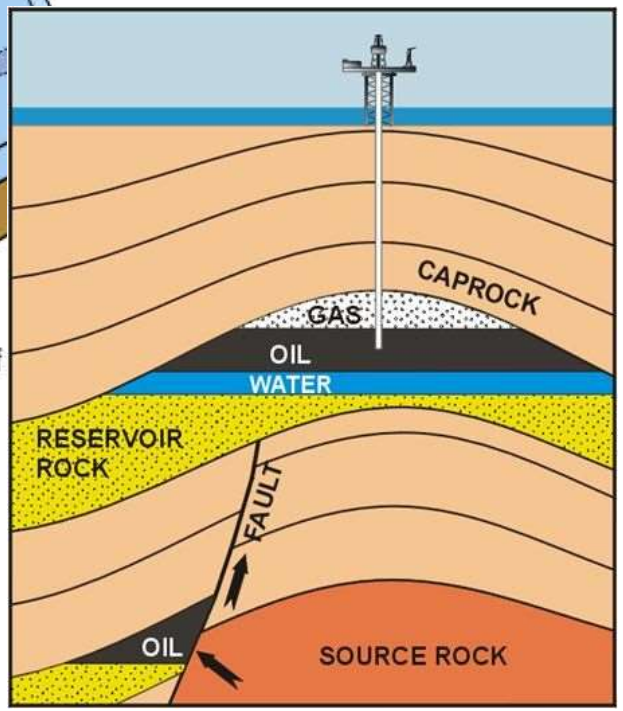


- **Unconventional Reservoirs (UR)**
- **Enhanced Oil Recovery in UR**
  - **History (2008 – today)**
  - **Operational Issue**
  - **Recovery Mechanisms**

# Idealized diagram of major sedimentary systems




## Conventional Reservoir Formation

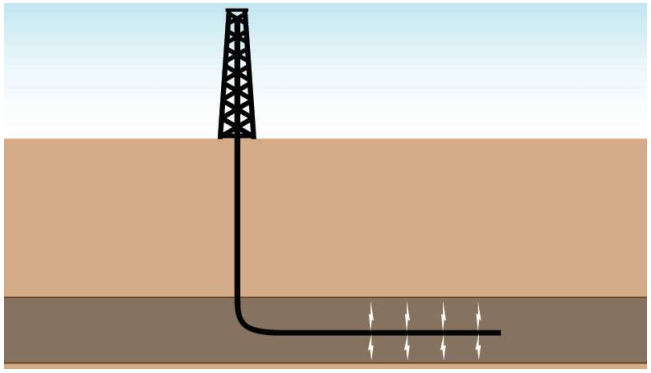


# Unconventional Reservoirs – What?



## also known as (aka)

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

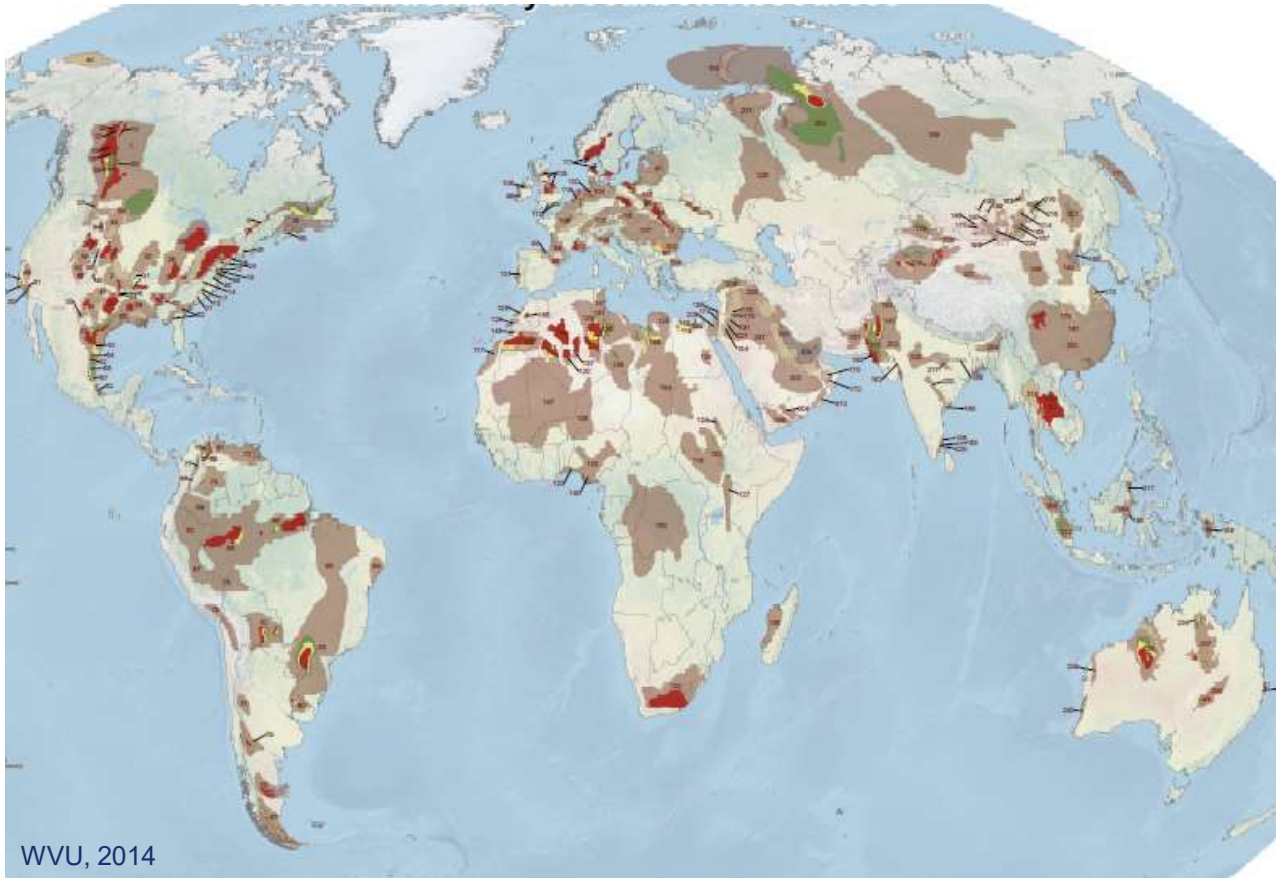


## Characteristics

- Source rock & reservoir rock are the same or nearby
- Extremely low permeability
- Requires long horizontal wells and multi-stage hydraulic fracturing

# Unconventional Reservoirs – Where?






## Worldwide potential

## Developed Resources

- United States
- Canada

Developed

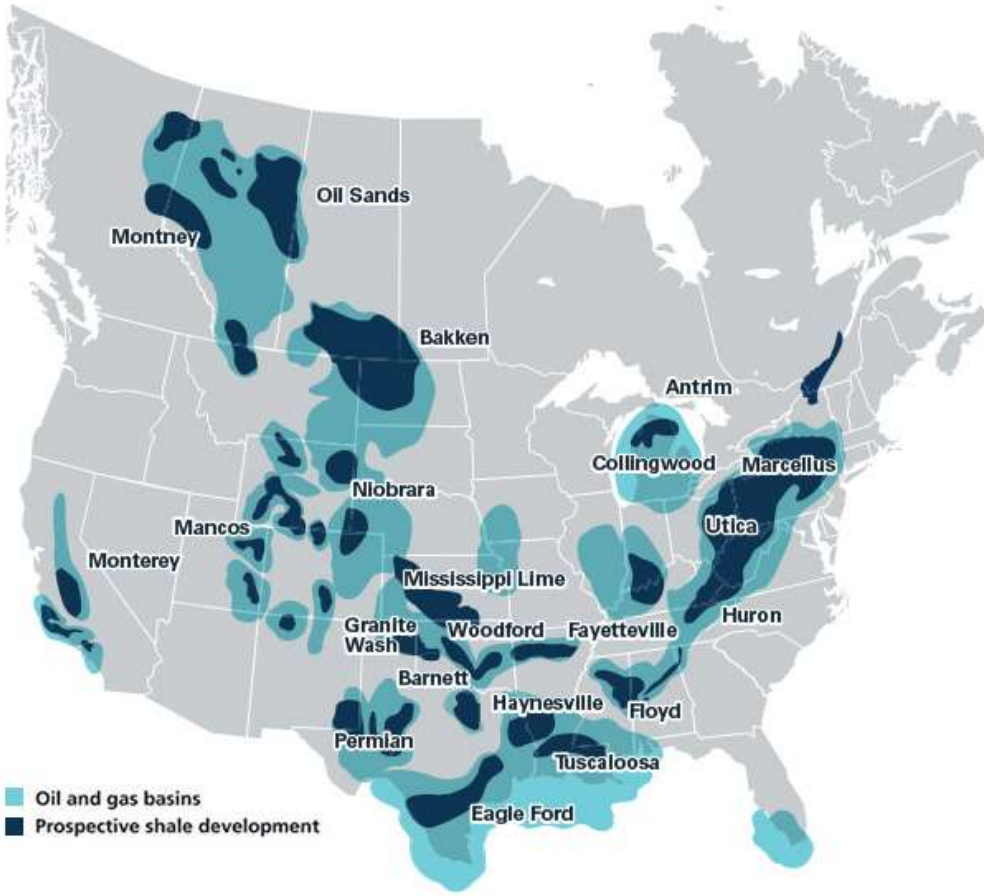
- Argentina
- Russia
- China

Early stages

- …

# Unconventional Oil Reservoirs



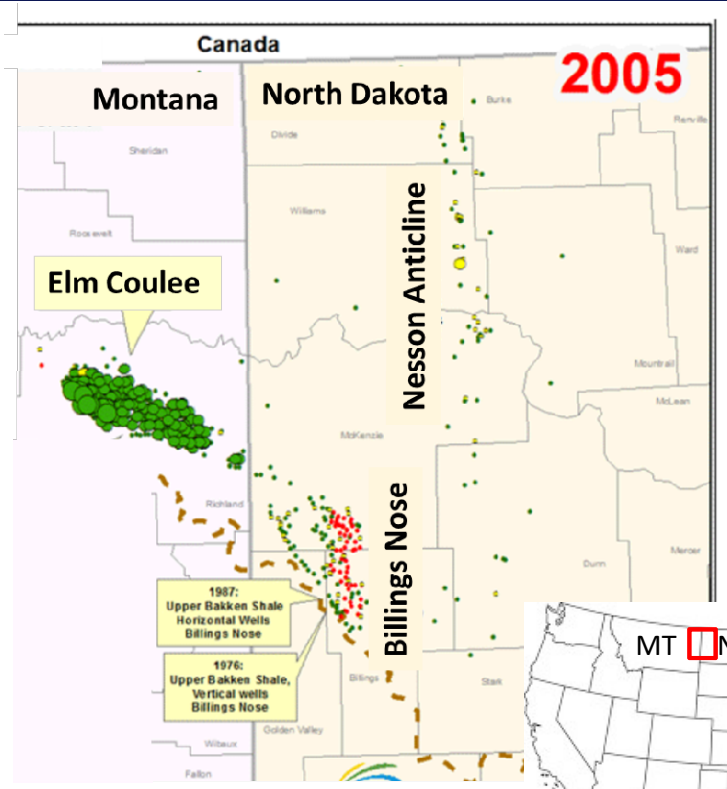


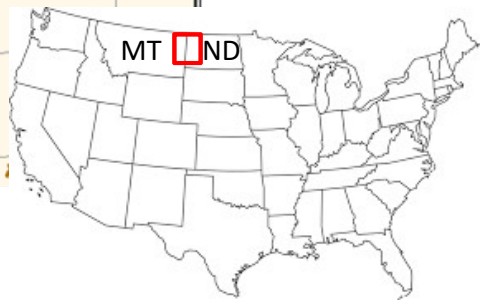

## North America Formations

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

# Elm Coulee Bakken (Montana)





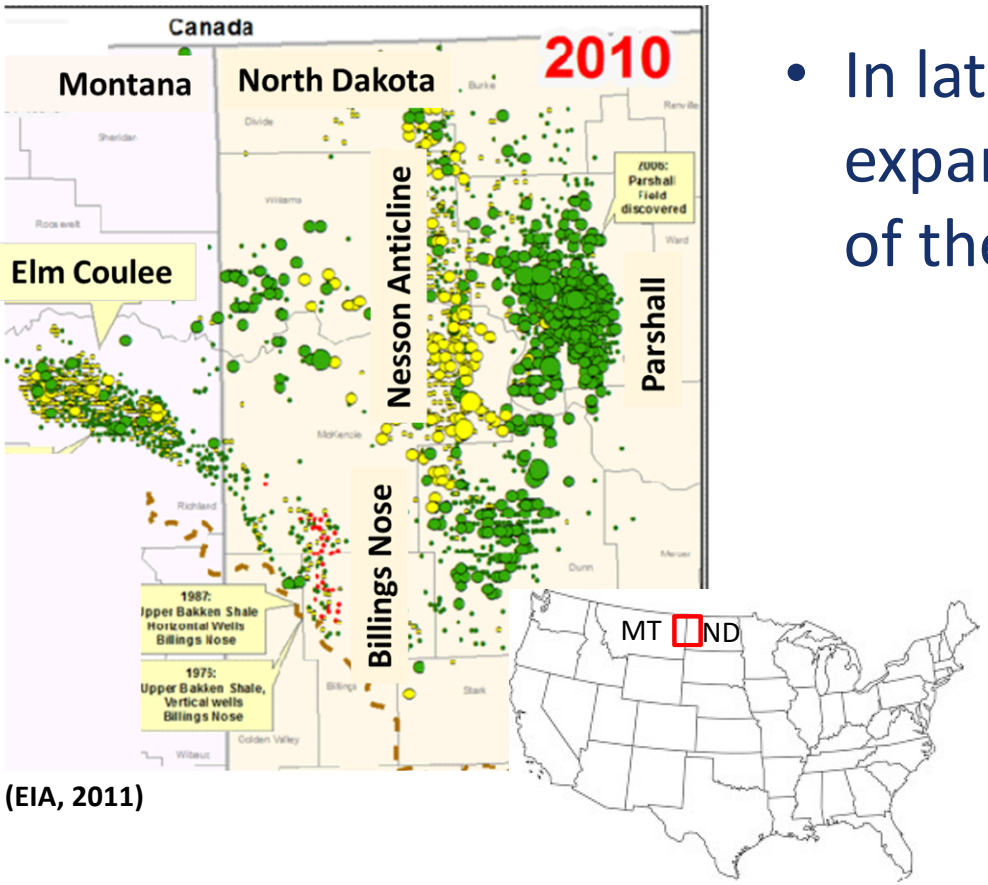




(EIA, 2011)

- R. Findley & Lyco Energy drilled first unconventional oil wells in Elm Coulee in late 1999 - fractured in 2000
- Numerous operators drilling wells in Elm Coulee in early 2000's
- By 2005, extensive development

# Bakken – Expanded Development



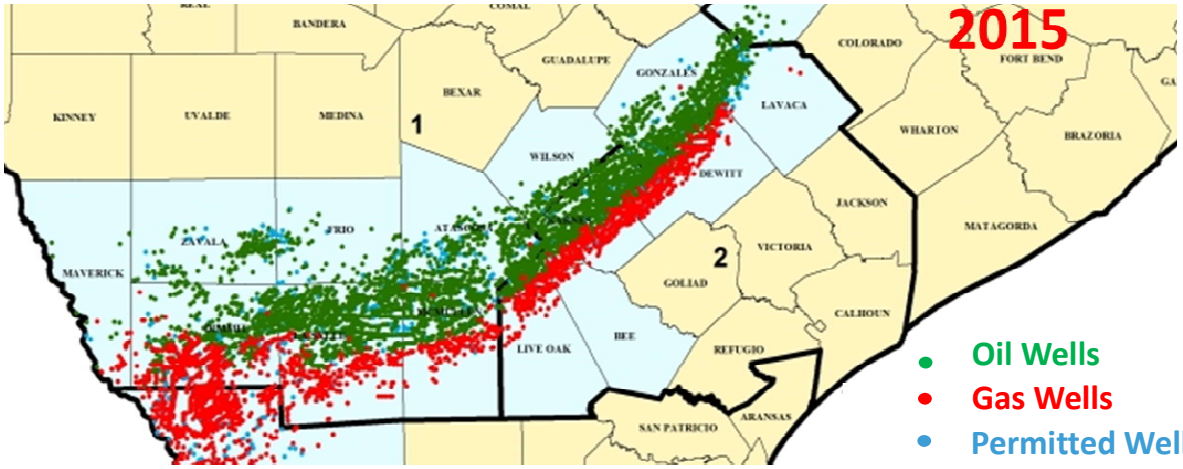



(EIA, 2011)

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

# Eagle Ford - Development



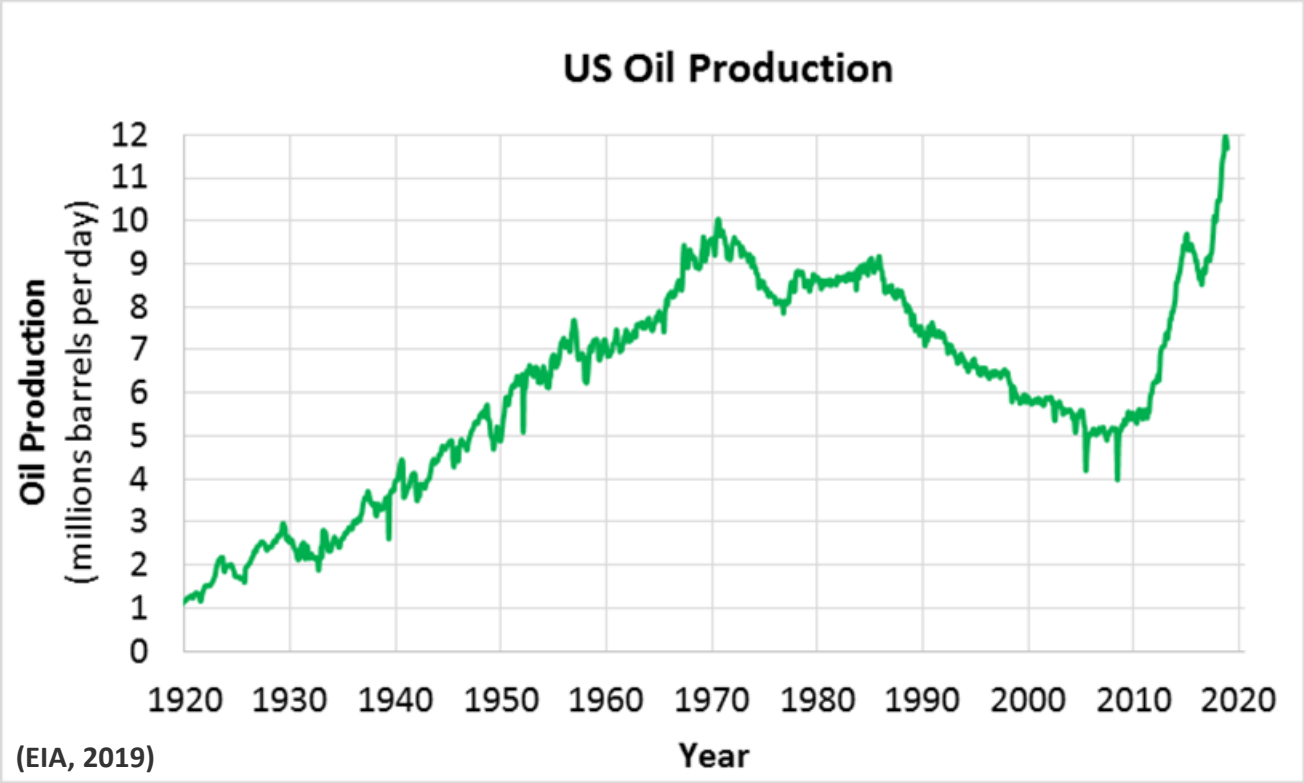



(TRC, 2015)


- Eagle Ford development exploded in early 2010's

# Unconventional Oil Success - US



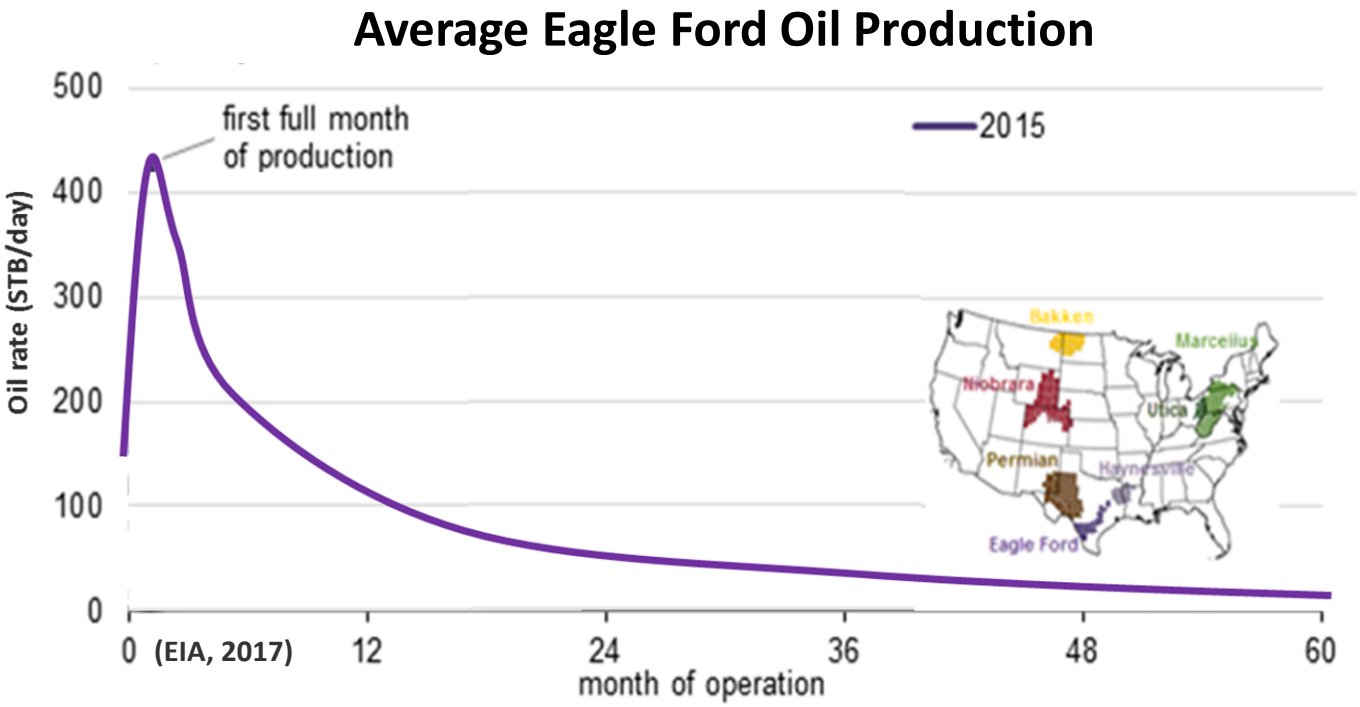



(EIA, 2019)

- **80% of increased US oil rate is from unconventional oil reservoirs**
- **Billions of barrels of oil resource in unconventional reservoirs**

# Unconventional Oil Opportunities






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

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

# Options for EOR in Unconventionals



## Gas

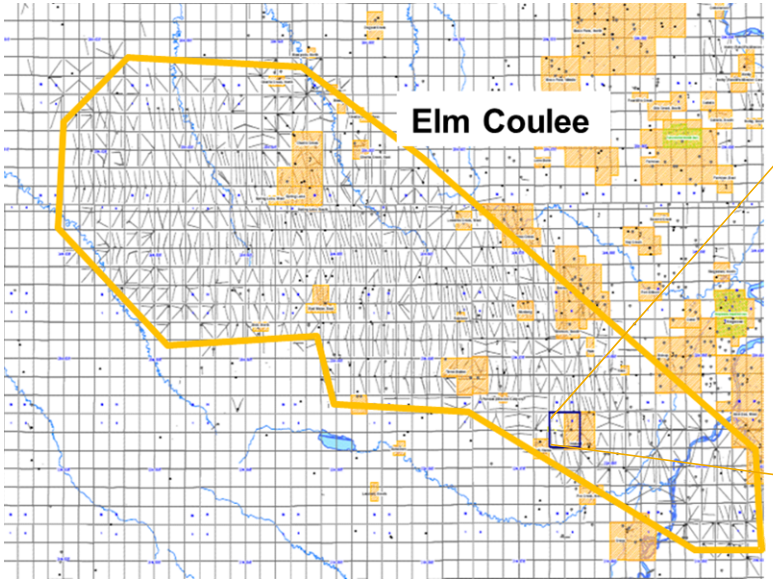
- $CO_2$
  - Source may be issue
- Rich natural gas
  - 60% $C_1$, 40% $C_2$+
  - Behaves similar to $CO_2$
- Lean natural gas
  - 90+% $C_1$, <10% $C_2$+
  - Vapor extraction
- Miscible / Immiscible

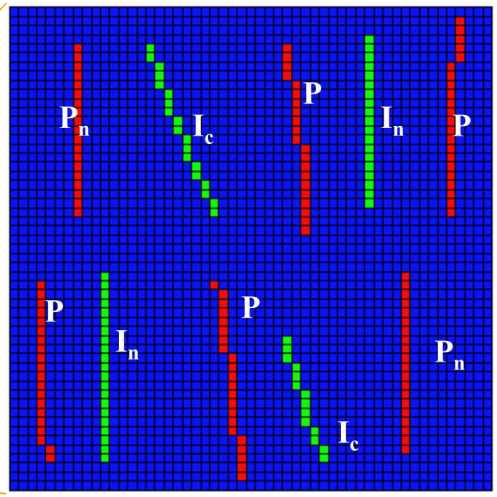
## Water / Surfactants

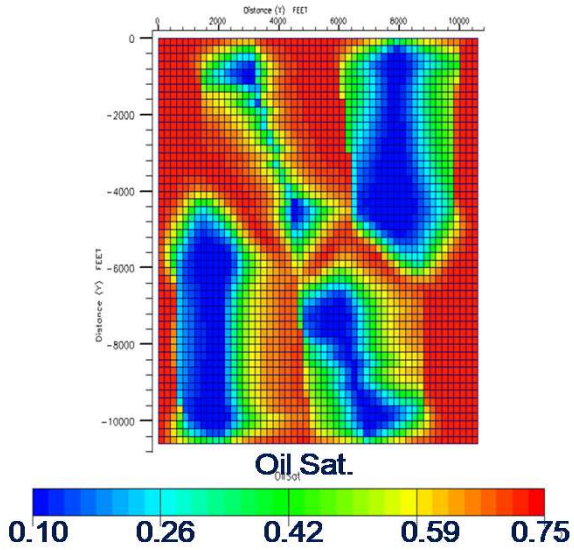
- Injectivity doesn't appear to be a concern
- Matrix imbibition
- Surfactants may help
  - Change wettability
  - Find low cost option?
- Low salinity

# Initial Simulation Study - Bakken






- Grad student at Montana Tech
- Summer intern at Continental

(Shoaib, 2009) SPE 123176

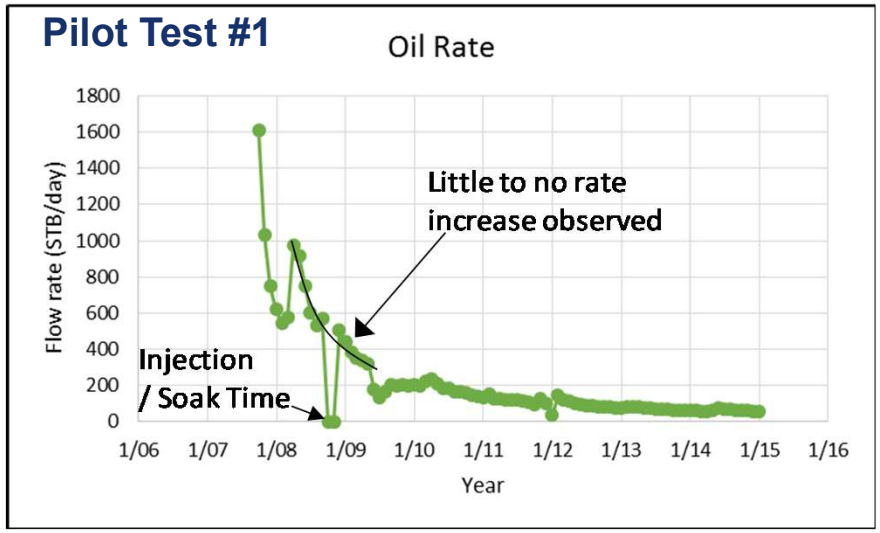
- 4 Sections (2 mi. x 2 mi.)
- 8 layers including upper shale and middle member
- Multiple $CO_2$ injection cases

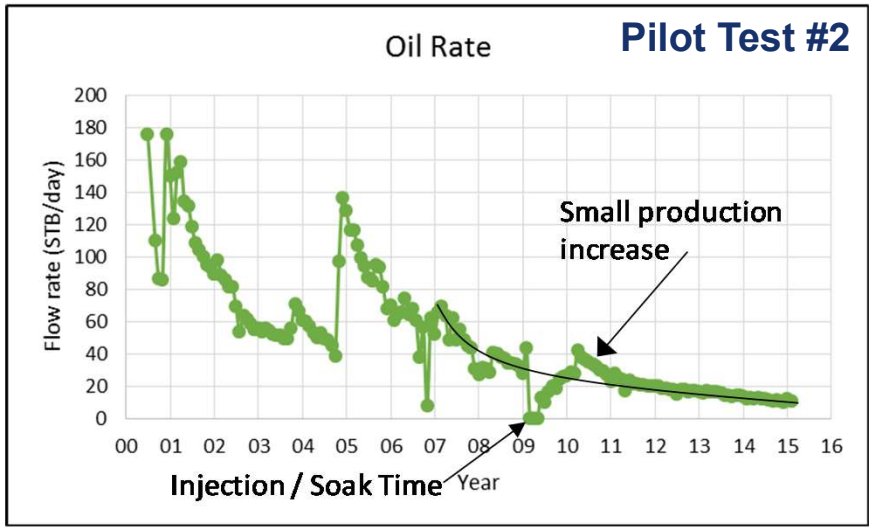
- Simple model
- Indicates added recovery

# 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

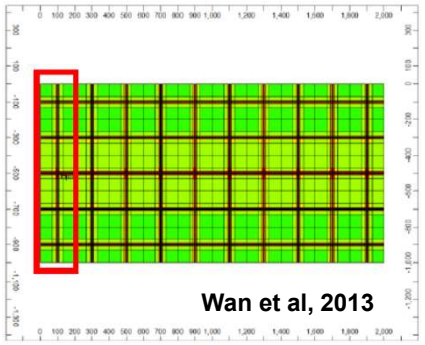


- Laboratory / Experiments
  - Gas Injection
  - Surfactants
- Analytical Analysis
- Reservoir Modeling / Flow Simulation
  - Generally, models showed success
  - Capturing true EOR response?

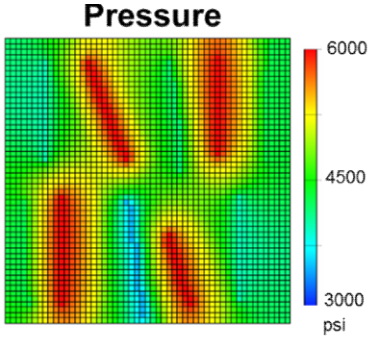

Nguyen et al, 2014

Adekunle et al, 2013

Kurtoglu, 2013



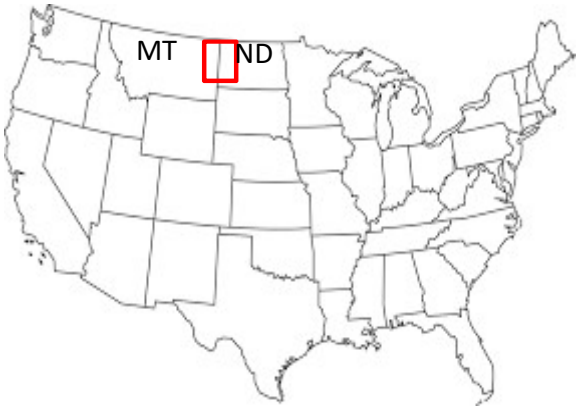
Wan et al, 2013

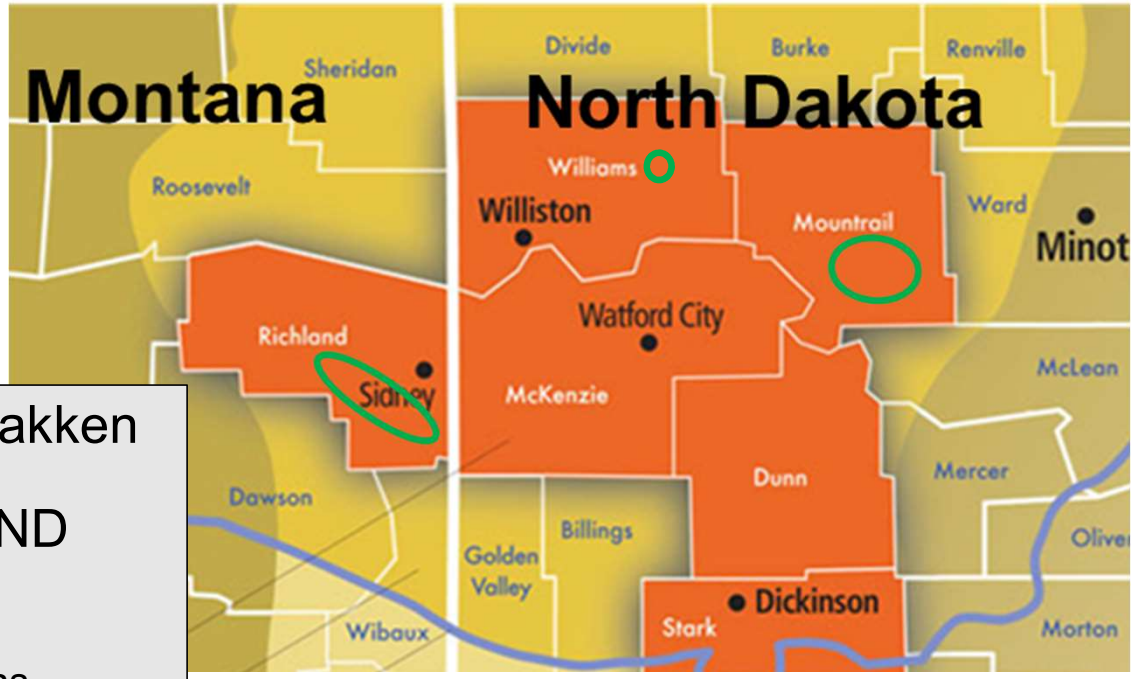



Hoffman, 2011

# EOR Pilots in the Bakken






8 pilots in MT/ND Bakken

- 2 in MT and 6 in ND

5 Gas → 3 $CO_2$
5 Gas → 2 Natural Gas

3 Water

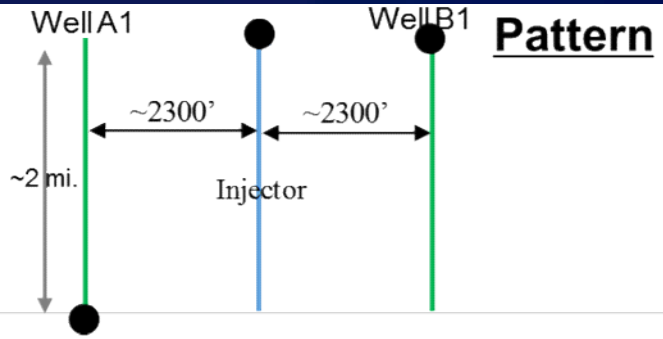
SPE 180270

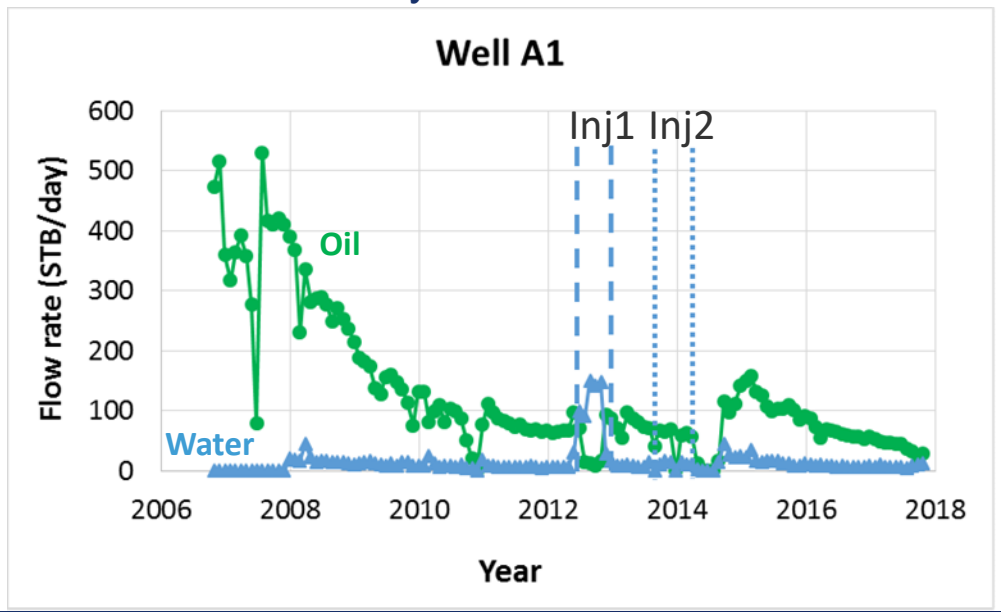
# Continuous Water Injection – Bakken Pilot

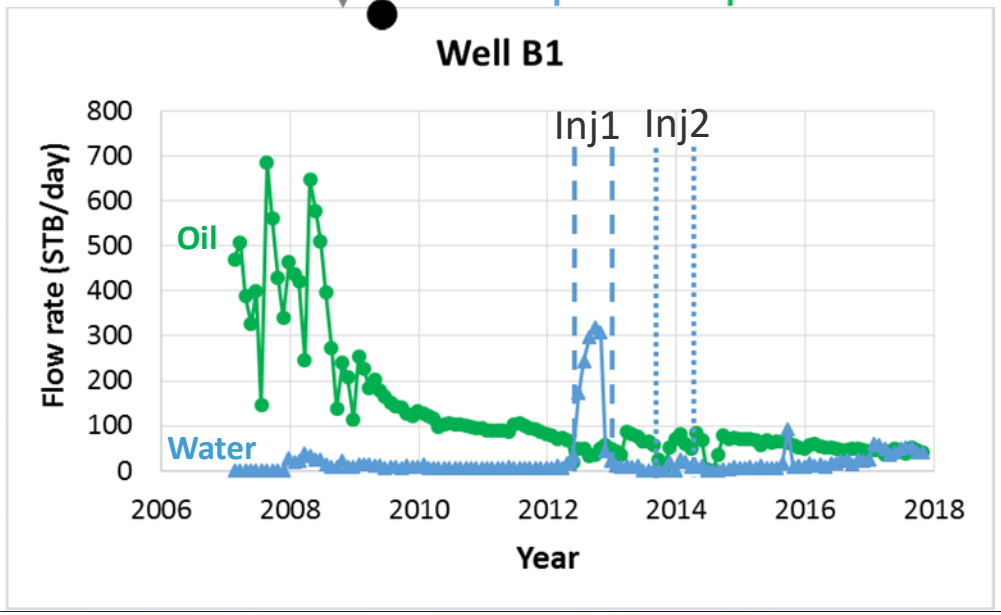


- **Injection rates**
  - ~1350 bbl/day for 8 months
  - then shut in for 6 months
  - ~380 bbl/day for 8 months

Pilot Test #7



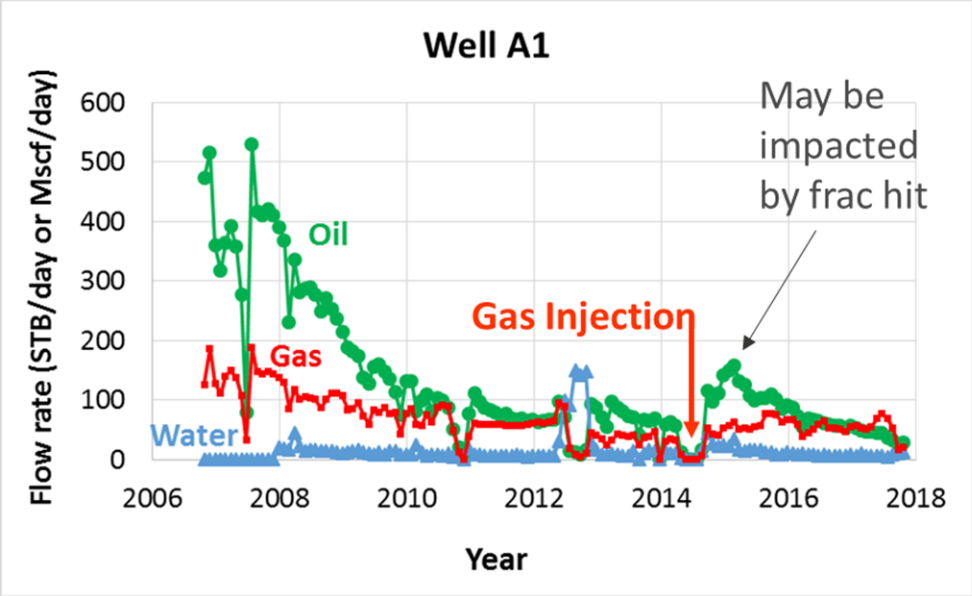



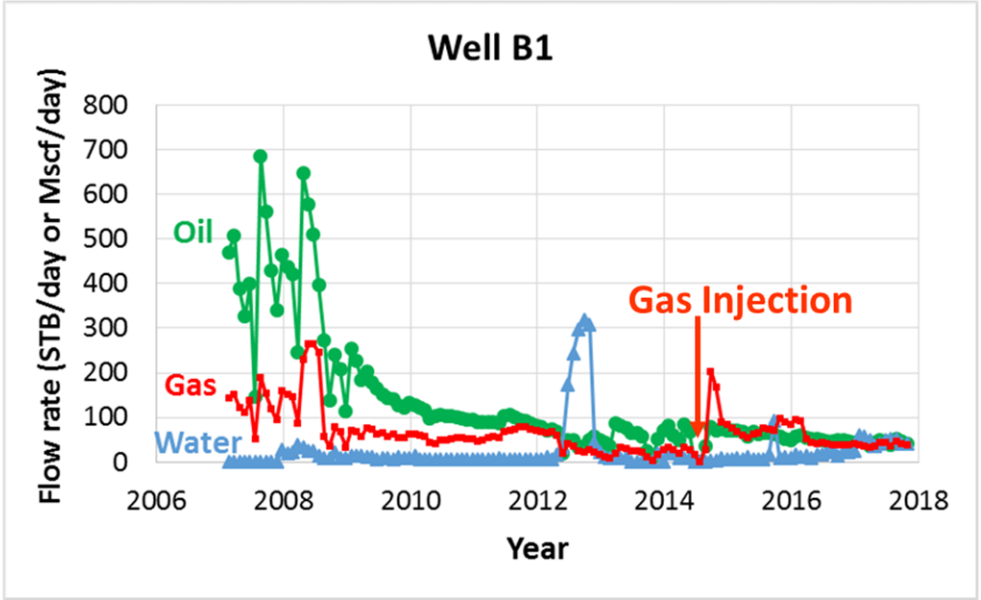
# Continuous Natural Gas Injection - Pilot



- **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)

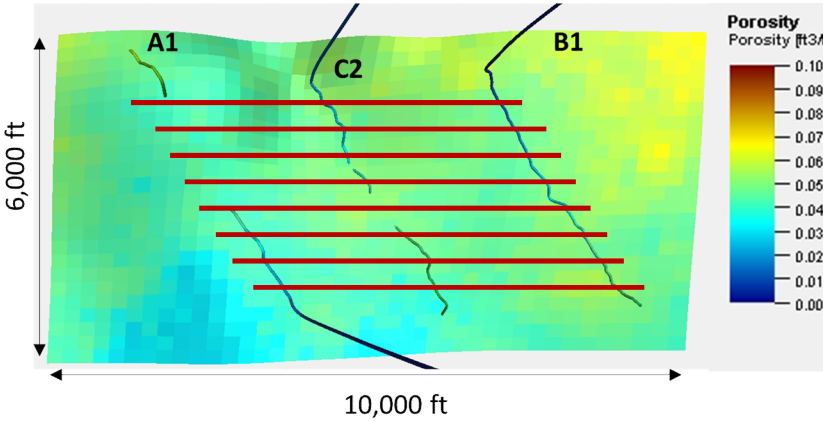
**Also looked at offset wells North and South of injection well**



# Injection Pilot - Flow Simulation Model






## Average properties

**H = 33 ft** $k_H$ **= 0.023 md**

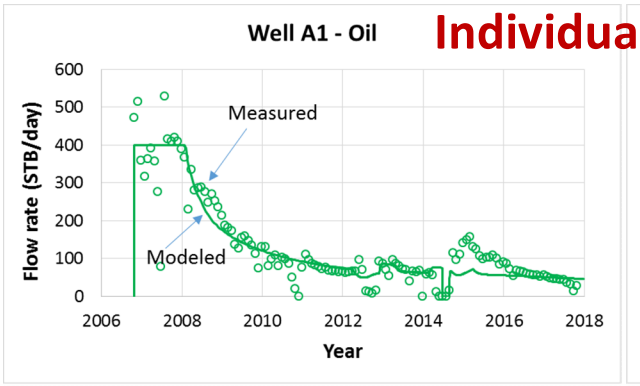
$\phi$ **= 4.3 %** $k_V$ **= 0.023 md**

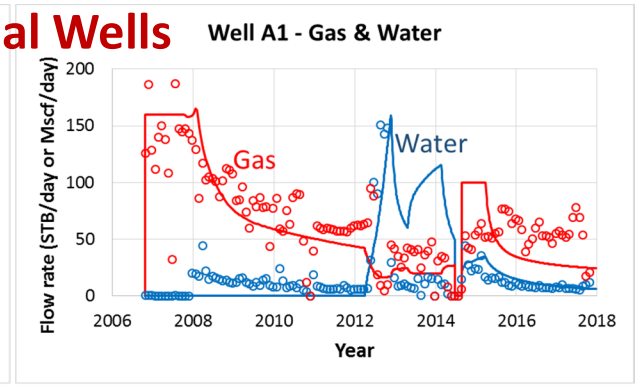
- **Hydraulic fractures modeled in dual porosity grid**

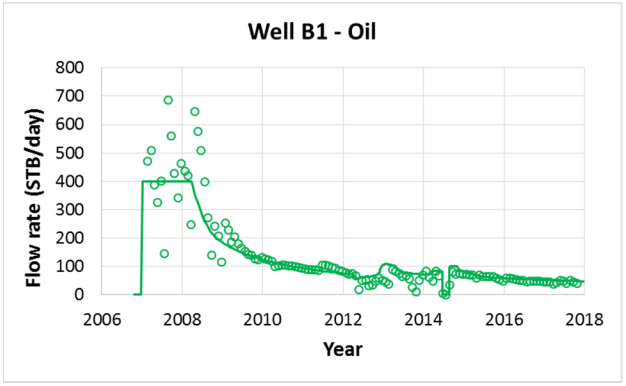
$\phi_f$ **= 0.01 %** $k_f$ **= 50 md**

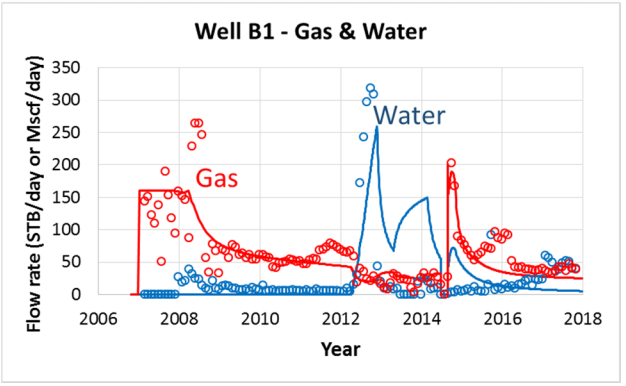
## ➢ History Matching Results

**Individual Wells**



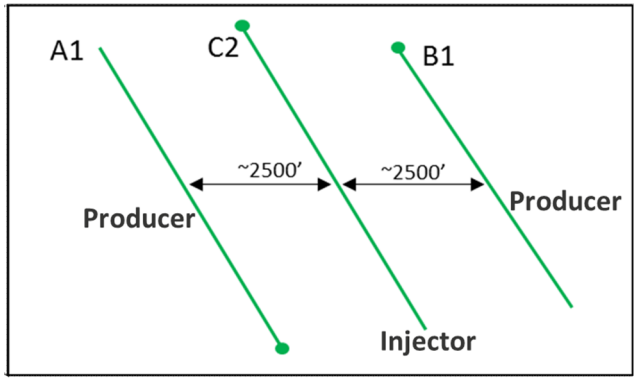



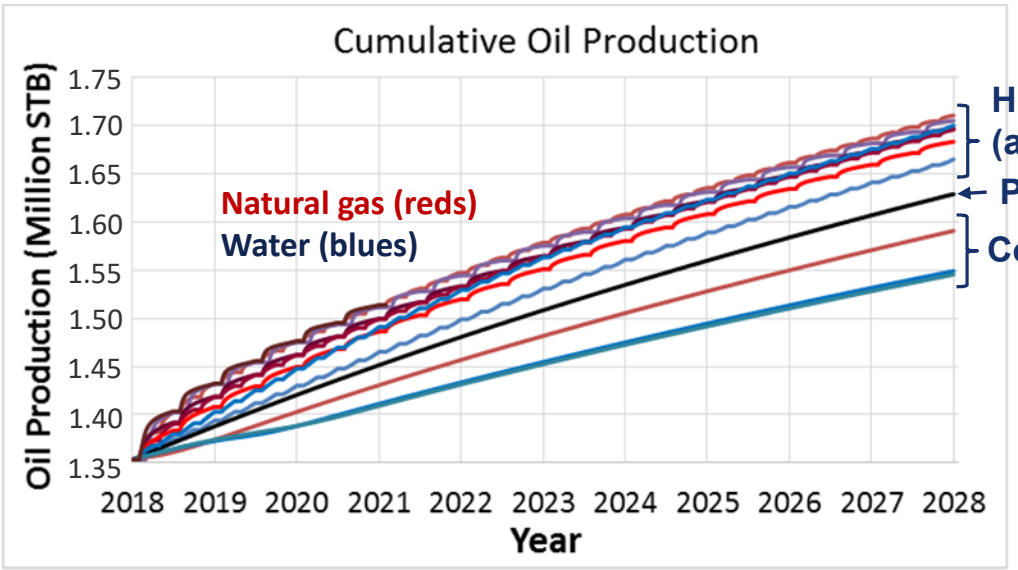



# Injection Pilot - Prediction Cases



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



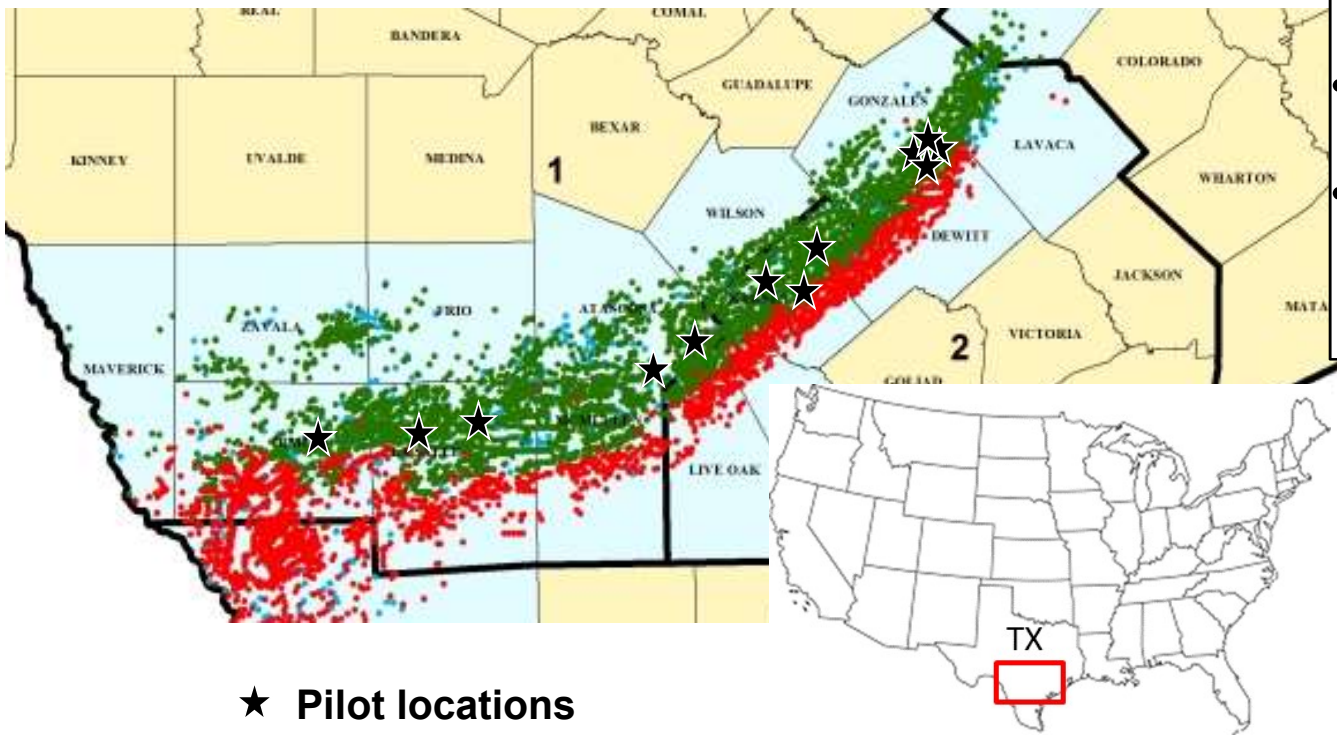

**Huff-n-Puff :: ~20% better than primary**

**Continuous :: ~20% worse than primary**

SPE 190221

# EOR Pilot Tests - Eagle Ford









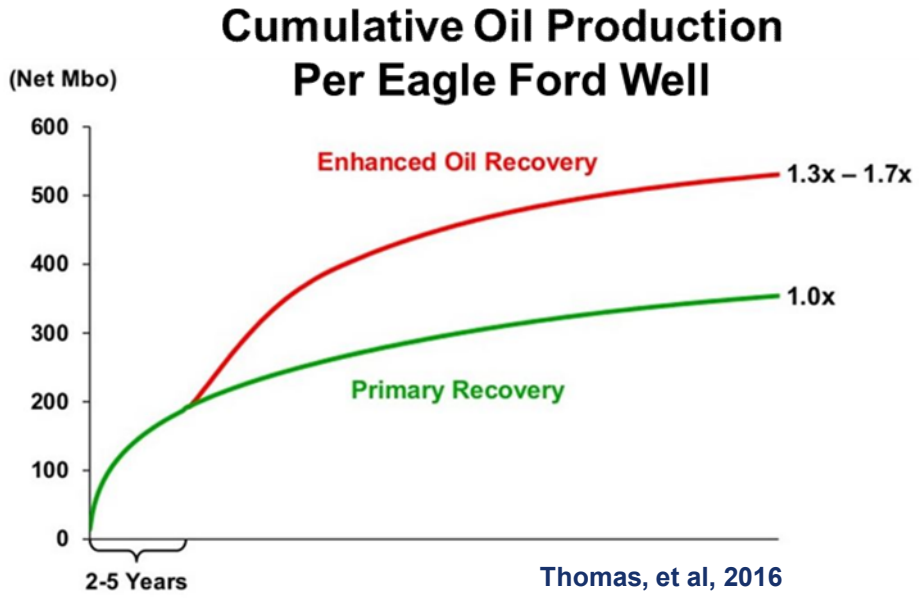
★ **Pilot locations**

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

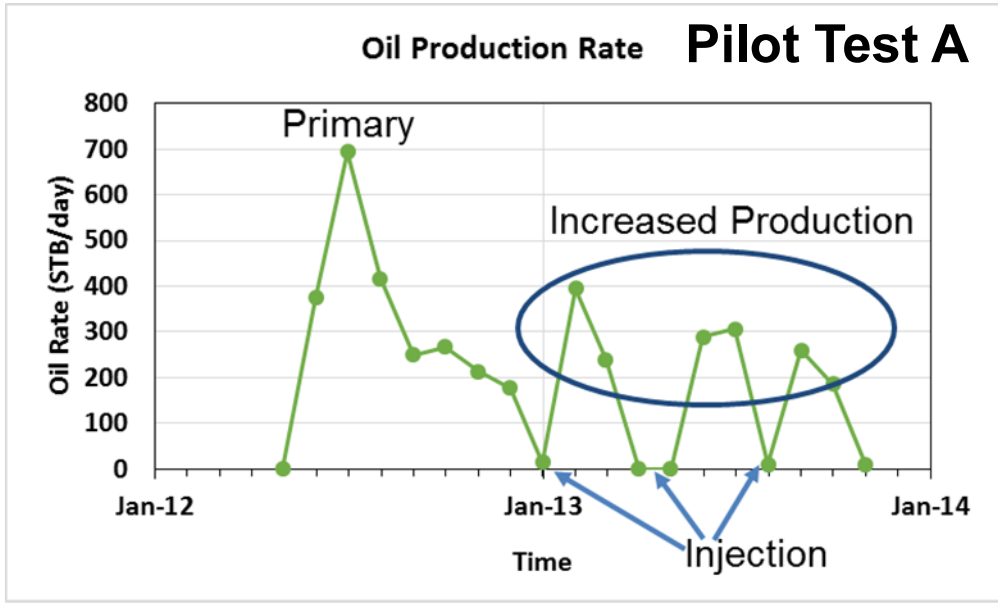
SPE 189816

# Eagle Ford - Huff-n-Puff EOR





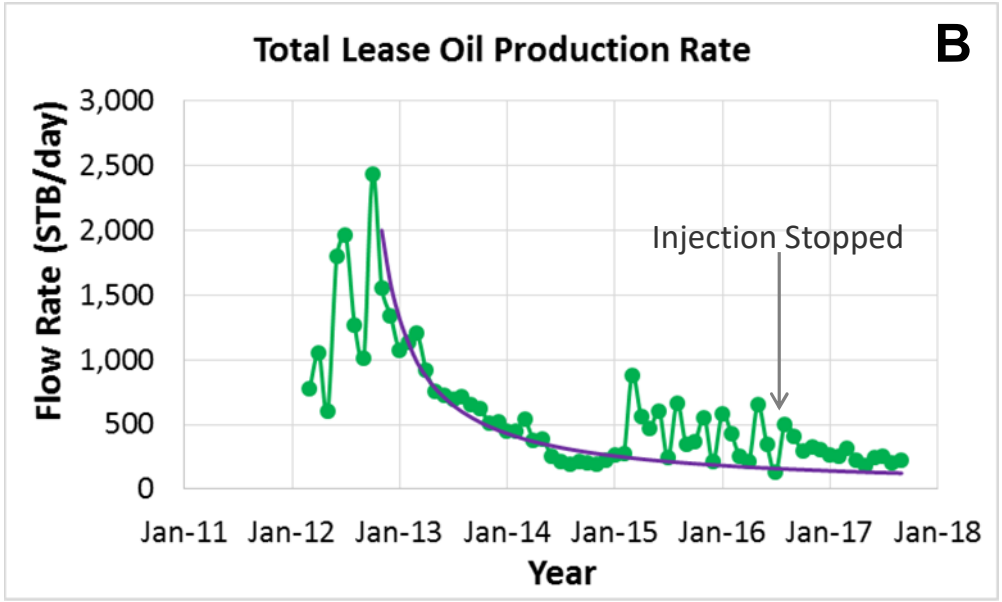

- Reported in investor relations presentation
- But no data presented

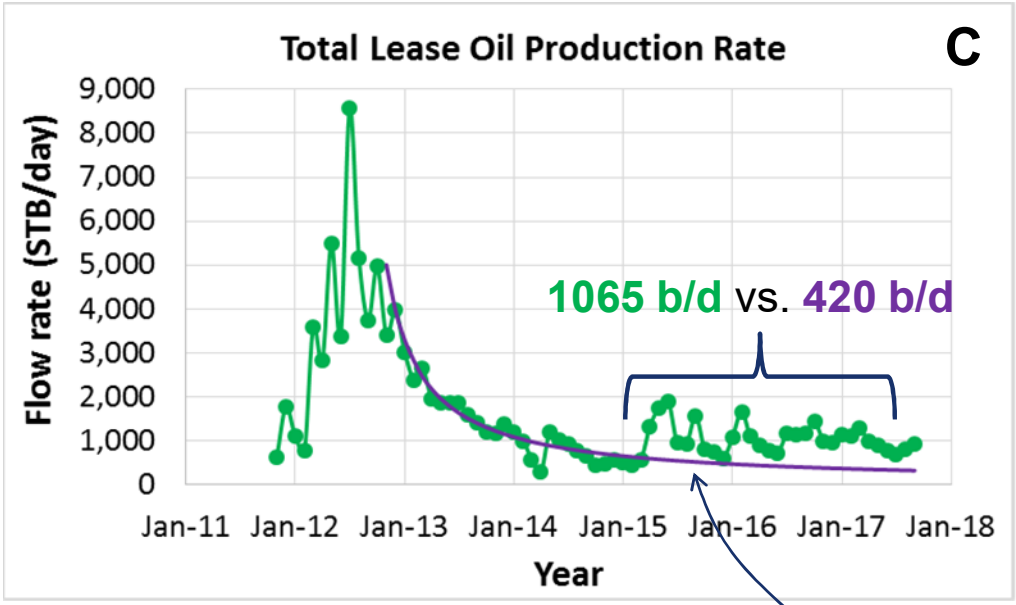



- Started at end of 2012
- Lean gas Inj. (90-95% $C_1$)
- 3 cycles in 2013

# Multi-Well - Huff-n-Puff EOR



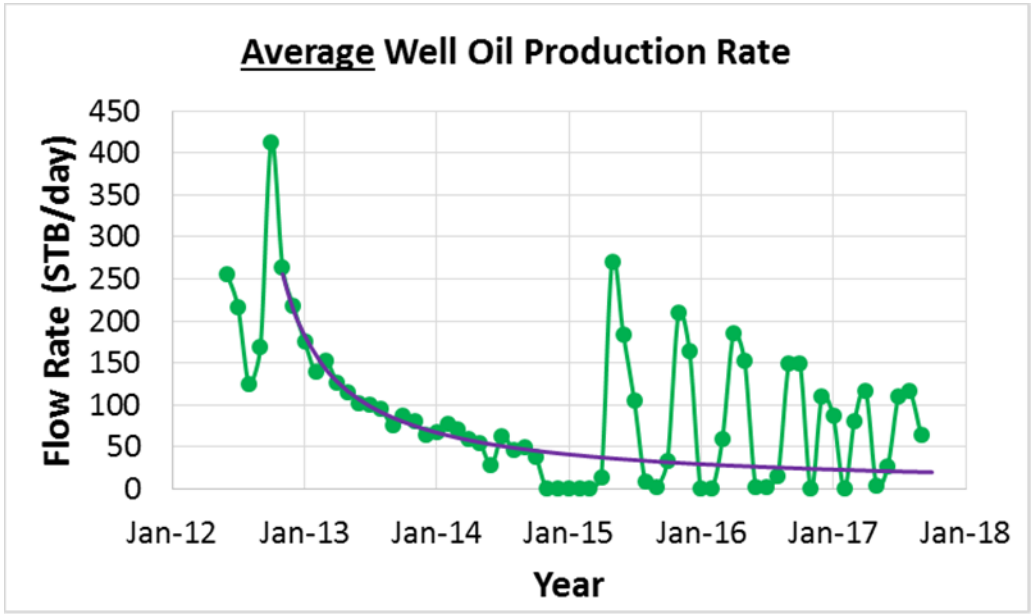



- ~ ½ wells injecting (4/8 in Pilot B, 6/14 in Pilot C)
- Increase in oil production is evident

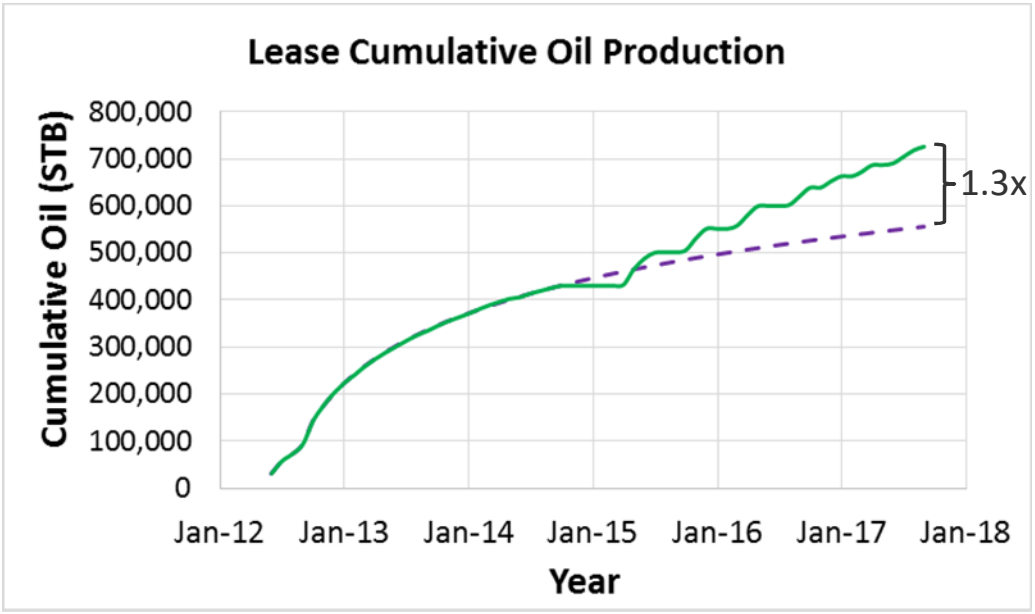
# Eagle Ford Huff-n-Puff Pilot D: 4 Wells





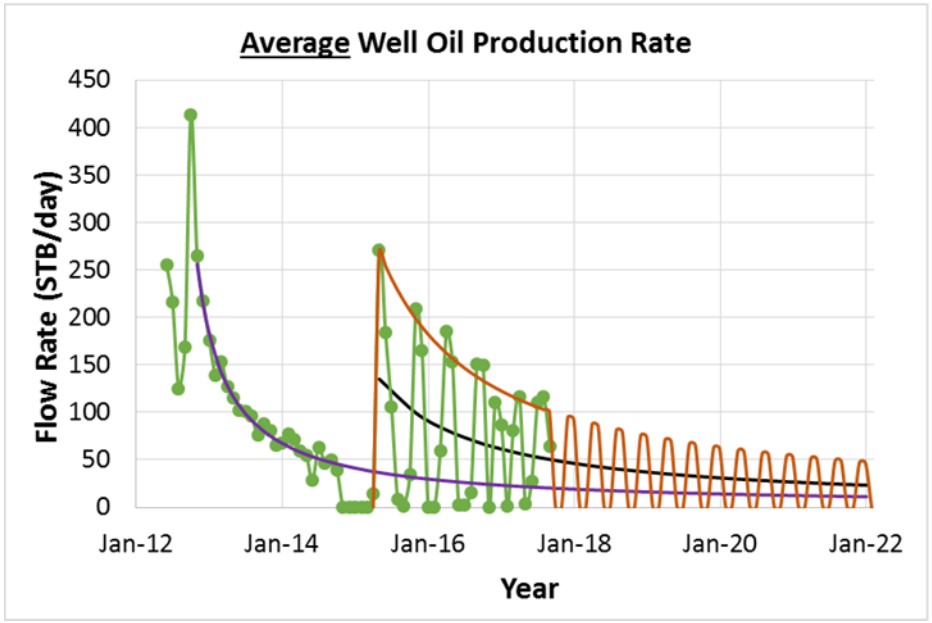

- After 3 years of injection, recovery is more than 30% greater than primary

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



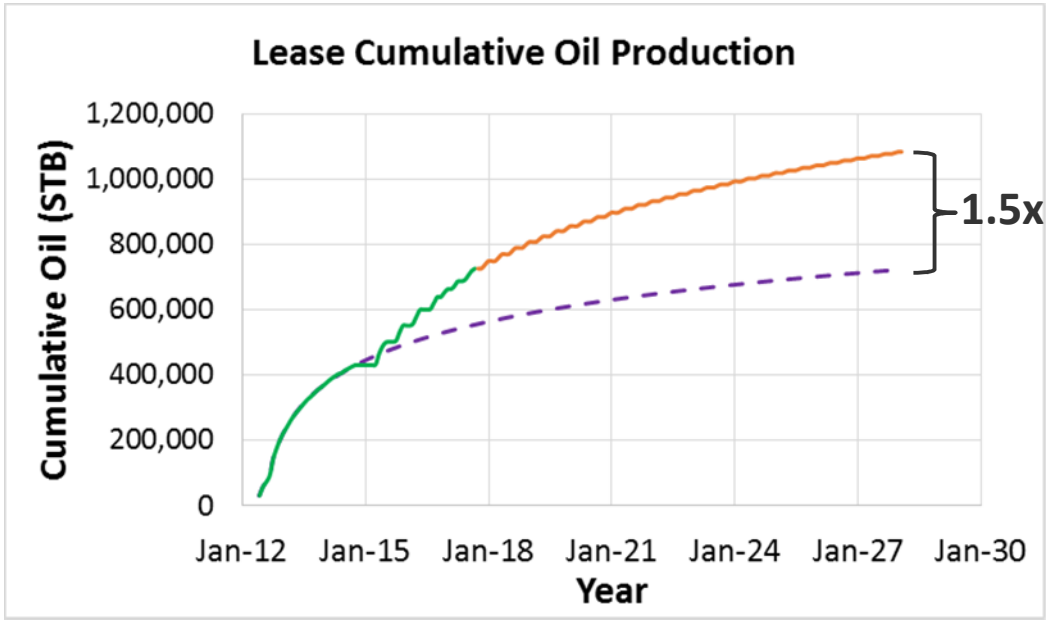
# Eagle Ford Huff-n-Puff Pilot: Predictions






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

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



# Eagle Ford Huff-n-Puff Pilot: Economics

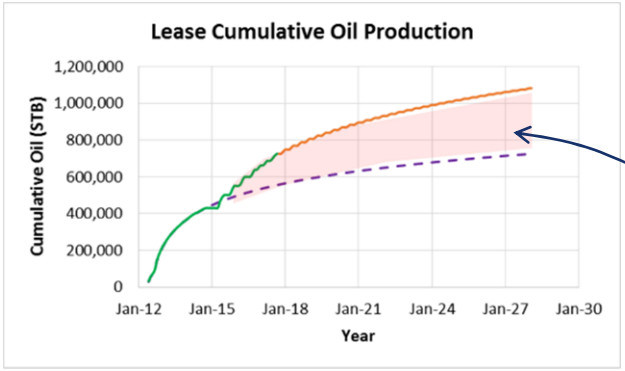


## Inputs

- CapEx: $1 million/well
  - compressors, flowlines, workovers, etc.
- Injection rate: 2 million scf/day ($2.50/Mscf)
  - 6 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 | -$2,600,000 | $400,000 | $3,400,000 |
| IRR | -- % | 17.7 % | 33.6 % |
| Payback | -- yrs | 2.3 yrs | 1.6 yrs |



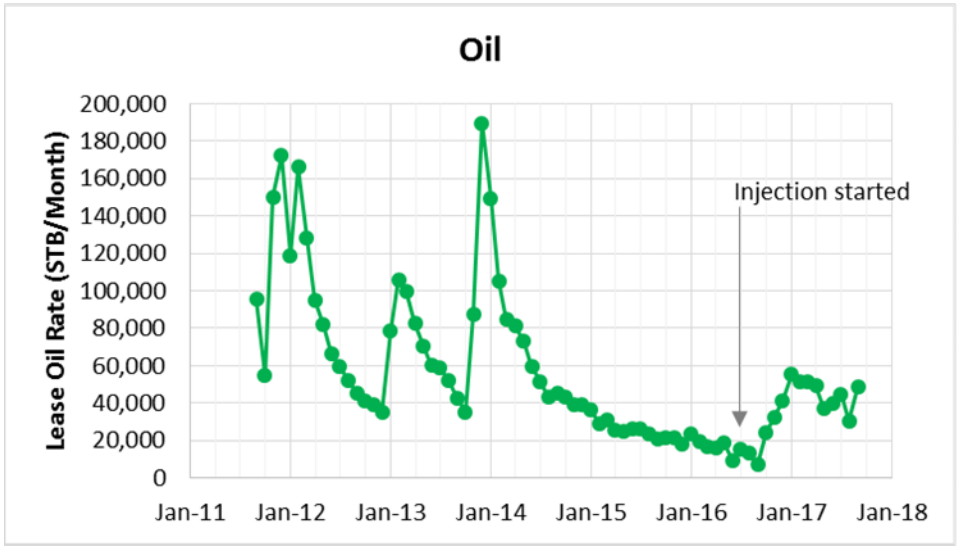

## Comments

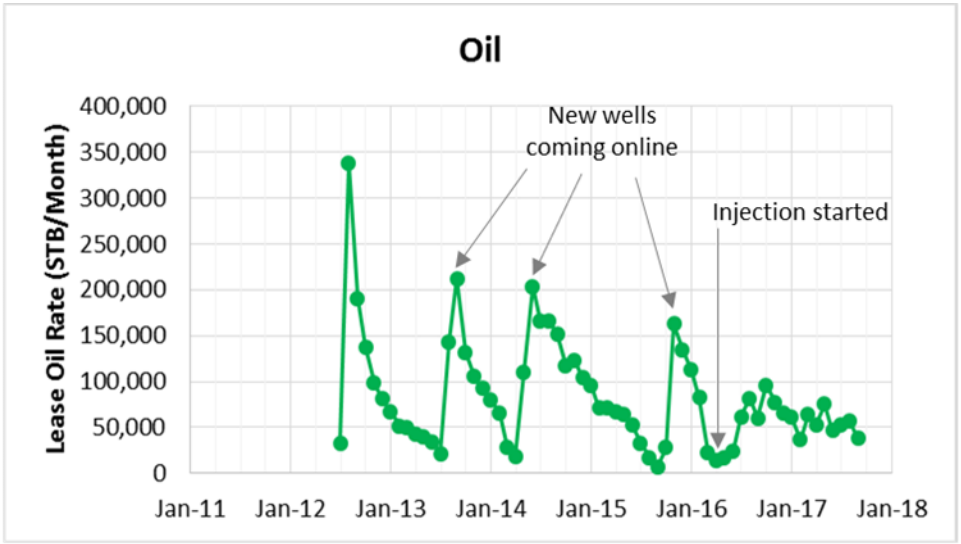
- Marginally economic
- More than half of the cost is gas fill up
- Efficiency gains should be realized over time

# Eagle Ford Summary



- **There are 200+ wells with Huff-n-puff gas injection**
- **At least 5 companies have injected in EF, and many more are planning pilots**
- **Early indications look promising, but issues? …**



# Concerns for Unconventional EOR



- **Future pilot floods need to focus on three things:**

**Conformance**

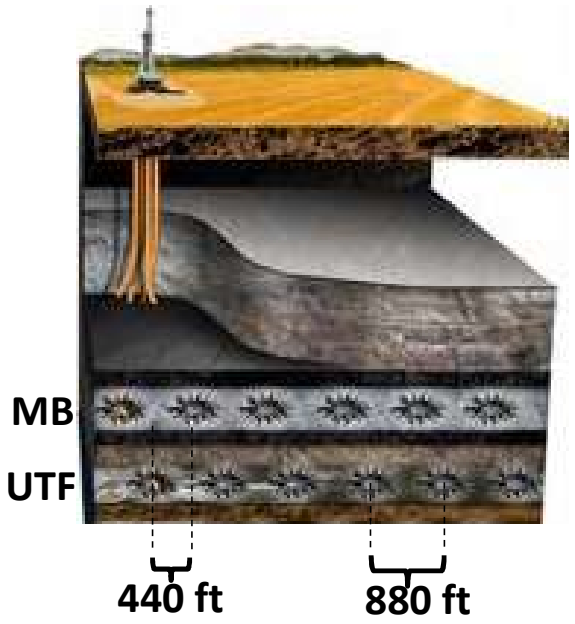
**Conformance**

**Conformance**

1. **Keeps pressure from building up**
2. **Loss of gas is costly**

# Conformance Control – Bakken

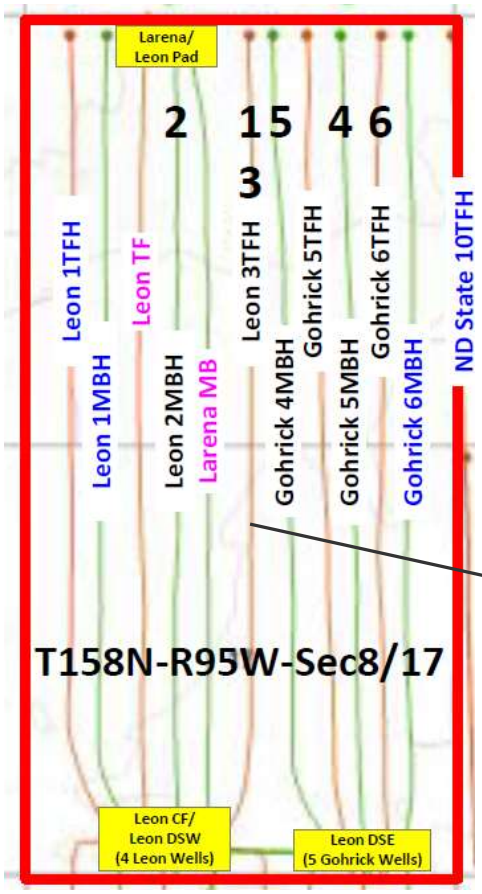




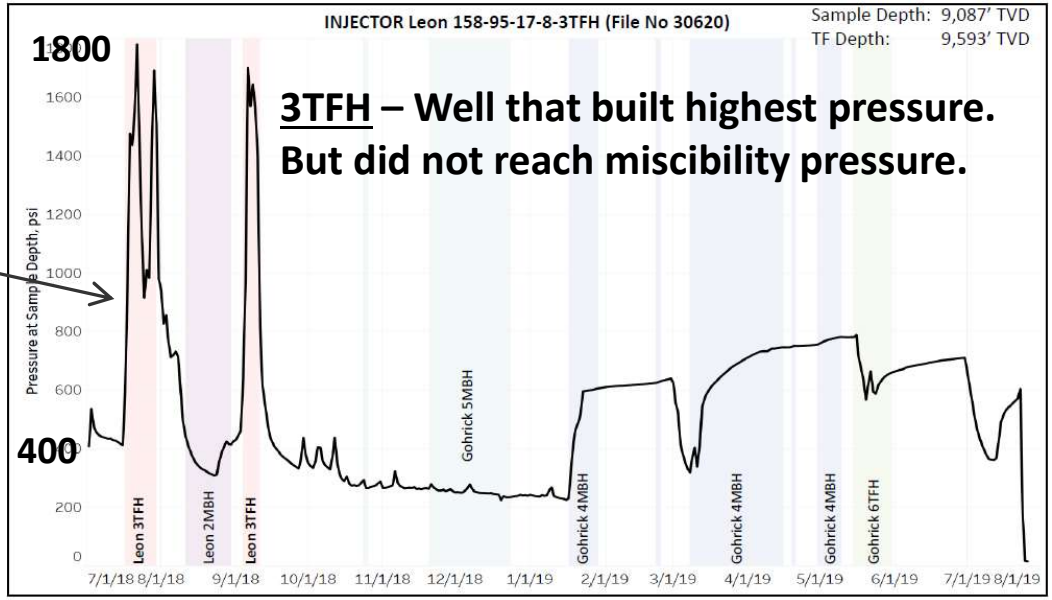

MB: Middle Bakken

UTF: Upper Three Forks

(NDIC, 2019)

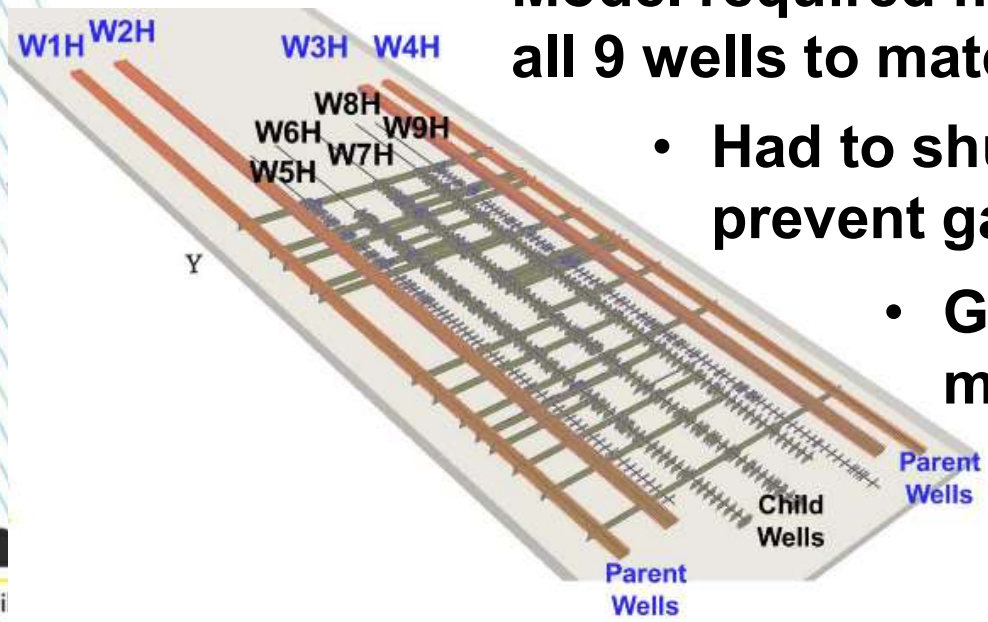



- **Difficult to build pressure**
- **Initial compressor too small**
- **Wells had low pressure (depleted)**
- **Pressure leaked off to offset wells**



# Conformance Control – Eagle Ford



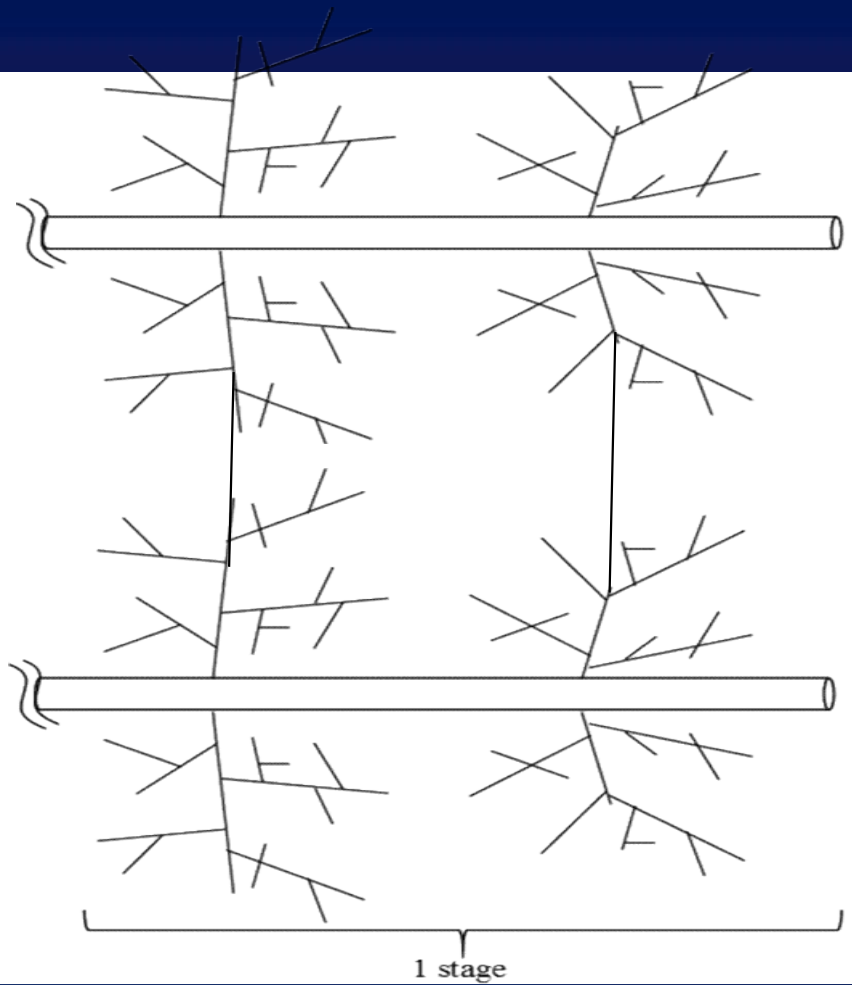




- **Model required fractures crossing all 9 wells to match breakthrough**
  - **Had to shut wells in to prevent gas breakthrough**
    - **Gas leakage was a major issue**

- **<u>Possible Solutions</u>: Isolate cluster of wells, pressure containment strategies.**

# Importance of Primary Completion






1. **Lots of surface area (10-100 million ft$^2$) close to wellbore**

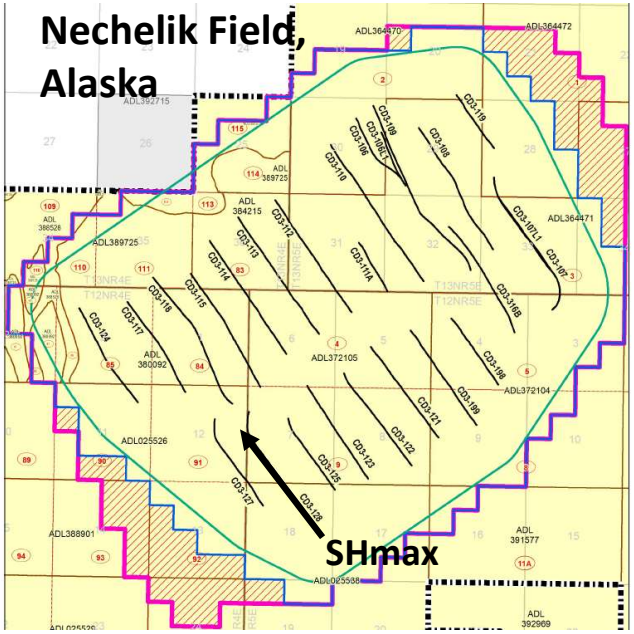
2. **Not intersecting with offset wells**

- **Better for primary, too**

# Other Operational Considerations



- Compressors → Huge, expensive and delayed delivery
- Other equipment (wellheads, packers, tubing, etc)
- Access to gas / type of gas injected
- Land Issues (royalties, offsets, partners)
- Continuous Injection options →



# Huff-n-Puff Gas Injection



## Proposed Mechanisms

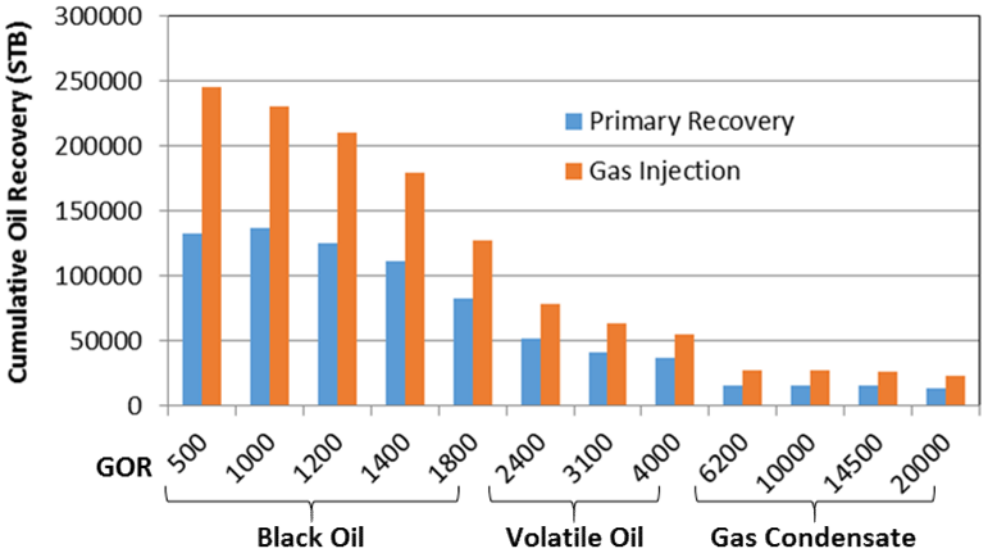
- Oil Swelling
- Secondary Solution Gas Drive
- Viscosity Reduction
- Vaporization
- Pressure Support
- Injection Induced Fracturing
- Wettability Alterations
- Others

## Conceptual Model

- During injection, gas fill fractures
- Pressure increases
- Gas interacts with reservoir liquids
  - Dissolution, Vaporization
- Fracture surface area is limiting factor

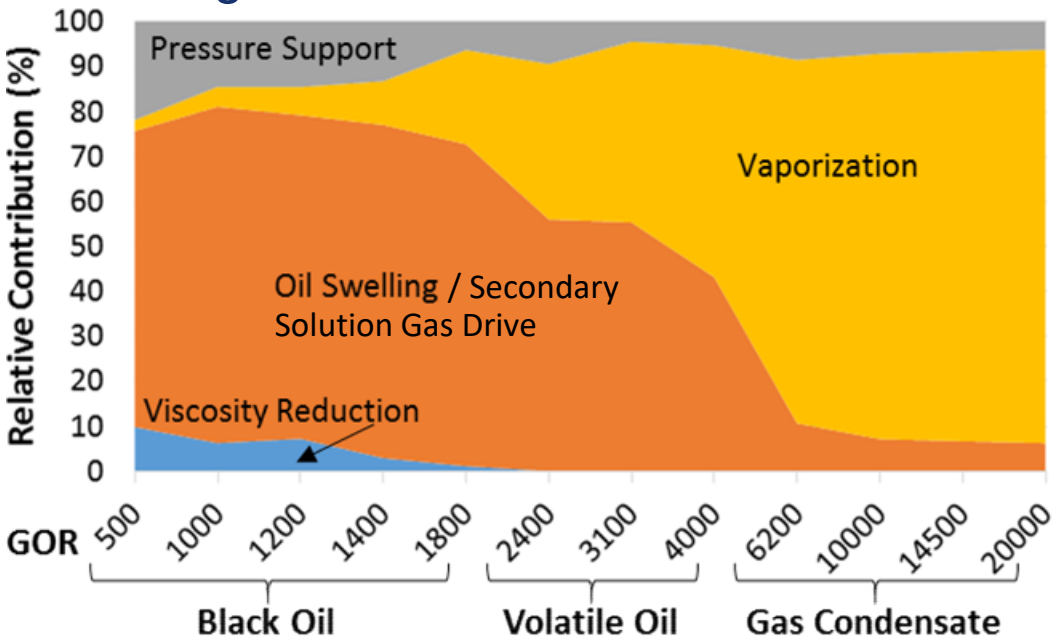
# Recovery Mechanisms






- Gas injection increases liquid production for all fluid types
- Black oils have a larger incremental

- Oil Swelling most important for low GOR fluids
- Vaporization most important for high GOR fluids



# 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 …
- Significant work to be done
  - Lab, modeling, and field trials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# Questions/Comments



**Thank you!**


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