SPE 195239-MS: Field Development Using Compositional Reservoir Simulation and Uncertainty Analysis in the Delaware Basin

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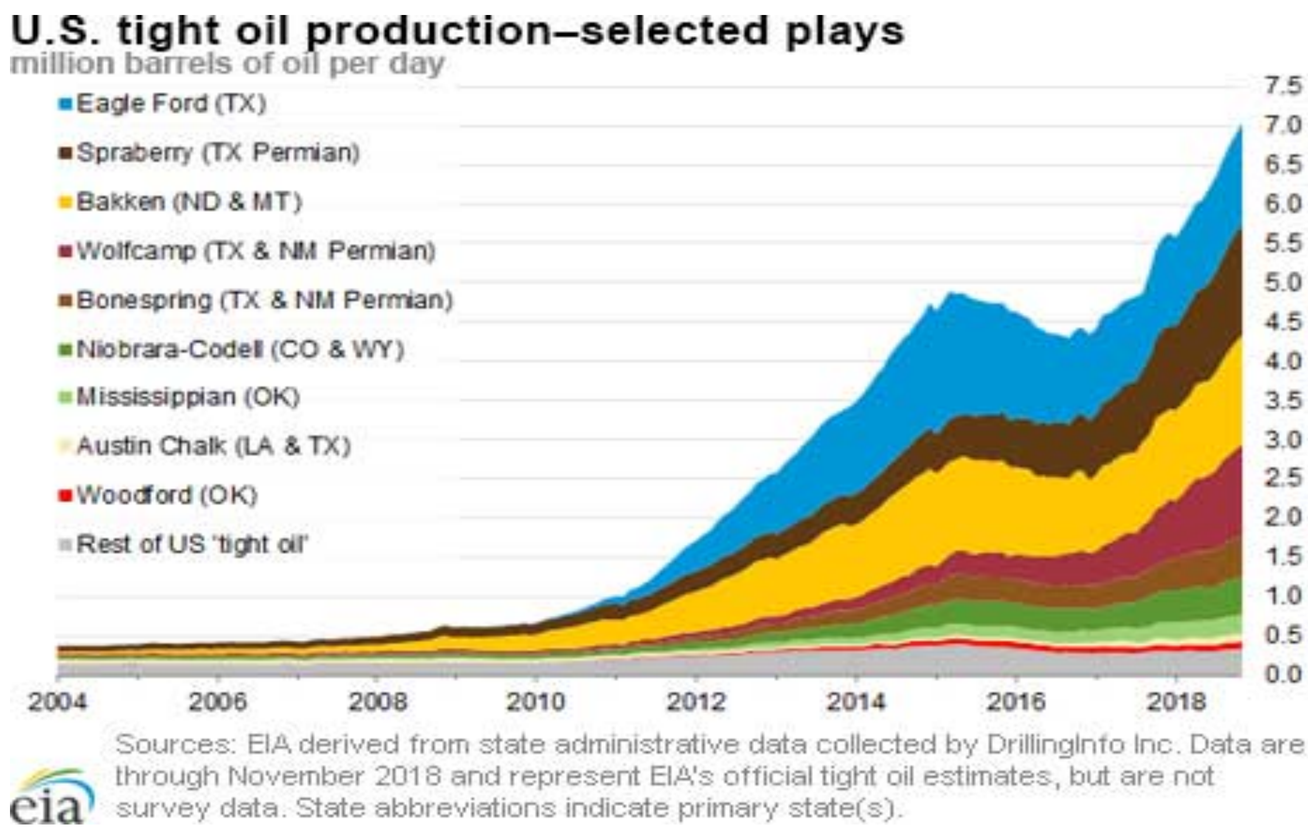
Presentation Outline

- Future Development Challenges in Permian Basin
- Overview of Mitigating Methods
- Delaware Basin Geomodel
- Fluid Properties for 2nd Bone Spring Formation
- Simulation Case Study
- S
- Conclusions


U.S. tight oil production–selected plays
million barrels of oil per day
Eagle Ford (TX)
Spraberry (TX Permian)
Bakken (ND & MT)
Wolfcamp (TX & NM Permian)
Bonespring (TX & NM Permian)
Niobrara-Codell (CO & WY)
Mississippian (OK)
Austin Chalk (LA & TX)
Woodford (OK)
Rest of US 'tight oil'
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
2004
2006
2008
2010
2012
2014
2016
2018
Sources: EIA derived from state administrative data collected by DrillingInfo Inc. Data are through November 2018 and represent EIA's official tight oil estimates, but are not survey data. State abbreviations indicate primary state(s).

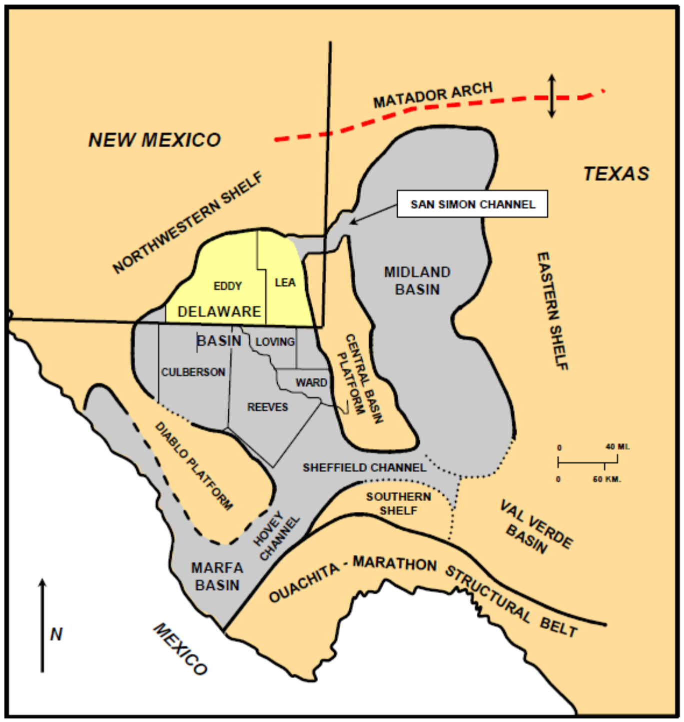
Future Development Challenges in Permian Basin

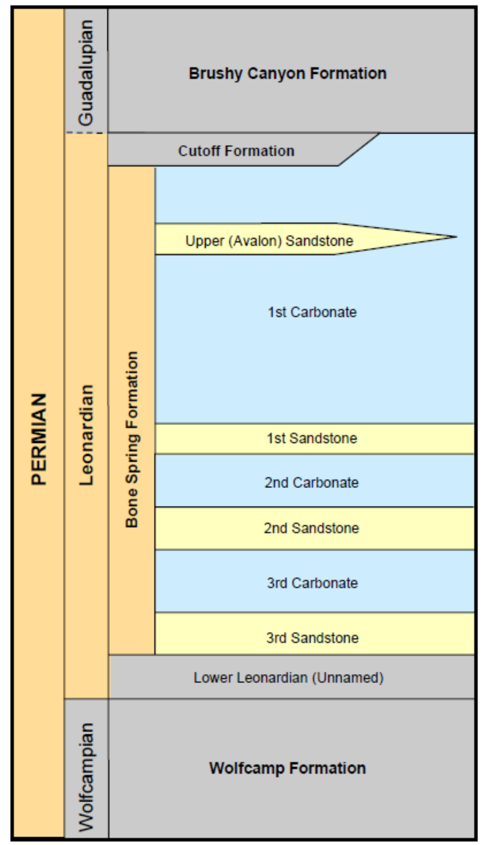
- Reservoir Characterization Accuracy?
  - Field Data Uncertainty
- Optimal Well Spacing
  - Recent Difficulty with Reserves
- Can Improved Recovery/EOR Work?
  - Historically Feasible Methods
- Increasing Time to Depletion

Overview of Mitigating Methods

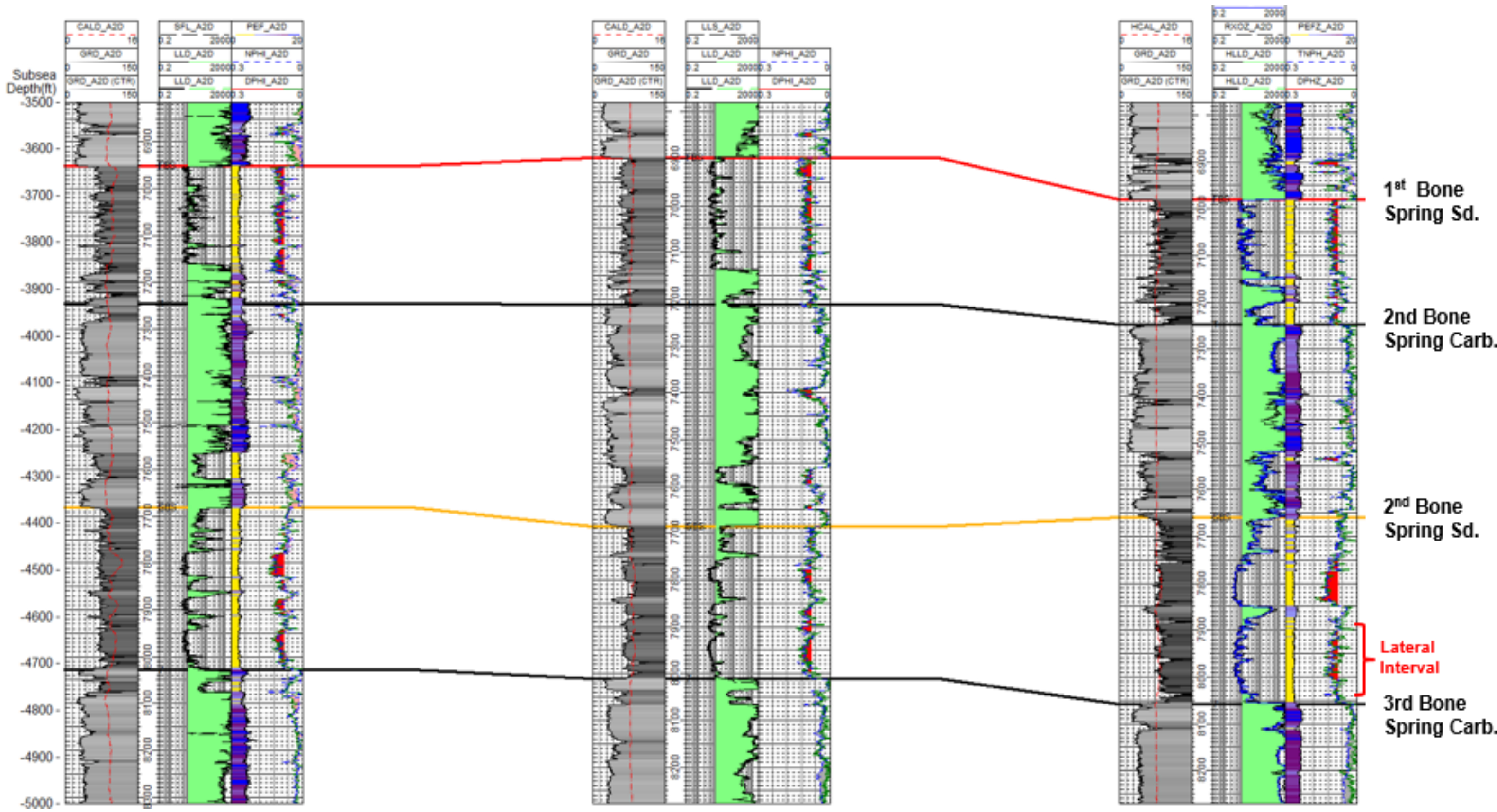
- Geomodel and Numerical Simulation (CMG GEM/WINPROP)
- History Matching (CMG CMOST)
  - Oil and Gas Production
  - Bottom Hole Pressure
  - GOR
  - WOR
- IOR/EOR Models
  - CO2
  - Low Salinity Water Injection

Delaware Basin Geology

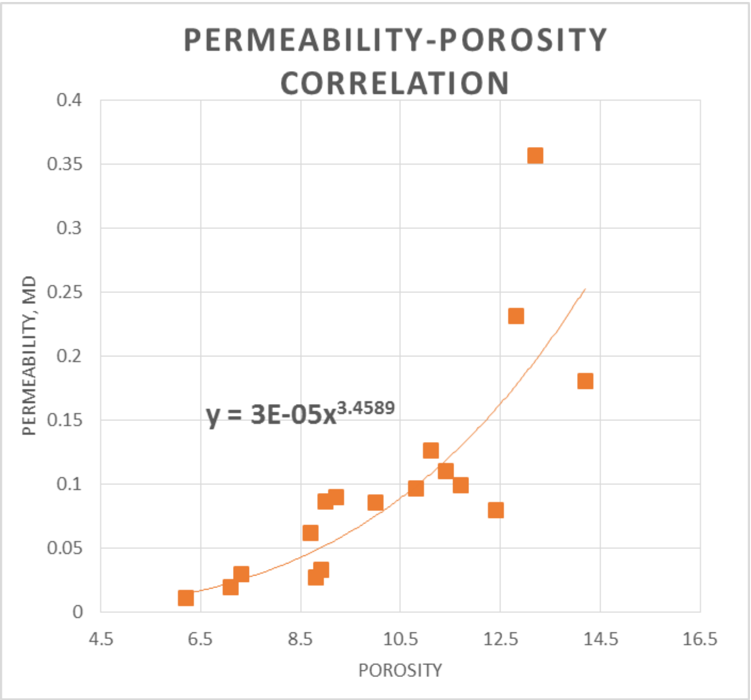


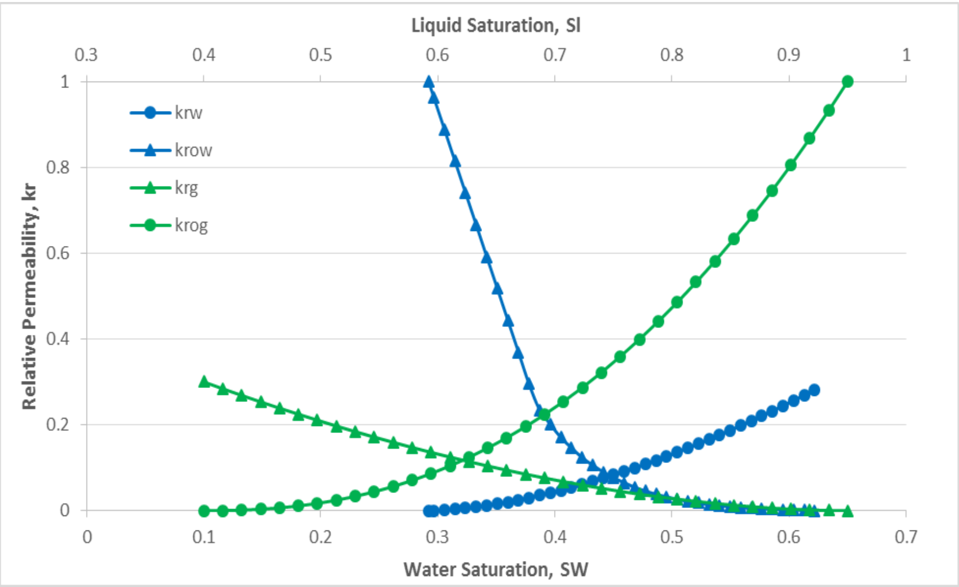


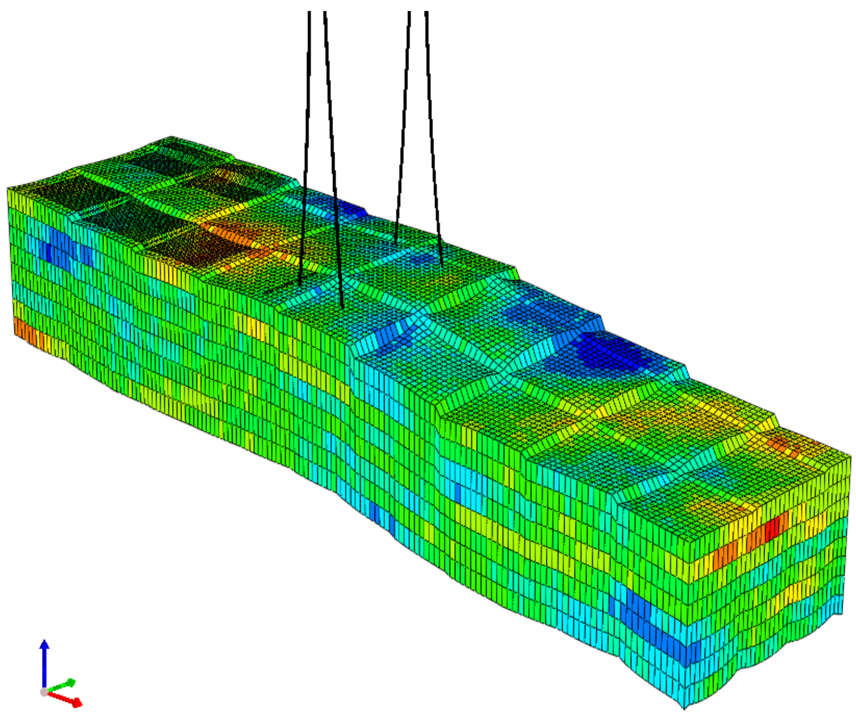
Cross-Section of Bone Spring Deposit



Rock Physics Data







Porosity, ϕ	**7-12%**
Permeability, k	0.008-0.09 mD
Reservoir Temperature	130 F
k_v/k_h Ratio	0.2
Rock Compressibility (psi^{-1})	3.00E-06
Reservoir Pressure	4027 psi
DWOC	4575 ft
Depth of Referenced Zone	4650 ft
Water Saturation	40%

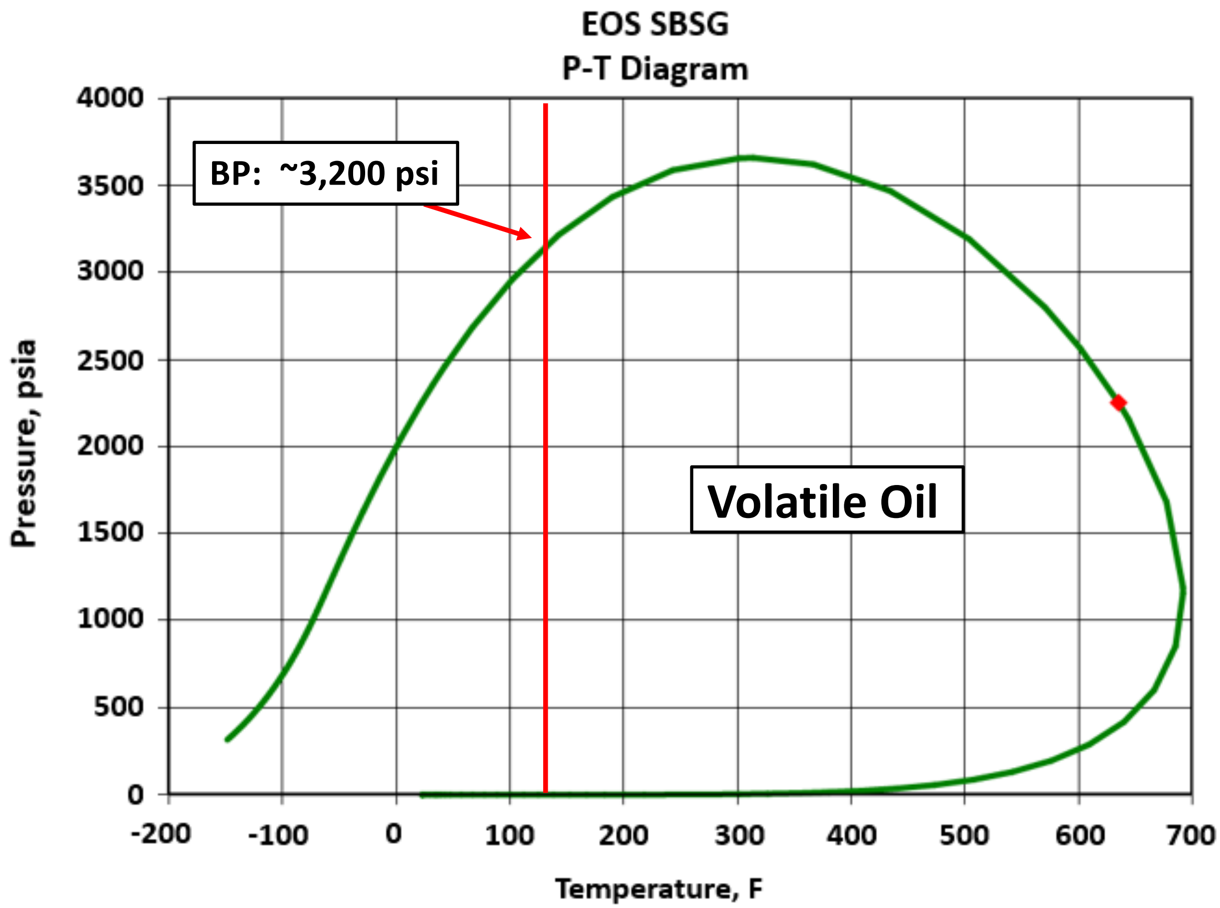
Fluid Properties of the 2nd Bone Spring

Component	HC	Pc (atm)	Tc (K)	Acentric Factor	Molecular Weight	SG
N2	0	33.5	126.2	0.04	28.013	0.809
CO2	3	72.8	304.2	0.225	44.01	0.818
CH4	1	45.4	190.6	0.008	16.043	0.3
C2H6	1	48.2	305.4	0.098	30.07	0.356
C3H8	1	41.9	369.8	0.152	44.097	0.507
IC4	1	36	408.1	0.176	58.124	0.563
NC4	1	37.5	425.2	0.193	58.124	0.584
IC5	1	33.4	460.4	0.227	72.151	0.625
NC5	1	33.3	469.6	0.251	72.151	0.631
NC6	1	29.3	507.4	0.296	86.178	0.664
C7+	1	19.836103	710.9353	0.52561252	180.9	0.8343

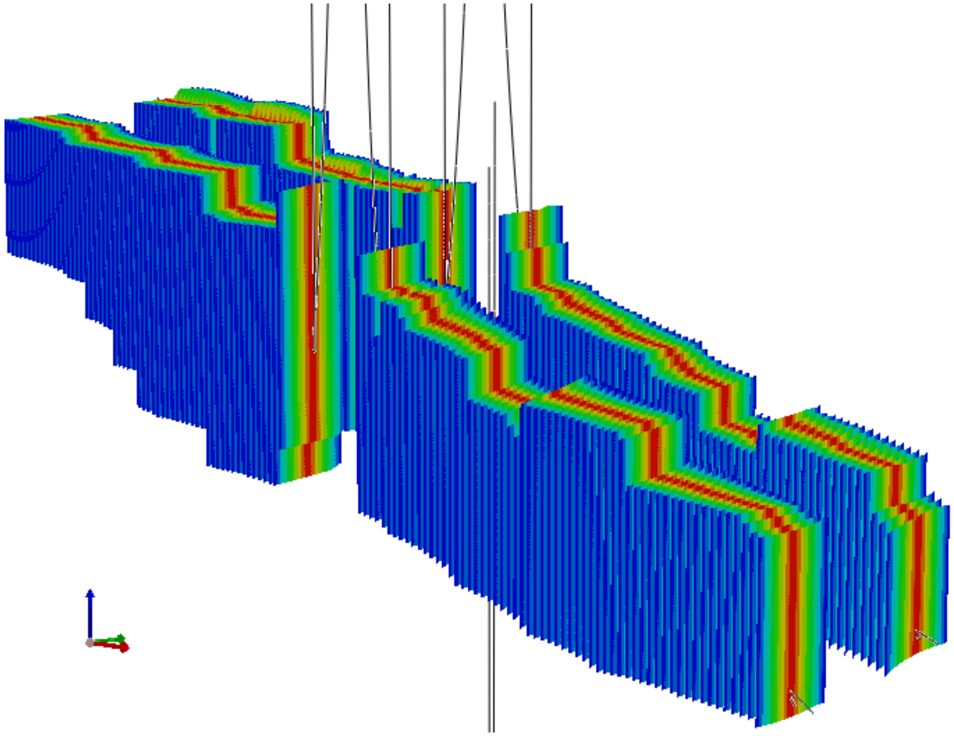
Component	Primary	Secondary
N2	0.056	1.684
CO2	0.020	0.162
CH4	3.824	73.017
C2H6	4.871	14.146
C3H8	7.237	6.732
IC4	1.750	0.830
NC4	5.490	1.851
IC5	2.559	0.395
NC5	3.399	0.413
NC6	4.409	0.256
C7+	66.385	0.514
Sum	100	100

Component	Primary
N2	1.072
CO2	0.109
CH4	46.984
C2H6	10.656
C3H8	6.922
IC4	1.176
NC4	3.220
IC5	1.209
NC5	1.536
NC6	1.819
C7+	25.297
Sum	100

- 11 Components
- CMG WINPROP
  - Recombination
  - Regression
  - Flash Calculations
- Validated with physical recombined sample
- All sampling done at surface 3-phase separator
- GOR 2500 scf/bbl


EOS SBSG
P-T Diagram
BP: ~3,200 psi
Volatile Oil
Pressure, psia
Temperature, F
4000
3500
3000
2500
2000
1500
1000
500
0
-200
-100
0
100
200
300
400
500
600
700

Well Placement and Completions



Well 1 Fracture Half Length, x_f	**475**
Well 2 Fracture Half Length, x_f	455
Well 3 Fracture Half Length, x_f	408
Well 4 Fracture Half Length, x_f	422
Well 1 Fracture Effective Permeability (md)	5
Well 2 Fracture Effective Permeability (md)	5.3
Well 3 Fracture Effective Permeability (md)	4.1
Well 4 Fracture Effective Permeability (md)	6.1
Well 1 Fracture Height	150
Well 2 Fracture Height	143
Well 3 Fracture Height	155
Well 4 Fracture Height	135

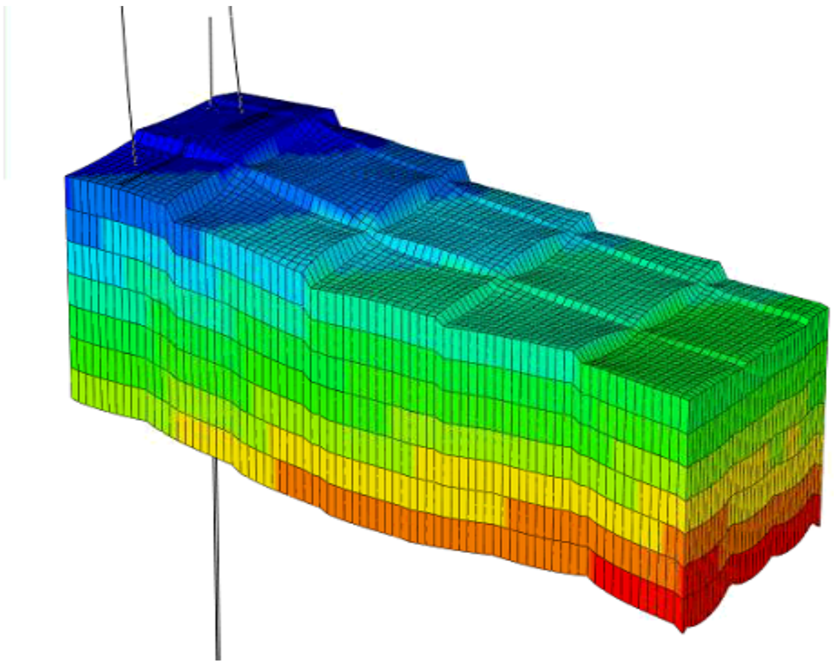
Development Simulation Case Study

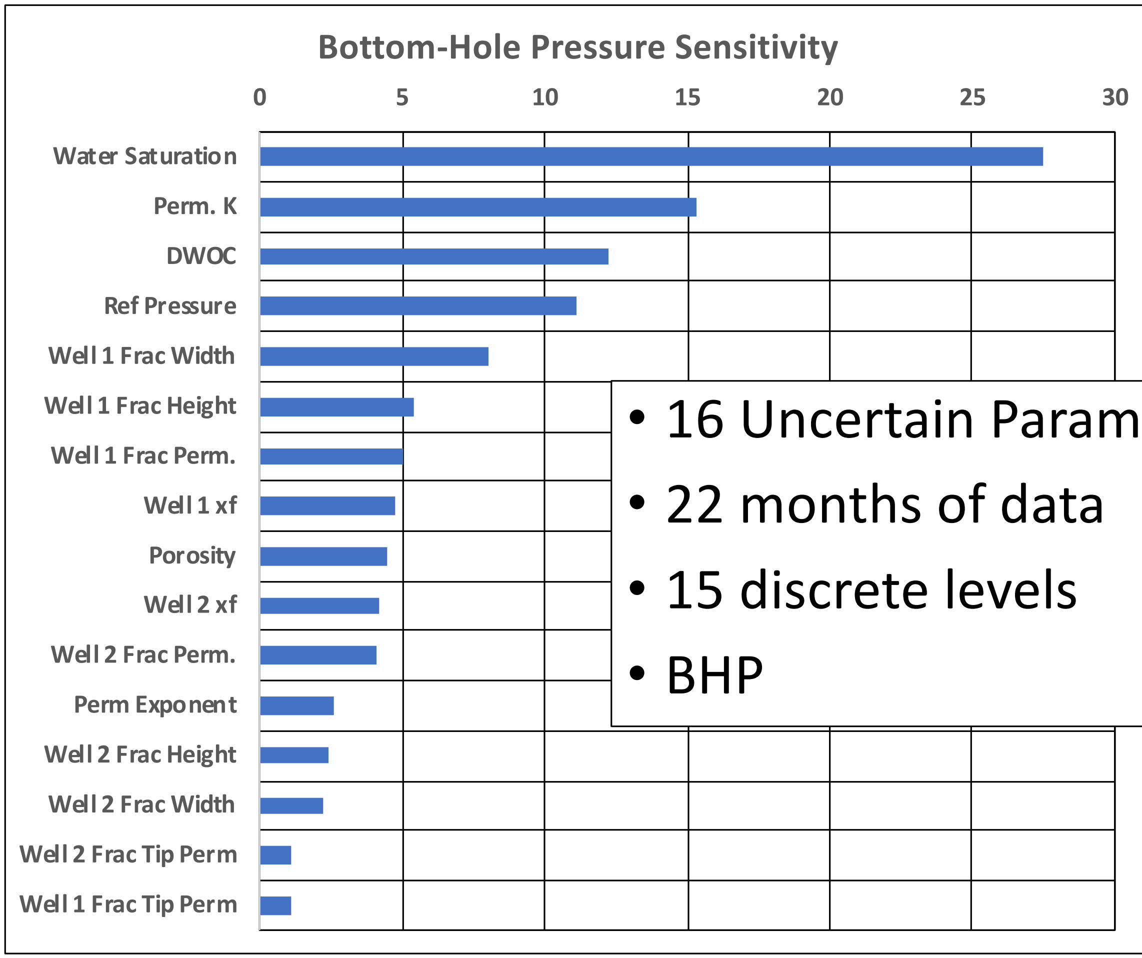
- Input Parameters
- Sensitivity Analysis Results
- History Match Uncertain Parameters (CMG CMOST)
- Well Spacing Optimization
- IOR/EOR Feasibility

Simulation Input

Simulation Model

- Originally 4 Wells, Now 2
- Core data taken from 4 well scenario
- Grid 75x35x8 (1 mile x 0.5 mile)





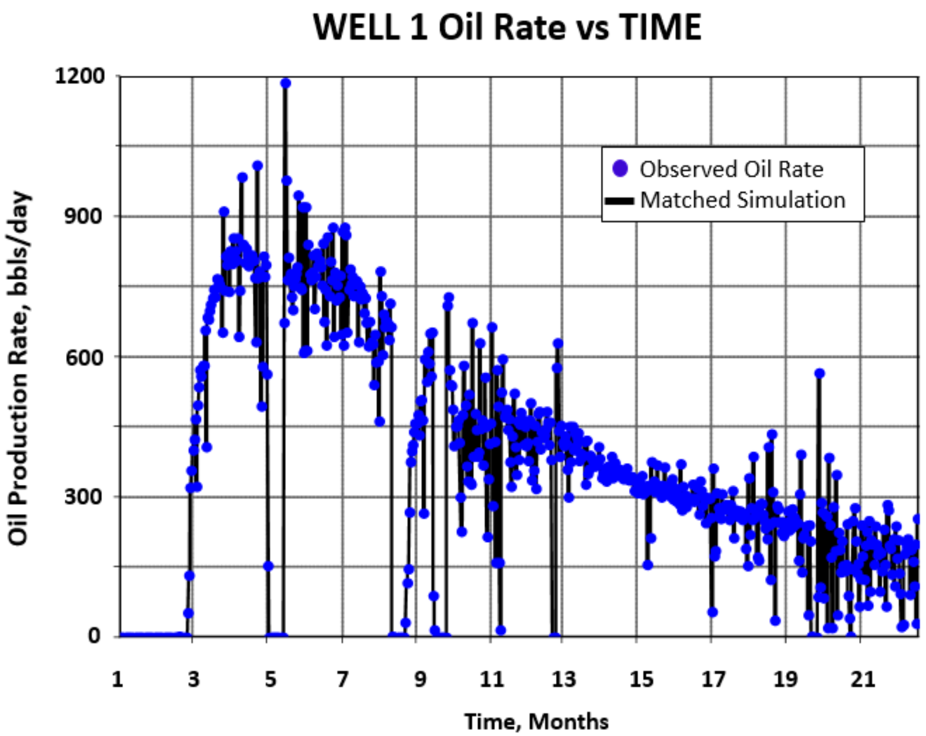
- 16 Uncertain Parameters
- 22 months of data
- 15 discrete levels
- BHP

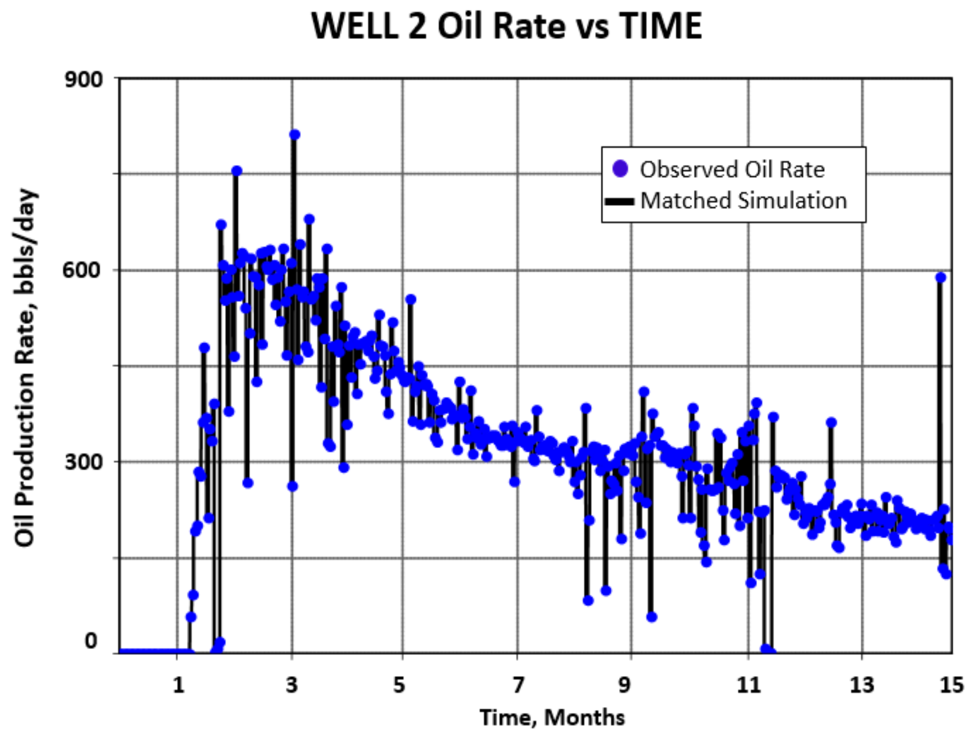
History Match

- Range end points from core data
- Remaining set from previous rock physics data
- Field history files
  - BHP
  - Production

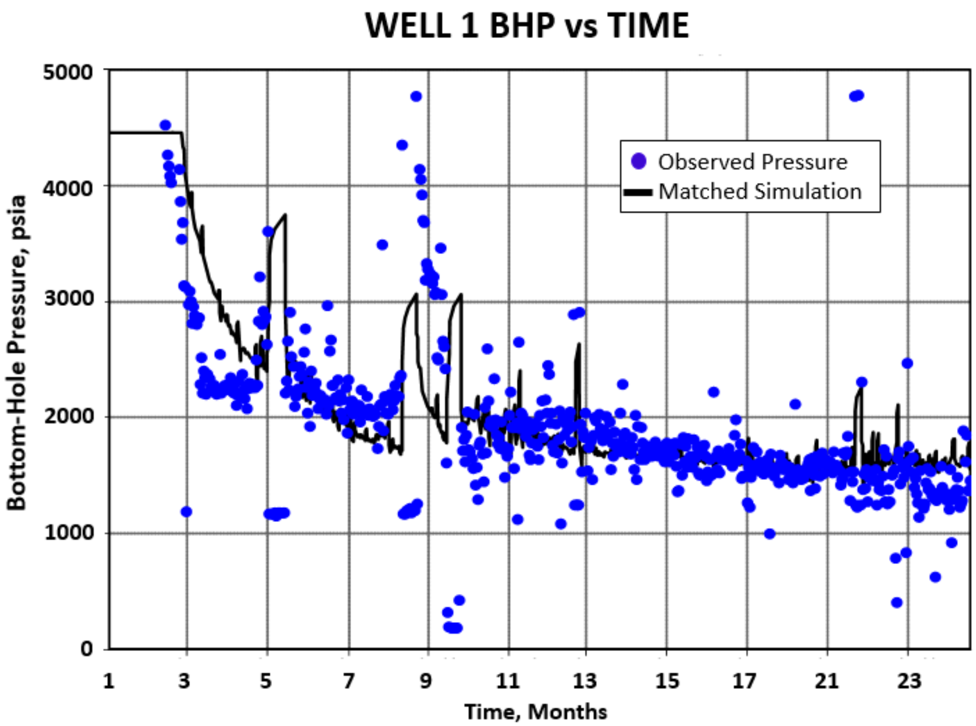
Uncertain Parameters	Range		
	Minimum	Maximum	Matched
Well 1 Fracture Half Length, x_f	300	500	480
Well 2 Fracture Half Length, x_f	300	500	455
Well 1 Fracture Inner Width	1.5	2.5	2.1
Well 2 Fracture Inner Width	1.8	3	2.4
Well 1 Fracture Permeability	2000	30000	10400
Well 2 Fracture Permeability	2000	30000	13125
Well 1 Fracture Tip Permeability	3.75	6.25	5.2
Well 2 Fracture Tip Permeability	3.75	6.25	5.25
k_v/k_h Ratio	0.1	0.9	0.52
Horizontal Permeability, k_h (mod)	0.825	1.375	1.1
Water Saturation at WOC	0.1	0.4	0.32
Depth of WOC	2400	4500	4495
Initial Reservoir Pressure	3300	5500	4275
Rock Compressibility (psi^{-1})	1.58E-06	2.63E-05	2.50E-06
Pore Pressure	3000	5000	4000
Porosity (modifier)	0.6	1.4	0.8
Permeability Equation (con)	2.5	3.6	3.1
Permeability Equation (exp)	1.3	1.5	1.398

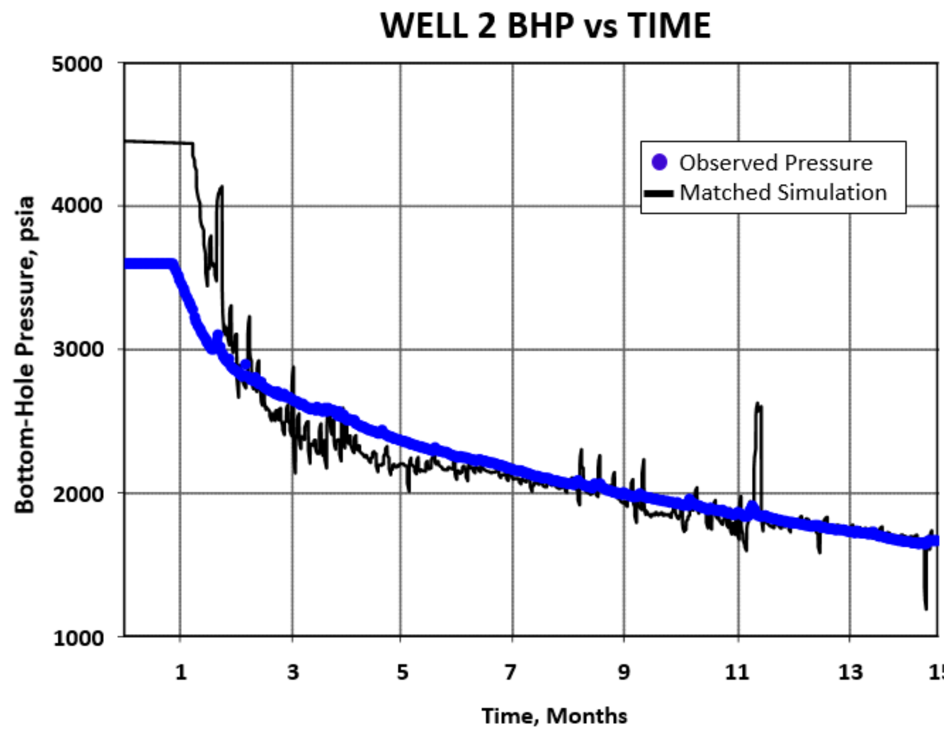
History Match: Oil Rate





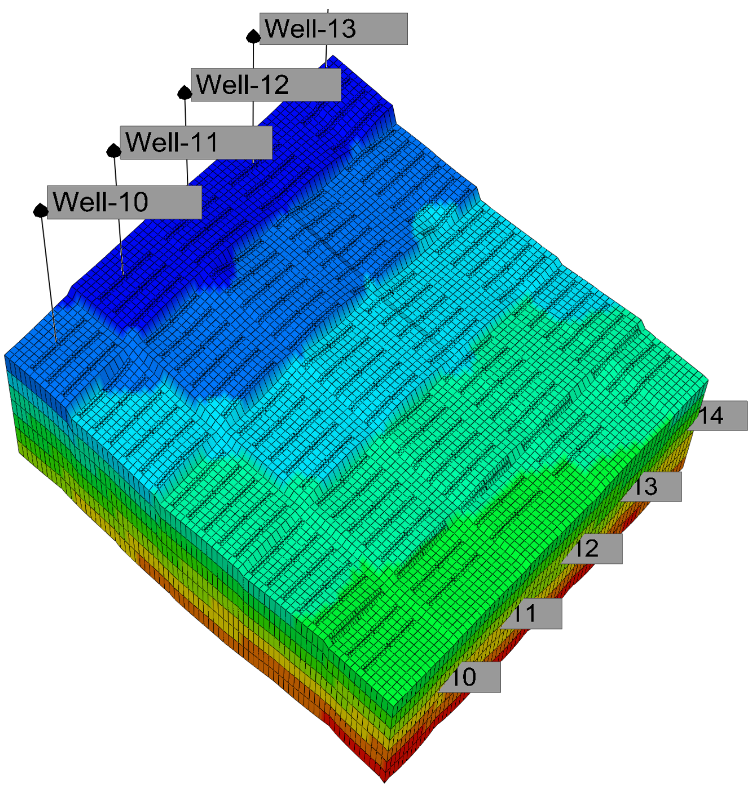
History Match: Bottom-Hole Pressure





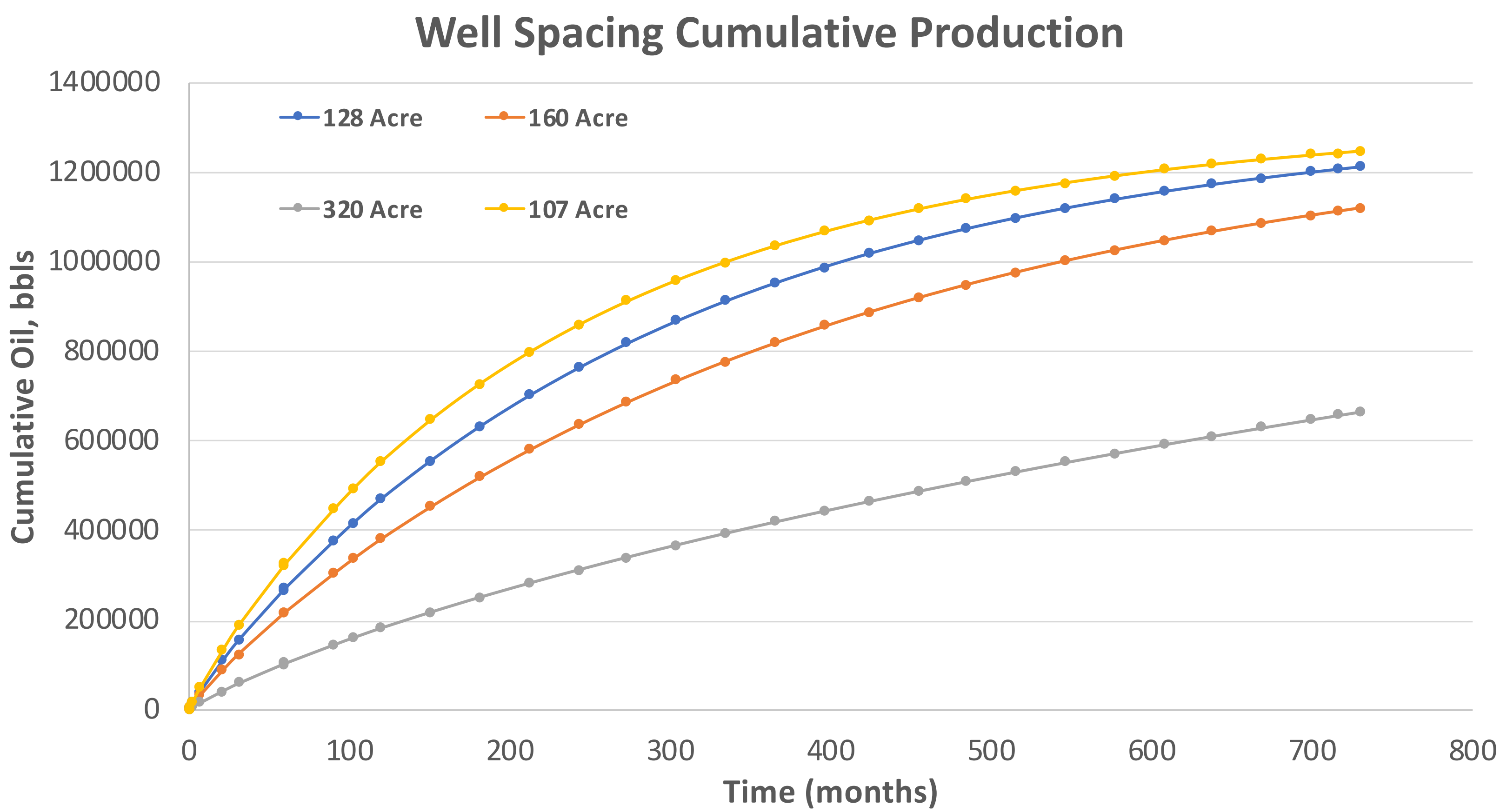
Well Spacing Analysis Overview

- Important Industry Challenge
- Optimizes Reserve Determination
- Avoid Drainage Area Overlap
- Potential for Higher Recovery Factor
- Plays More Economical



- History Matched data
- Variations of Well Placement
- Assumptions:
  - Zipper Hydraulic Fracturing
  - Same Reservoir Bench
  - Produce Until Depletion

Fracture Half Length, x_f	**450**
Lateral Length (ft)	4500
Fracture Inner Width	2.25
Fracture Effective Permeability (md)	5
Fracture Height	140
Fracture Tip Permeability (md)	5.25

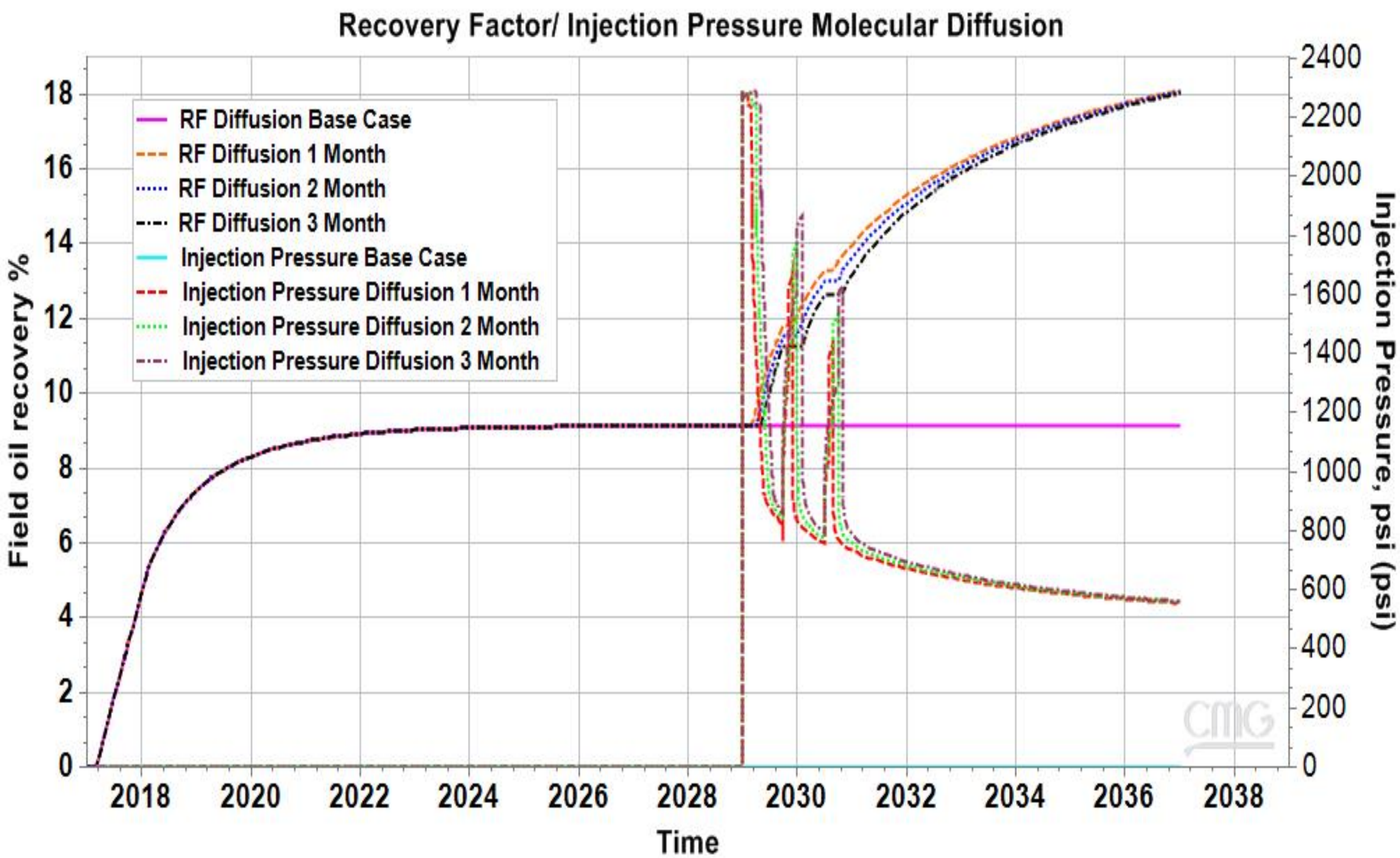

Well Spacing Cumulative Production
128 Acre
160 Acre
320 Acre
107 Acre
Cumulative Oil, bbls
1400000
1200000
1000000
800000
600000
400000
200000
0
0
100
200
300
400
500
600
700
800
Time (months)

EOR Feasibility

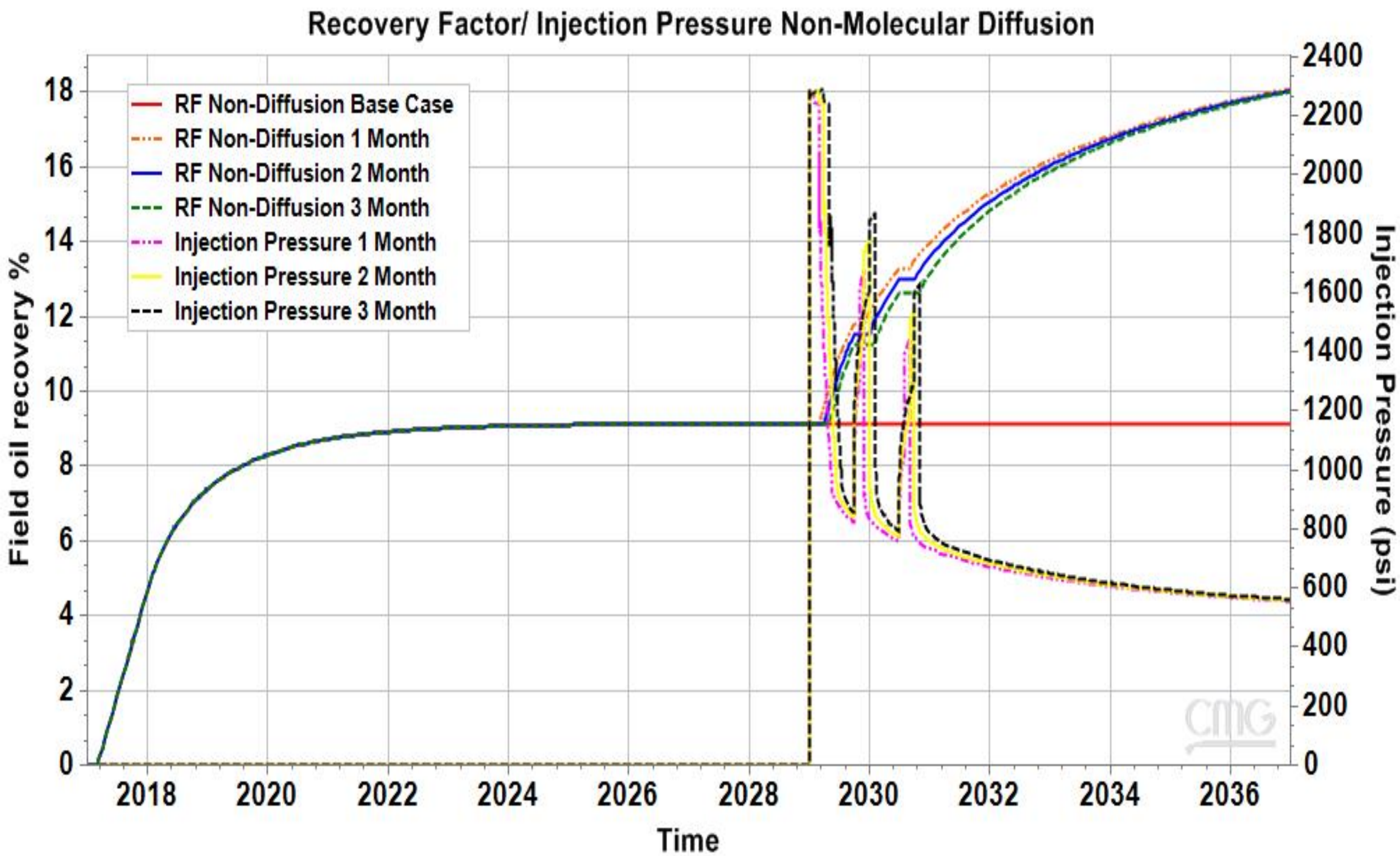
- Existing pilot projects in similar formations
- Mechanisms of enhanced production
- 2 processes that are most feasible
  - Carbon Dioxide Injection (CO_2)
  - Low Salinity Water Injection (LSWI)
- Only tertiary process simulated
- Natural depletion met prior to injection

CO_2 Injection

- Miscible injection
- Huff-n-puff
  - Cycles of 1-3 months
  - Production after 1 month soaking time
  - 500 mcf/day
- Molecular diffusion toggle
- Analyze post shut-in production/EOR production



Recovery Factor/ Injection Pressure Molecular Diffusion
RF Diffusion Base Case
RF Diffusion 1 Month
RF Diffusion 2 Month
RF Diffusion 3 Month
Injection Pressure Base Case
Injection Pressure Diffusion 1 Month
Injection Pressure Diffusion 2 Month
Injection Pressure Diffusion 3 Month
Field oil recovery %
Injection Pressure, psi (psi)
Time
0
2
4
6
8
10
12
14
16
18
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2018
2020
2022
2024
2026
2028
2030
2032
2034
2036
2038
CMG



Recovery Factor/ Injection Pressure Non-Molecular Diffusion
RF Non-Diffusion Base Case
RF Non-Diffusion 1 Month
RF Non-Diffusion 2 Month
RF Non-Diffusion 3 Month
Injection Pressure 1 Month
Injection Pressure 2 Month
Injection Pressure 3 Month
Field oil recovery %
Injection Pressure (psi)
Time
0
2
4
6
8
10
12
14
16
18
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2018
2020
2022
2024
2026
2028
2030
2032
2034
2036
CMG

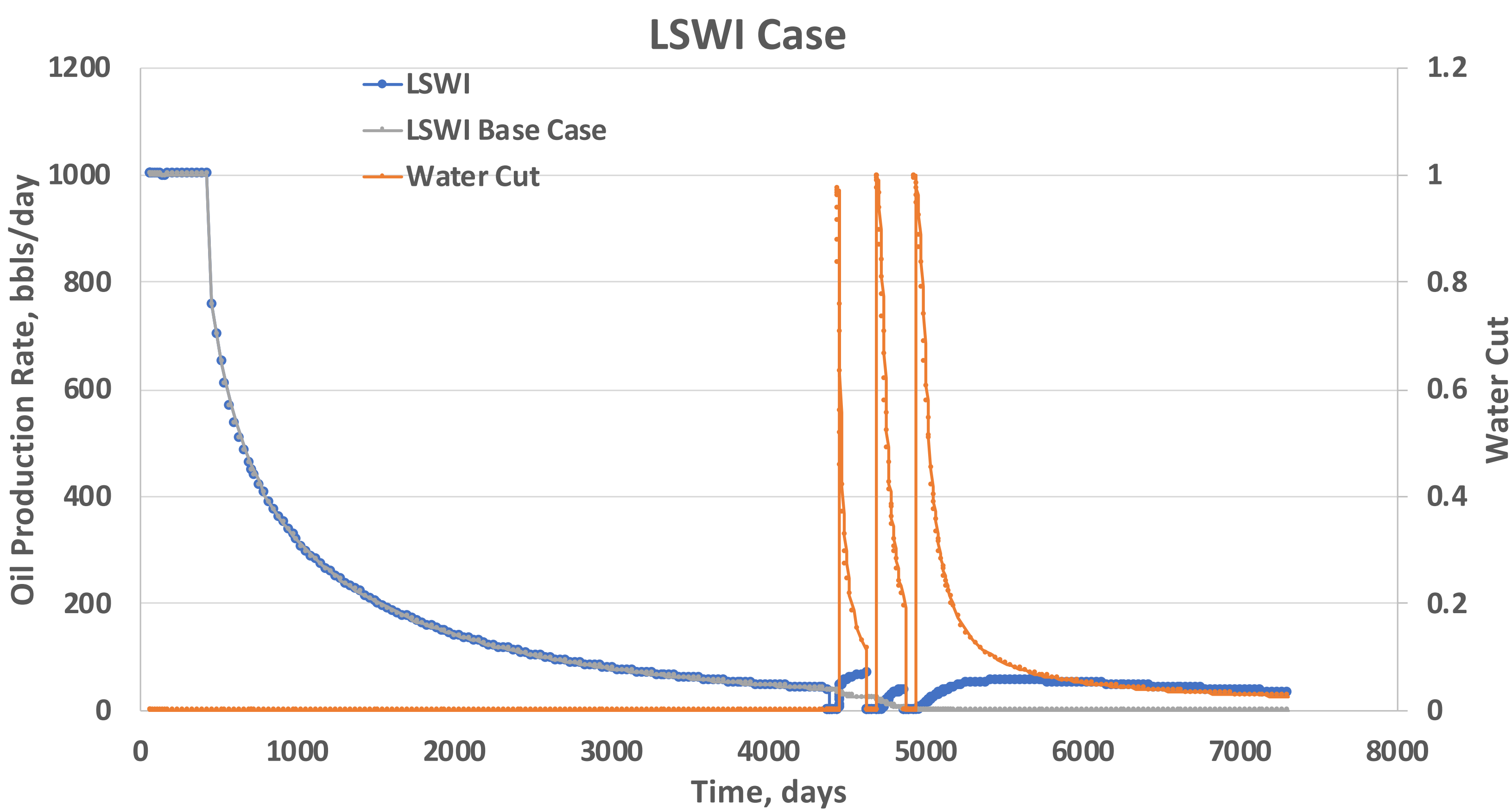
Low Salinity Water Injection

- Tertiary, not secondary, process
  - Local increase in pH?
- Natural depletion
- Tested samples of formation water
- Single well process
  - History Matched Well 1
- Analyzing oil rate and water cut

Water Properties for LSWI

- Tested during flowback and normal production
- LSW from tested operations in Midland Basin
- No pilot data for Delaware Basin

Formation Water Dissolved Solids			LSW Dissolved Solids	
	mg/L			mg/L
Sodium (Na)	35844		Sodium (Na)	660
Calcium (Ca)	5237		Calcium (Ca)	26
Magnesium (Mg)	874		Magnesium (Mg)	77
Potassium (K)	785		Potassium (K)	785
Chloride (Cl)	72700		Chloride (Cl)	1170
Sulfate (SO4)	525		Sulfate (SO4)	525
Bicarbonate (HCO3)	266		Bicarbonate (HCO3)	1E-06
Water pH	6.56			



LSWI Case
LSWI
LSWI Base Case
Water Cut
Oil Production Rate, bbls/day
Water Cut
Time, days
1200
1000
800
600
400
200
0
1.2
1
0.8
0.6
0.4
0.2
0
0
1000
2000
3000
4000
5000
6000
7000
8000

Conclusions

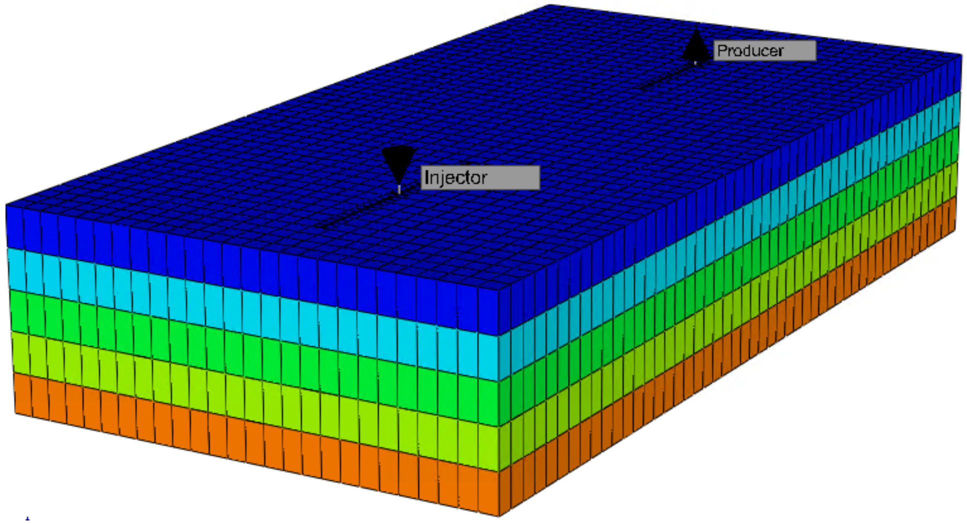
- Initial reservoir character did not represent field data
  - Historical production
  - Bottom-hole pressure
- Uncertain parameters identified and matched
  - Completions
  - Fluid properties
- Optimal spacing could be smaller
- EOR has the potential for positive impact

Further Research

- First step of multiple research projects
  - General overview of area
  - In depth reservoir characterization
  - Detailed completion model
  - Multiple zone research
- More lab tests and pilot projects to confirm
  - Field-post fracture analysis
  - EOR testing
  - In-Situ Combustion

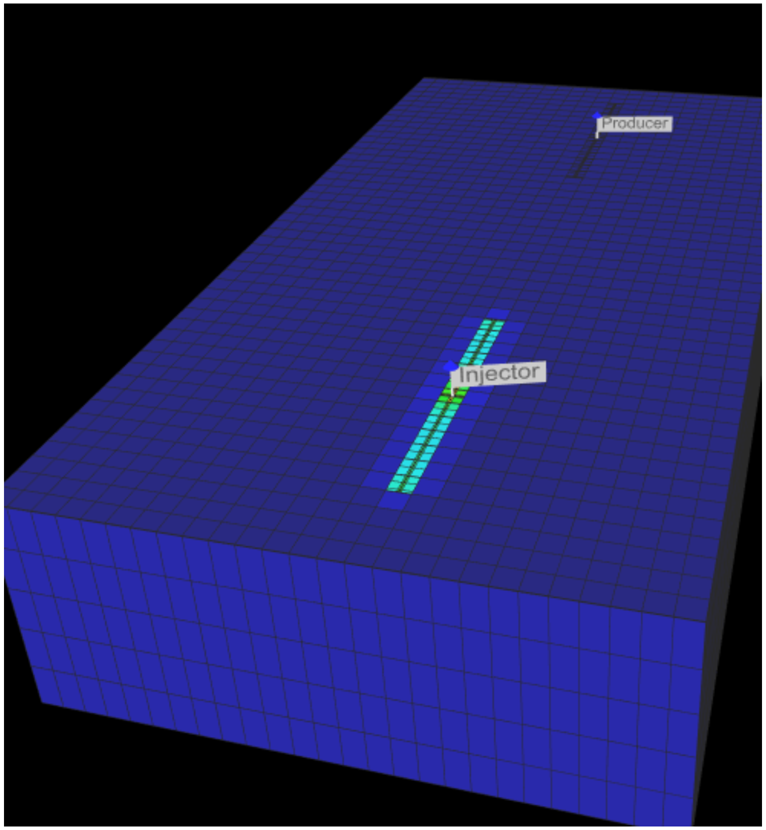
Preliminary In-Situ Combustion

- Air injection for reaction at in-situ conditions.
- 2 wells, 1 hydraulic fracture per well.
- Fluid composition, petrophyics and rock type based on SBSG sand.
- Huff-n-puff process to optimize injection cycles.



In-Situ Process in Unconventional Sand

- Inject air at a rate of 40-400 mcf/day.
- Huff-n-puff schedule:
  - 1 month inj, 1 month shut-in
  - 2 month inj, 1 month shut-in
  - 3 month inj, 1 month shut-in
  - Corresponding injection periods to what pressure and temperature is available.
- A large, noticeable increase in temperature and energy around injection well.



Thank You
Questions?