# Success and Failure Factors for Cyclic Gas Injection in Unconventional Reservoirs

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# Outline

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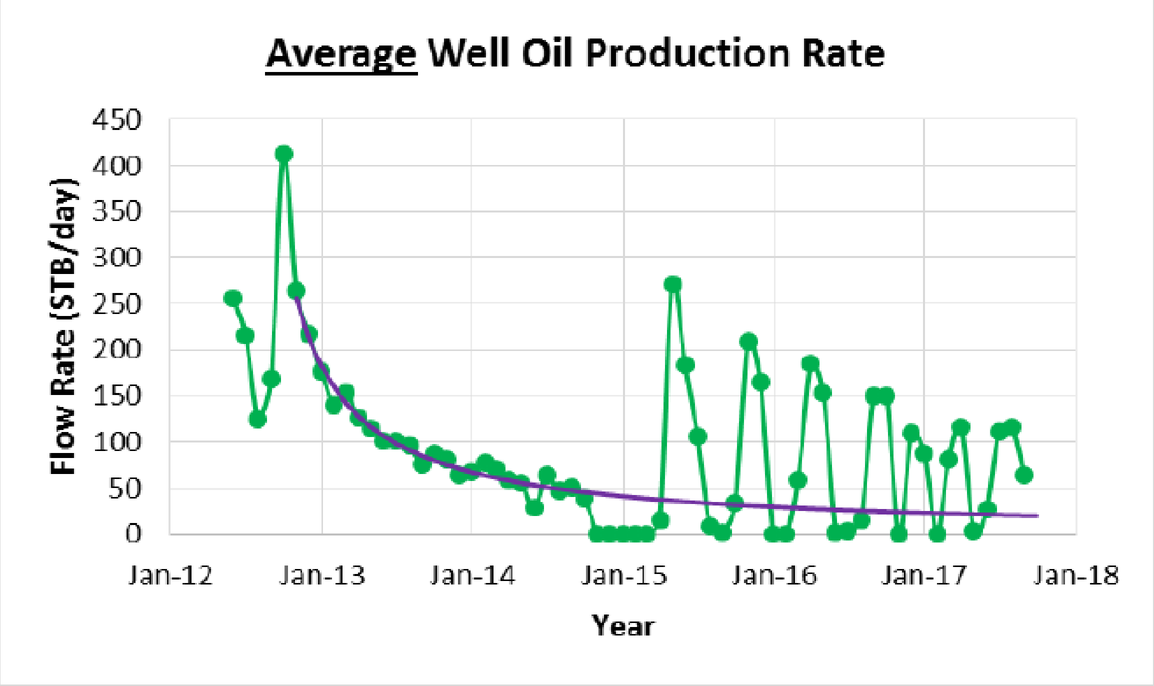
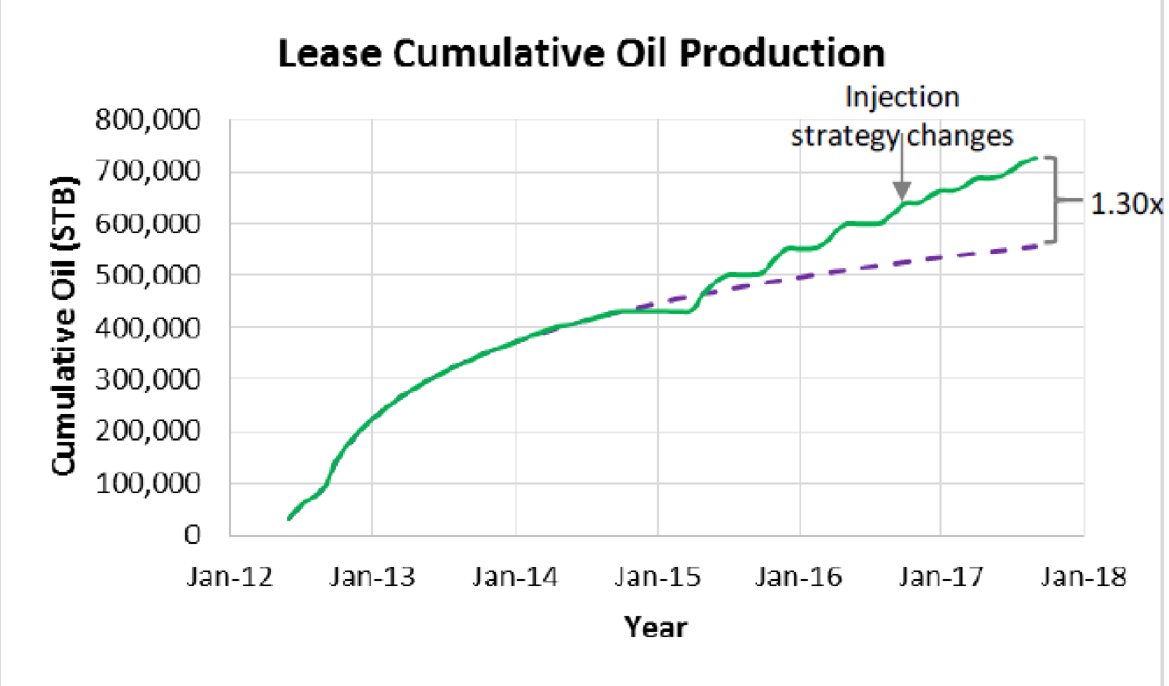
- Introduction
- Why is Unconventional Gas Injection different?
- Success Factors - Challenges
    - Containment
    - Contact
- Design using modeling
    - Design Parameters
    - Feasibility Sensitivities

# Introduction

It all started with successful pilots by EOG Resources in Eagle Ford and their announcement to the share holders

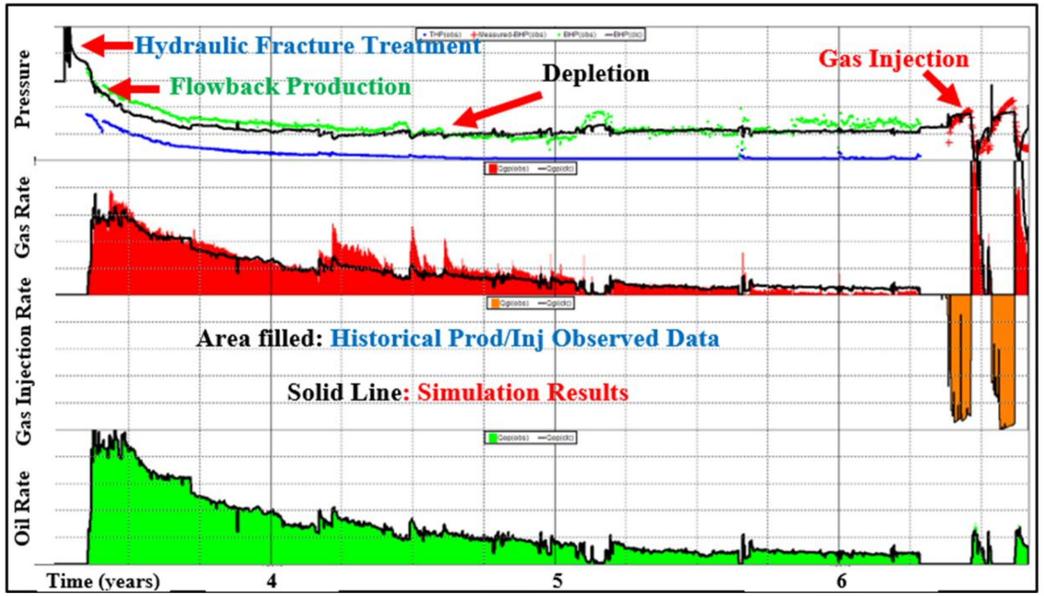


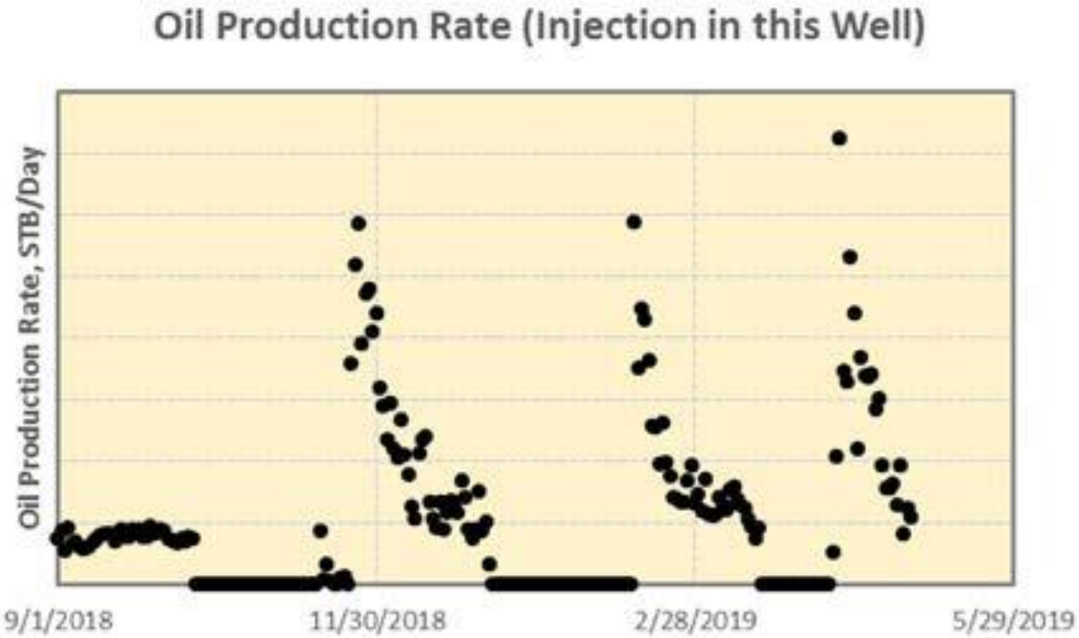

Performance improvement observed from an EOG Pilot based on Public data (SPE189816)

# Introduction

Similar Results followed:




Improved oil production observed by Murphy after cyclic gas injection in Eagle Ford (SPE 200430)




Improved oil production observed by EP Energy after cyclic gas injection in Eagle Ford (SPE 195996)

# Why is Unconventional Gas Injection Different?

## Matrix- Oil Storage

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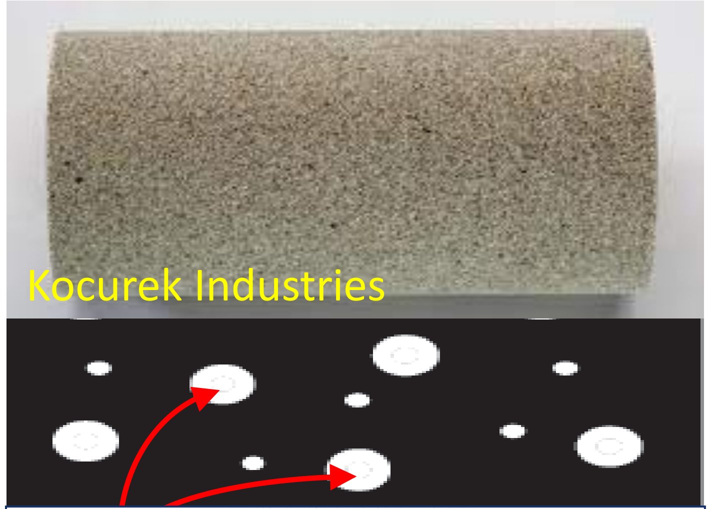
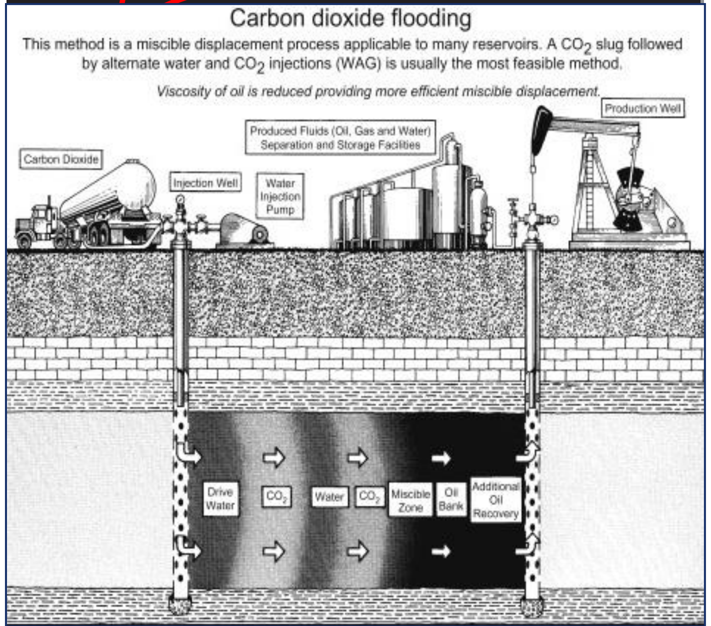
### Conventional Oil and Gas




$$d_{pore} \geq 1 \mu m$$

$$k \geq 1 mD$$

Micro-pores
(Darcy Flow)

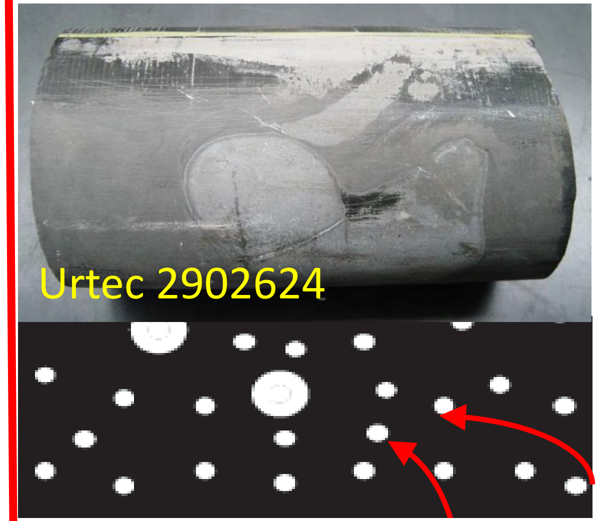



Displacement possible

Gas Flooding

(Joe Lindley, DOE)

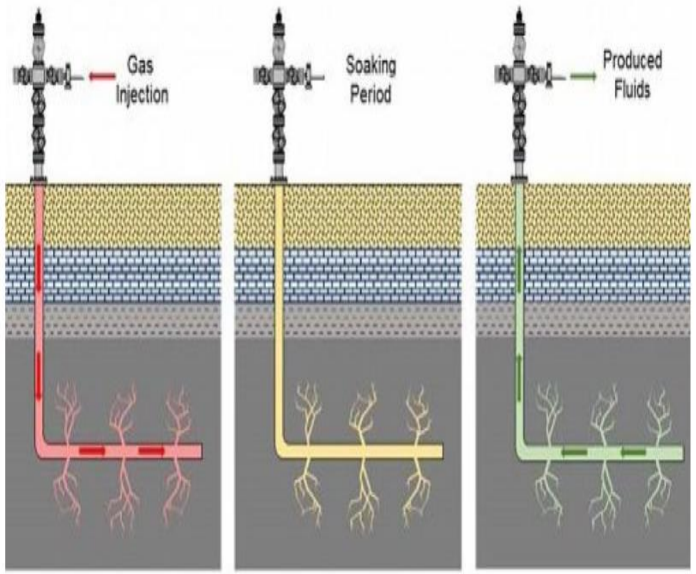
### Shale Oil and Gas




$$10^{-1} \mu m \geq d_{pore} \geq 10^{-2} \mu m$$

$$1 \mu D \geq k \geq 10^{-3} \mu D$$

Nano-pores




No displacement

Hydraulic fracturing

Flooding not feasible

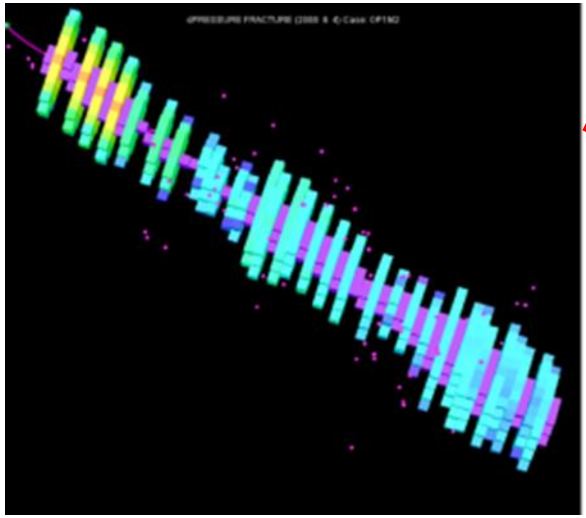
**Cyclic Injection**

(Ertahan et al. 2020)

# Why is Unconventional Gas Injection Different?

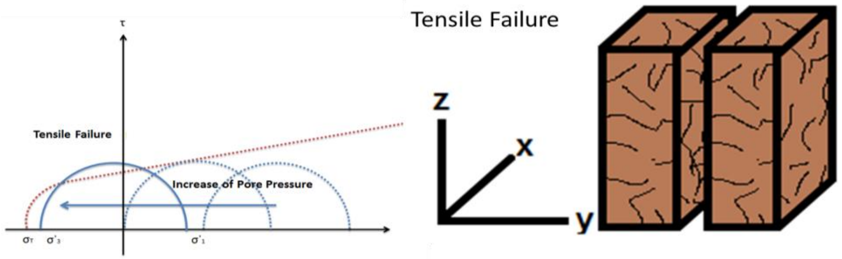
## Man made Conductivity - Complexity – Matrix Access – How it works

### Tensile Dominated



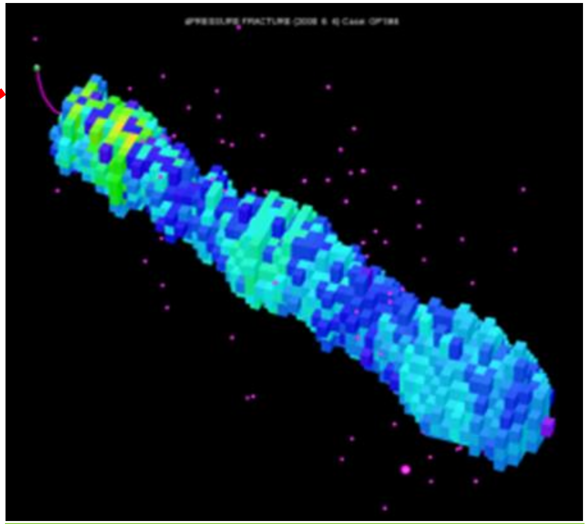
### Bi-wing fractures

Dilation based – opens in max stress direction
Provides initial conductivity
Provides minimal surface area with matrix
Tends to close during depletion



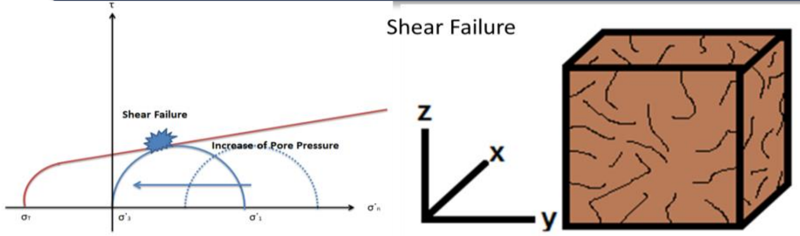

Reality is a combination which determines performance.

### Shear Dominated



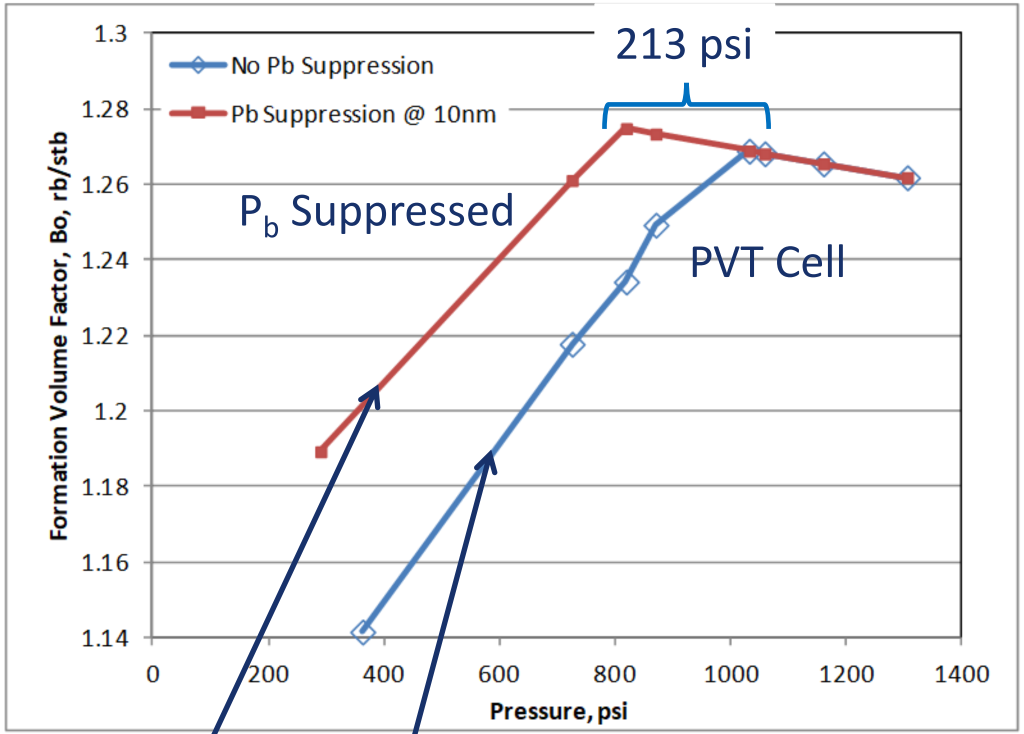
### Complex fractures

Displacement based – opens in directions other than stress (usually 45 degrees)
Provides minimal conductivity
Provides maximum surface area with matrix
Tends to stay open during depletion

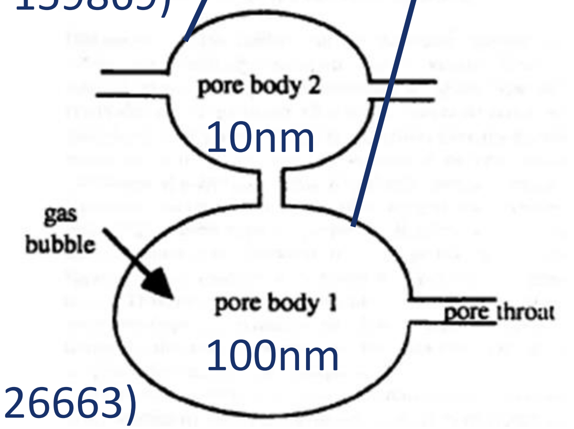


# Why is Unconventional Gas Injection Different?

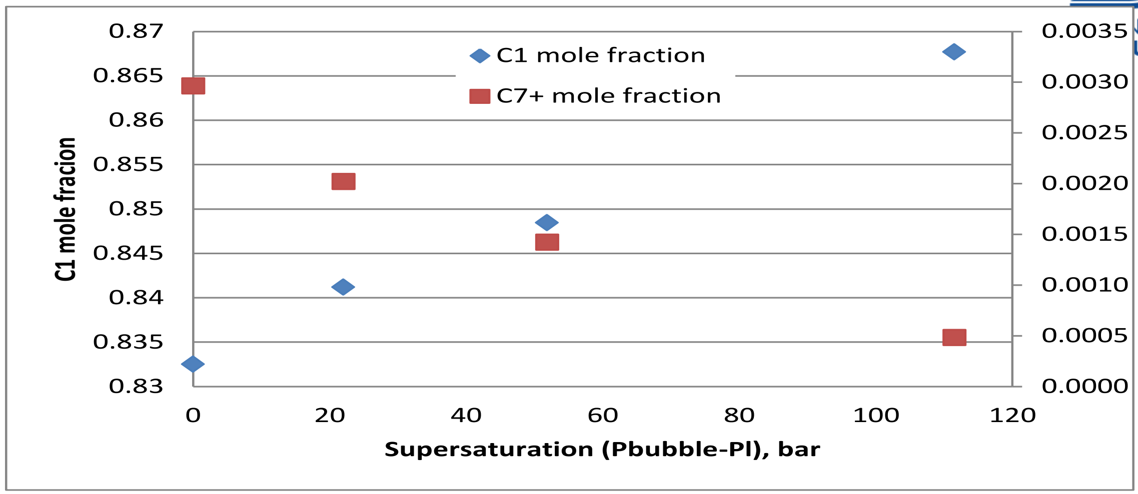
## Other Complications due to Confinement



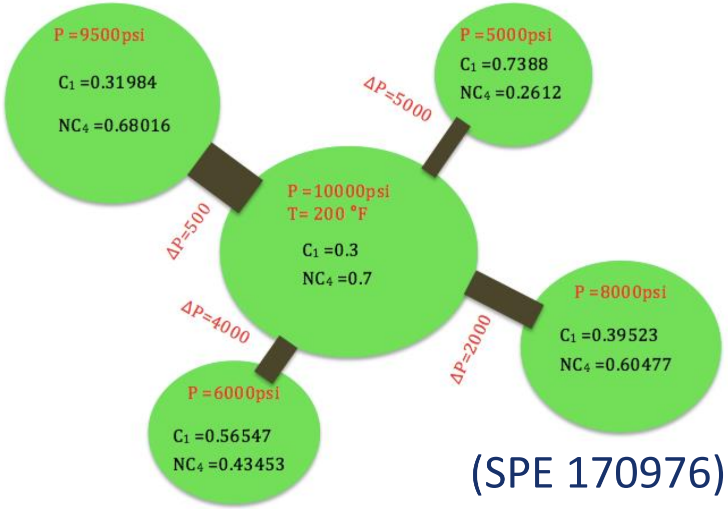

(SPE 159869)




(SPE 26663)




The gaseous phase contains lighter components as the bubble-point suppression increases.




(SPE 170976)

Due to filtration the composition of the fluid may differ in different pores

# Success Factors of Unconventionals

## What is good for primary is good for Cyclic Gas Injection

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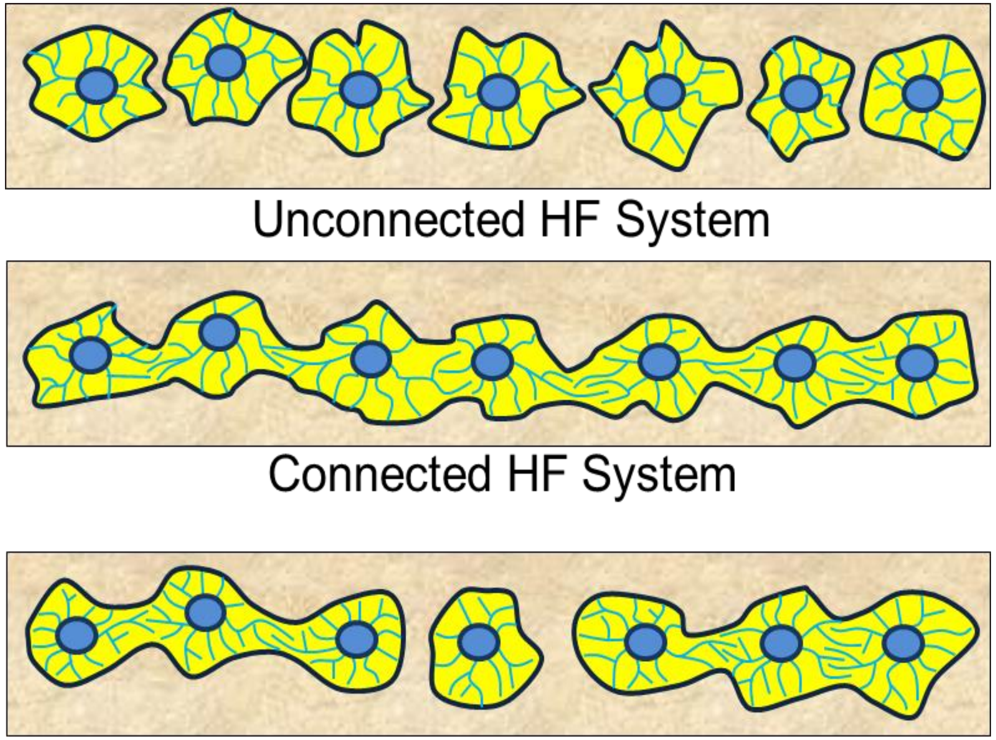
- Initial Pressure – High
- Frac pressure- High
- Fluid type (Volatile vs. Black oil) – Volatile higher performance
- Facies/Minerology – Young Modulus/Poisson’s ratio/Matrix porosity and perm
- Good matrix access after hyd. Frac. – Complex fractures

# Success Factors of Cyclic Gas Injection in Unconventionals

<u>**Success Factors**</u>

- **Containment of gas**
- **Contact of gas with oil**

Multiple well gun barrel view

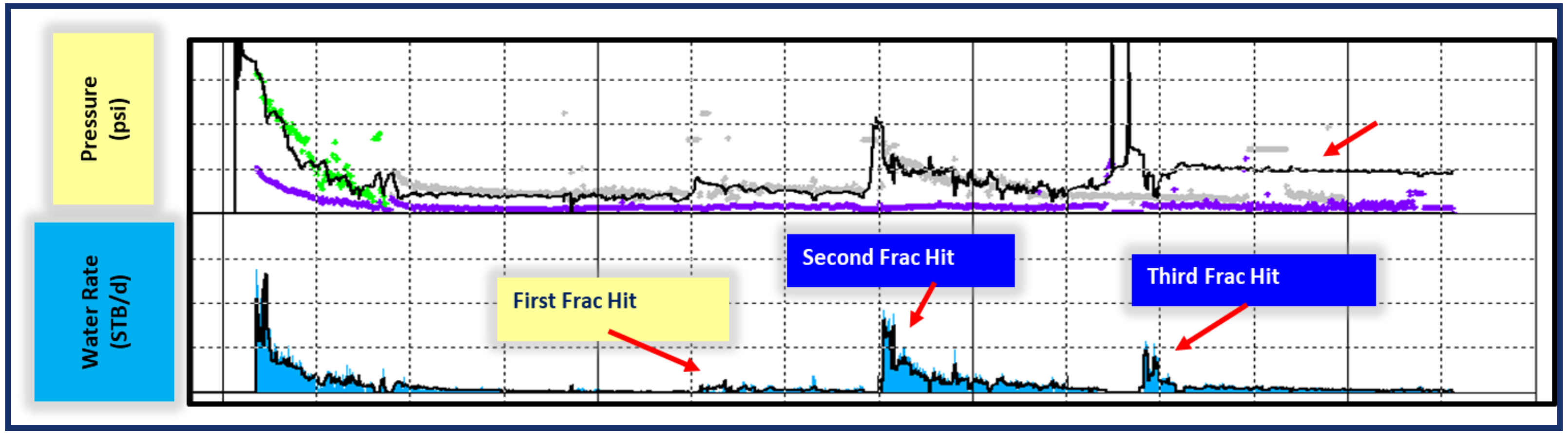



Partially connected HF System

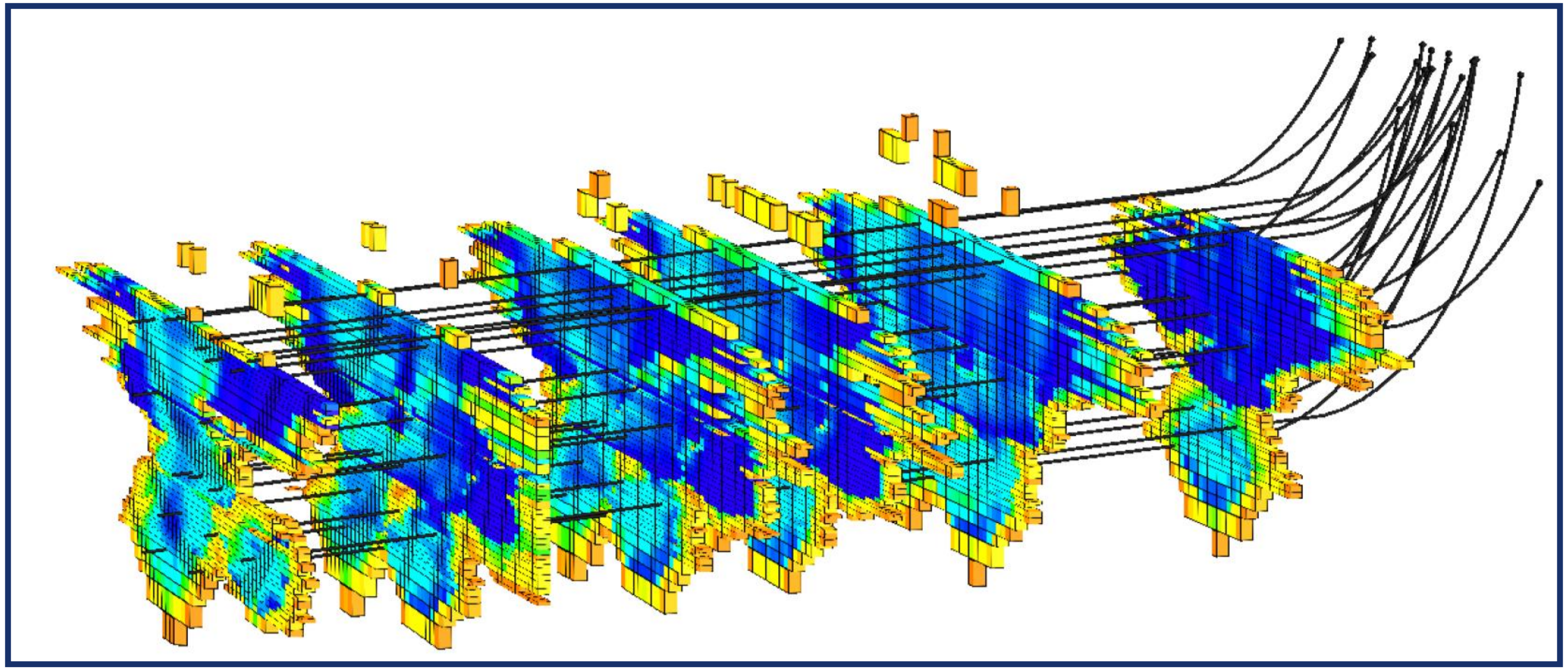
Additionally, to consider:

- Faults – Stay away
- Pressure before injection – higher better
- GOR level and trend before injection – before GOR increases

# Success Factors - Containment – Complicated Connectivity




Verifying existence of communication during hydraulic fracturing is relatively easy



Predicting the exact communication paths in a multi-well multi-formation development is difficult

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# Success Factors - Containment – Dynamic Connectivity

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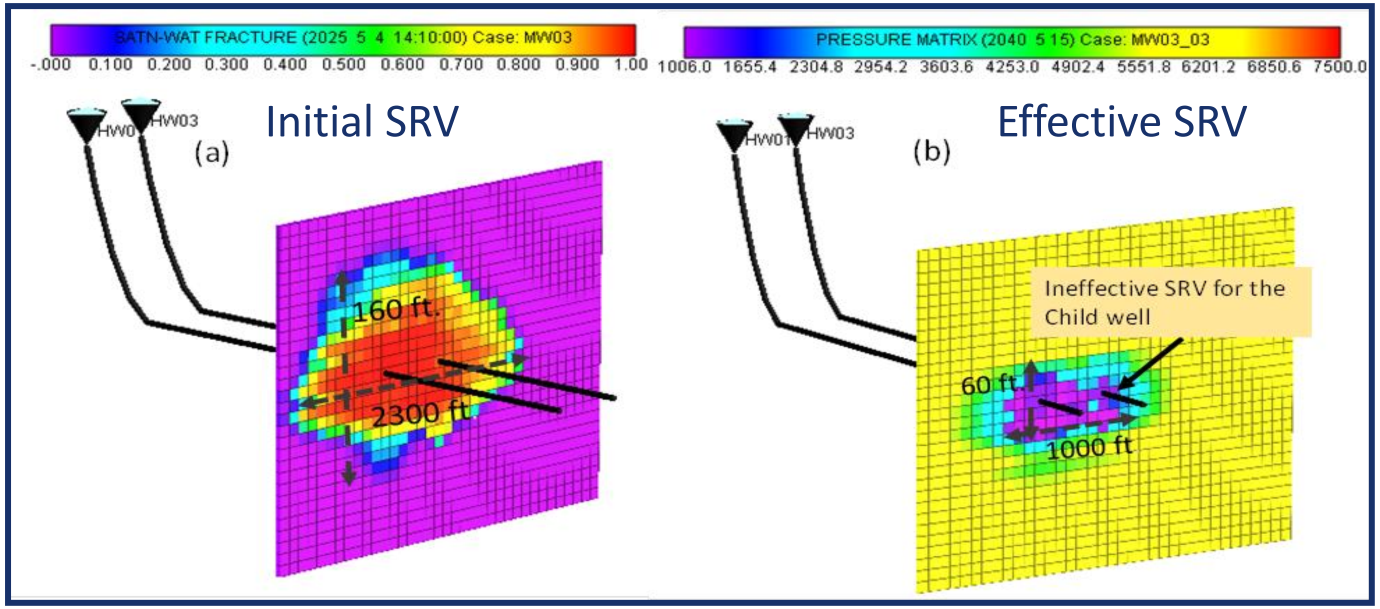
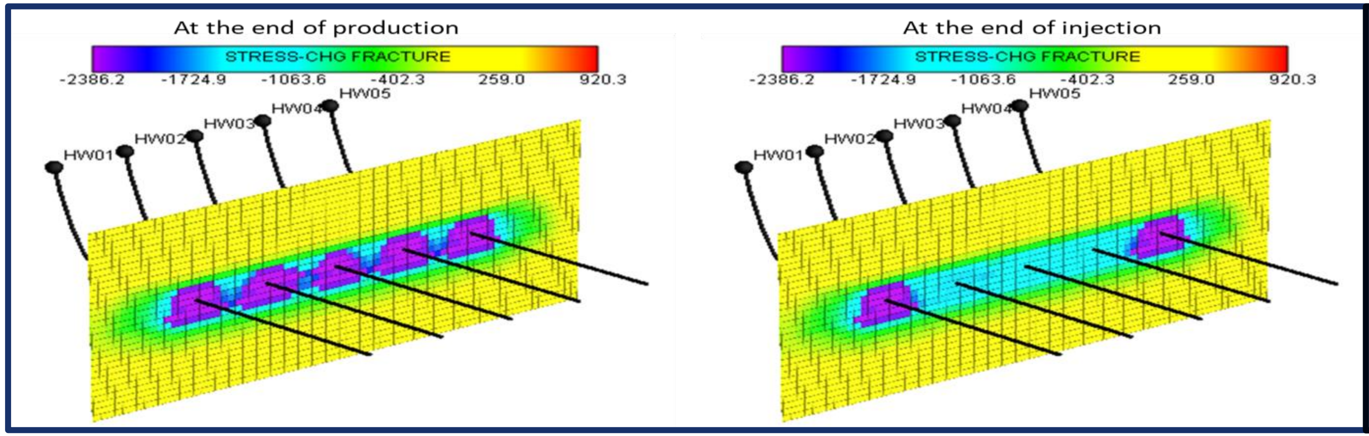
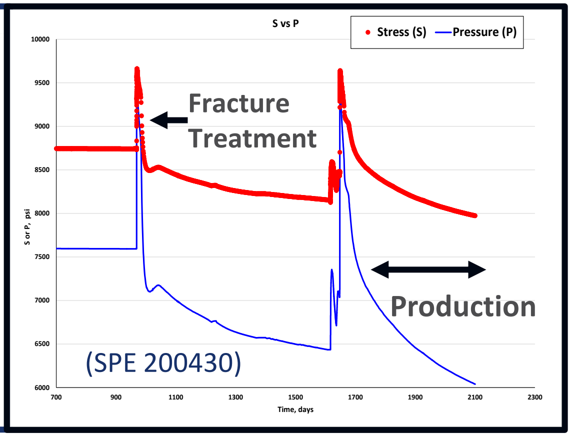



- Communication paths close during depletion as the stresses and pore pressure changes.
- Closure is different for propped and stimulated but not propped areas
- The SRV size and geometry also differs for different vintage wells

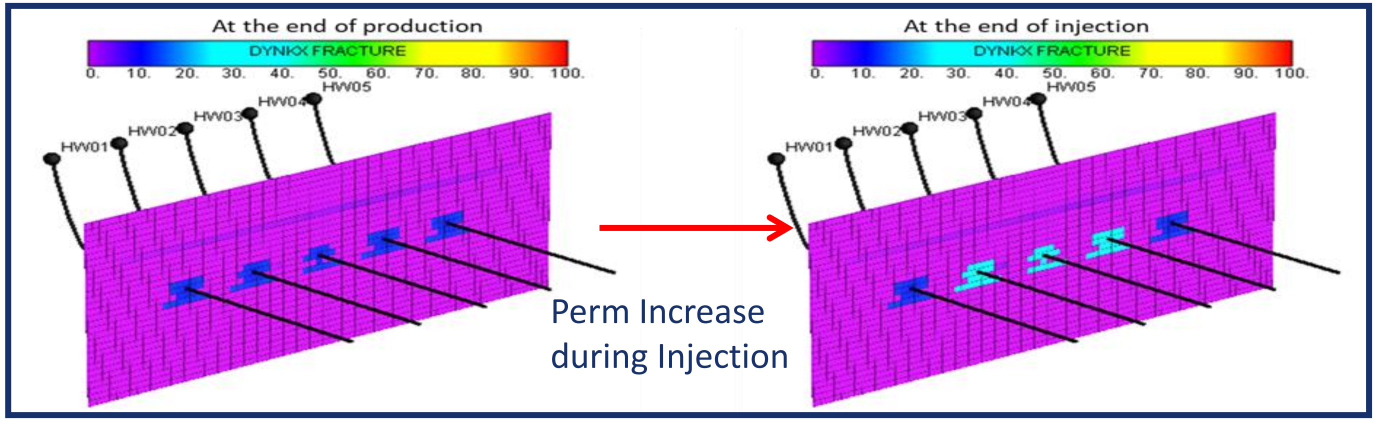
(Urtec 3221)

# Success Factors - Containment – Dynamic Connectivity



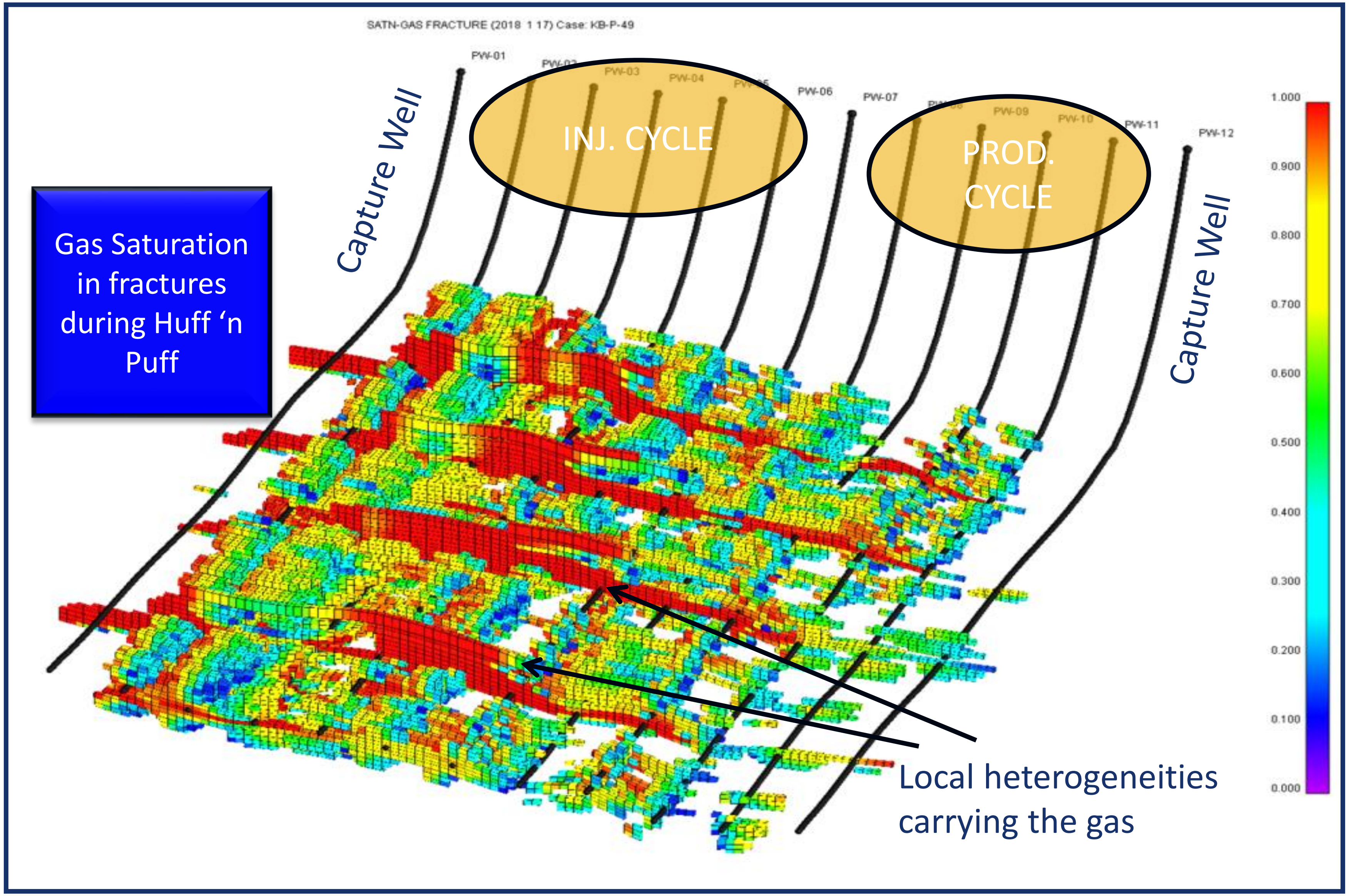

Stress changes during injection as a function of pore pressure




It is possible that some/all of the closed paths to open during gas injection

(Urtec 3221)

# Success Factors - Containment – How to manage?




- Understand connectivity distribution
- Use Multiple wells to inject and produce, Utilize all wells in the DSU
- Pattern is determined by the connectivity distribution
- Use capture wells to contain and account for the gas in the system

# Success Factors - Contact

## Oil Recovery Mechanisms

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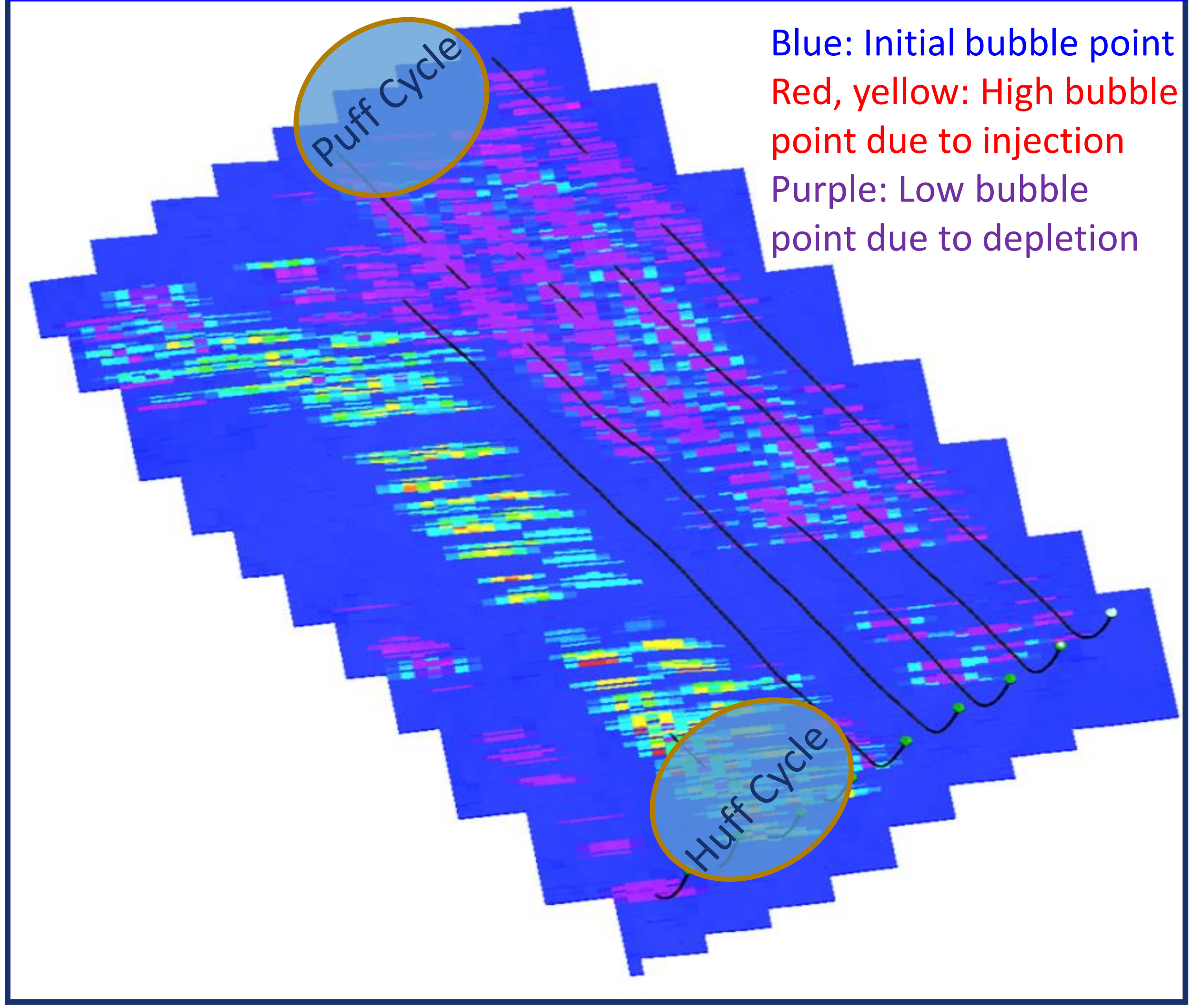
**Bubble point pressure in the matrix during cycling**




### Changing Oil Properties

- Oil will swell as more injected gas contacts and dissolves in oil increasing the saturation pressure, solution GOR and formation volume factor
- Lighter components of the oil vaporizes in the gas

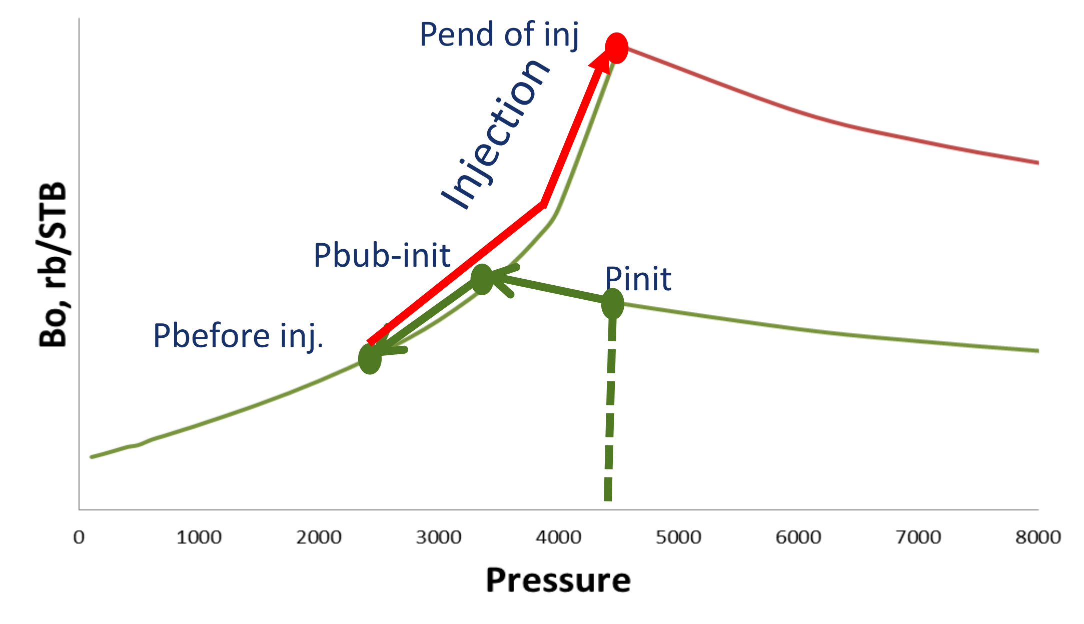
Diffusion and capillary pressure are other forces to be considered

**The more oil is contacted by gas, the more oil will be unlocked and extracted**

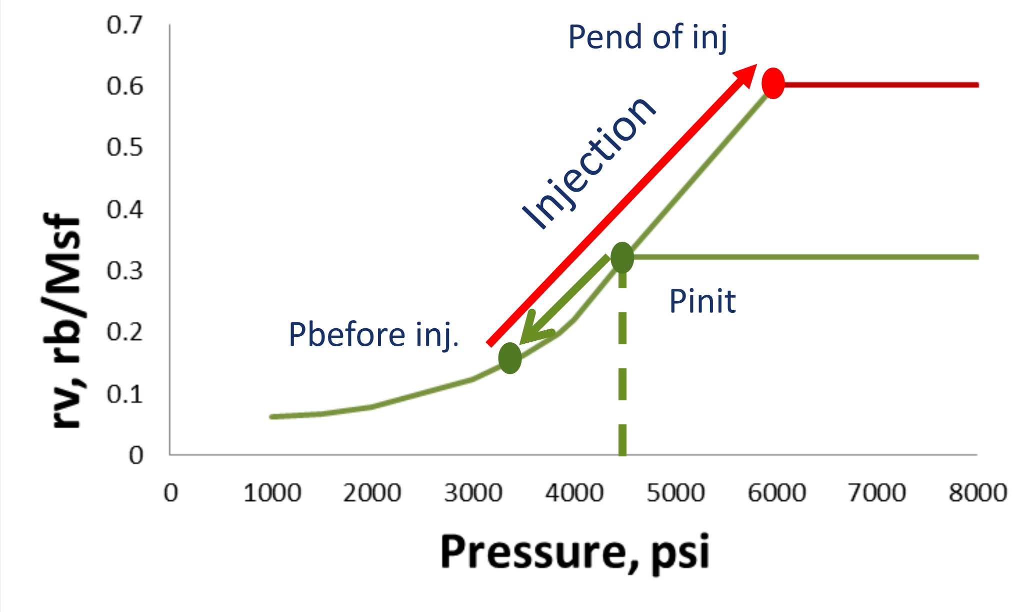
# Success Factors - Contact

## Oil Recovery Mechanisms

**Changing Oil Properties**
**Oil becomes less gaseous after depletion. Injection replenishes the oil. The fluid system becomes lighter**




**Changing Gas Properties**
**Lighter components of the oil vaporizes in the gas enriching the gas and produced as liquid in the surface**




**The more oil is contacted by gas, the more oil will be unlocked and extracted**

# Success Factors - Contact – How to manage?

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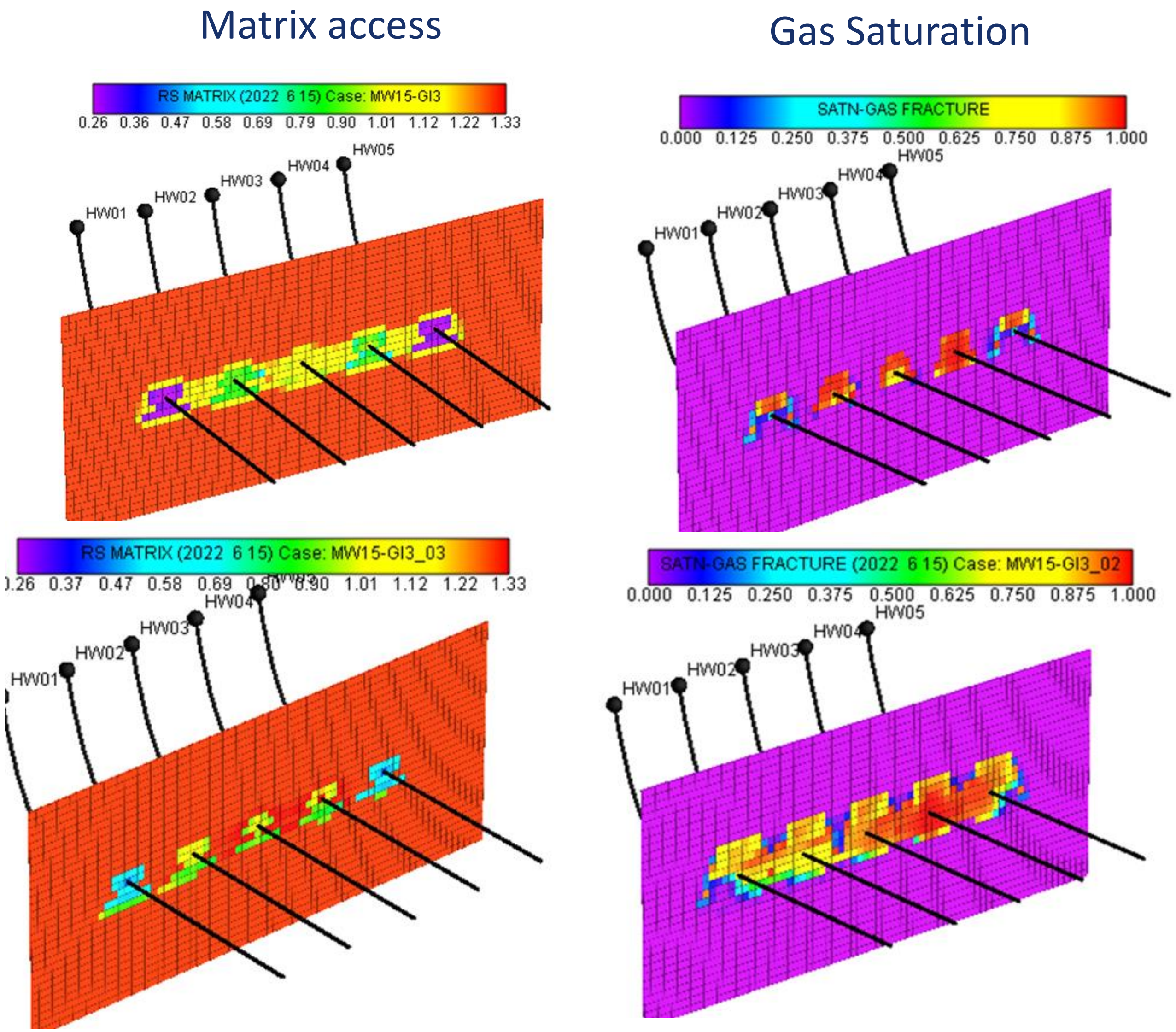
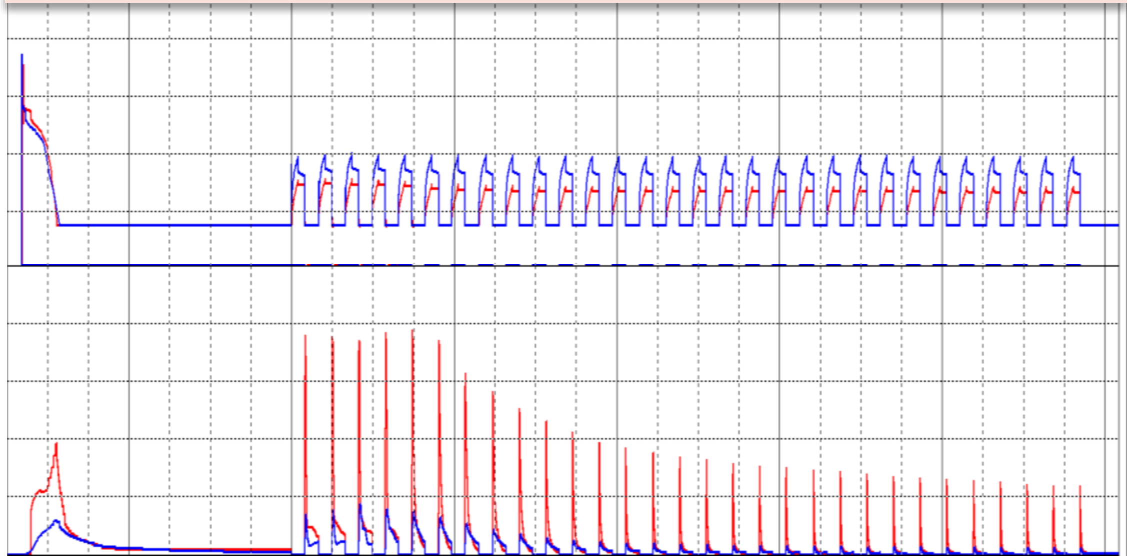



**Old Style completion-Gel, large cluster spacing**

**New Style completion-slick water low cluster spacing**

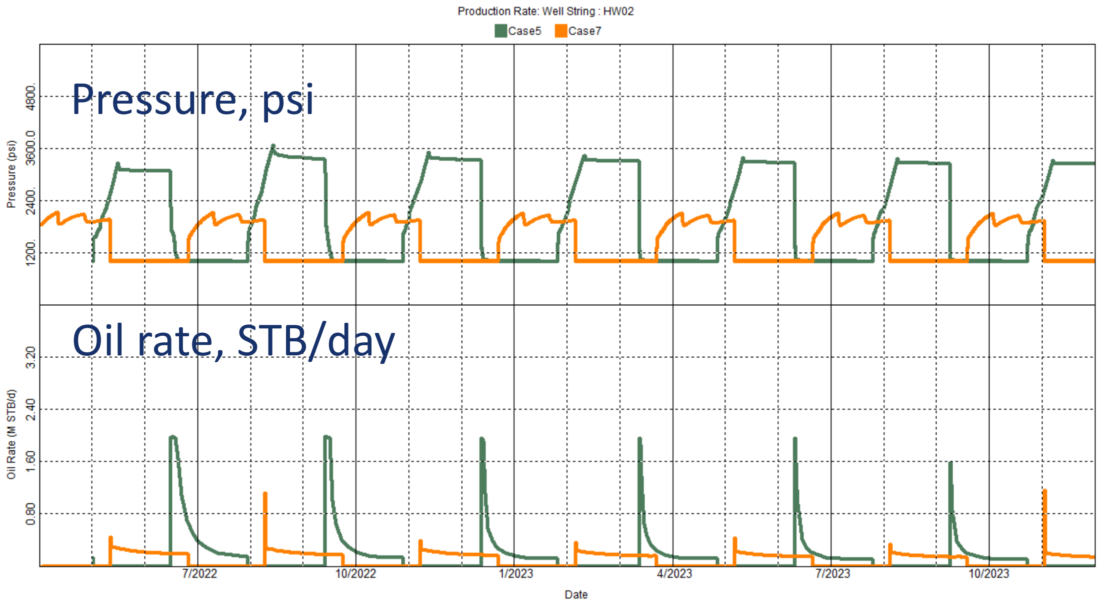


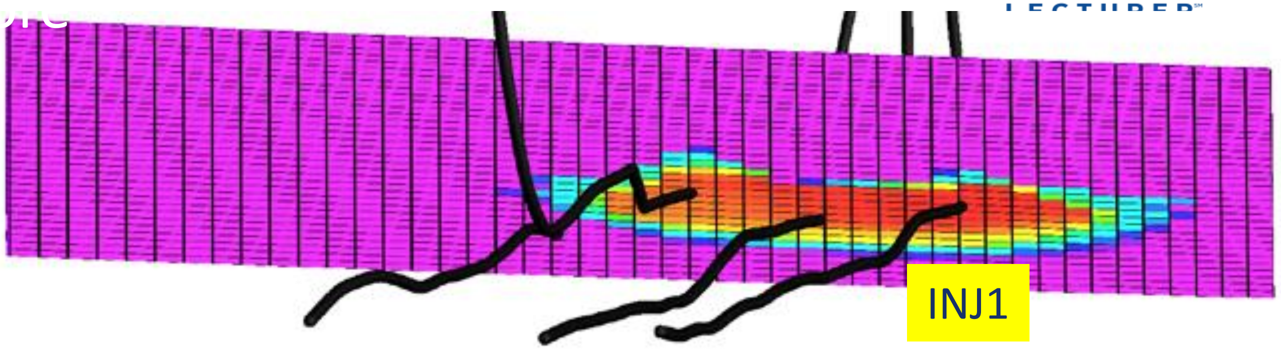
**Significant Production Increase with more complexity**

(Urtec 3221)

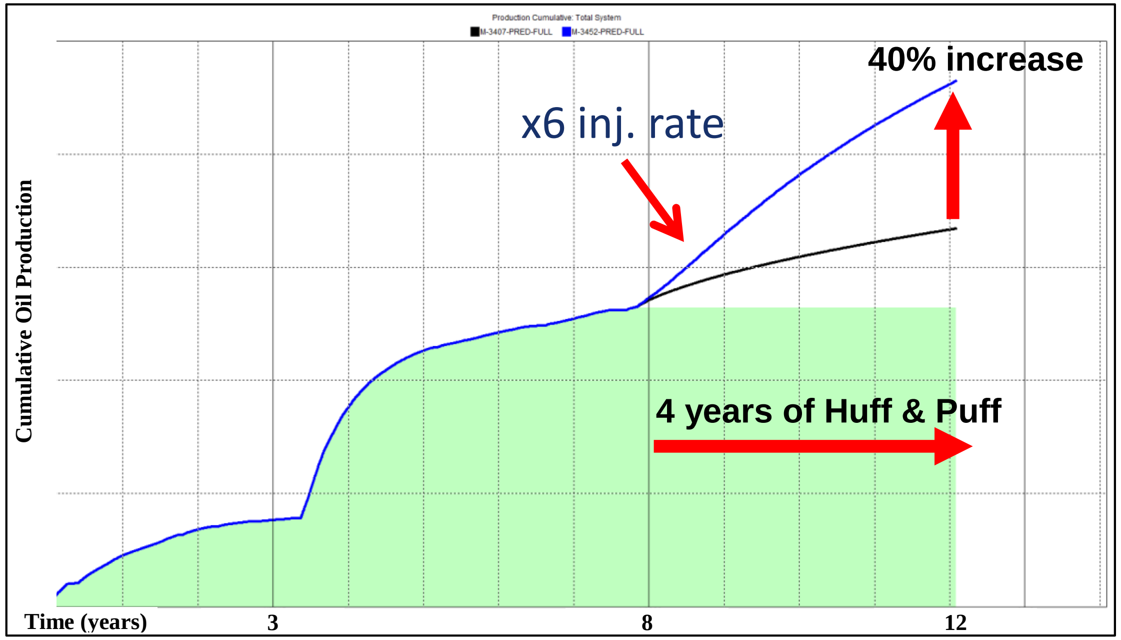
# Success Factors - Contact – How to manage?

High pressure, high rate injection, containment of the gas around the well




Gas saturation increases but stays within the pattern




(SPE 200430)

# Modeling Solutions to create a successful design

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**What we cannot control**

Geology
Well completions
Well location/orientation
Uneven depletion

→ We have to understand their impact

**What we can control**

- Injection fluid composition
- Fill up time and volume
- Number of wells to utilize
- Injection rates
- Injection and soak times
- Injection order
- Production time
- Production order
- Maximum injection pressure
- Minimum production pressure
- Well Scheduling
- Recompletion
- WAG, Foam

→ To successfully design and optimize these

# Using Modeling Solutions

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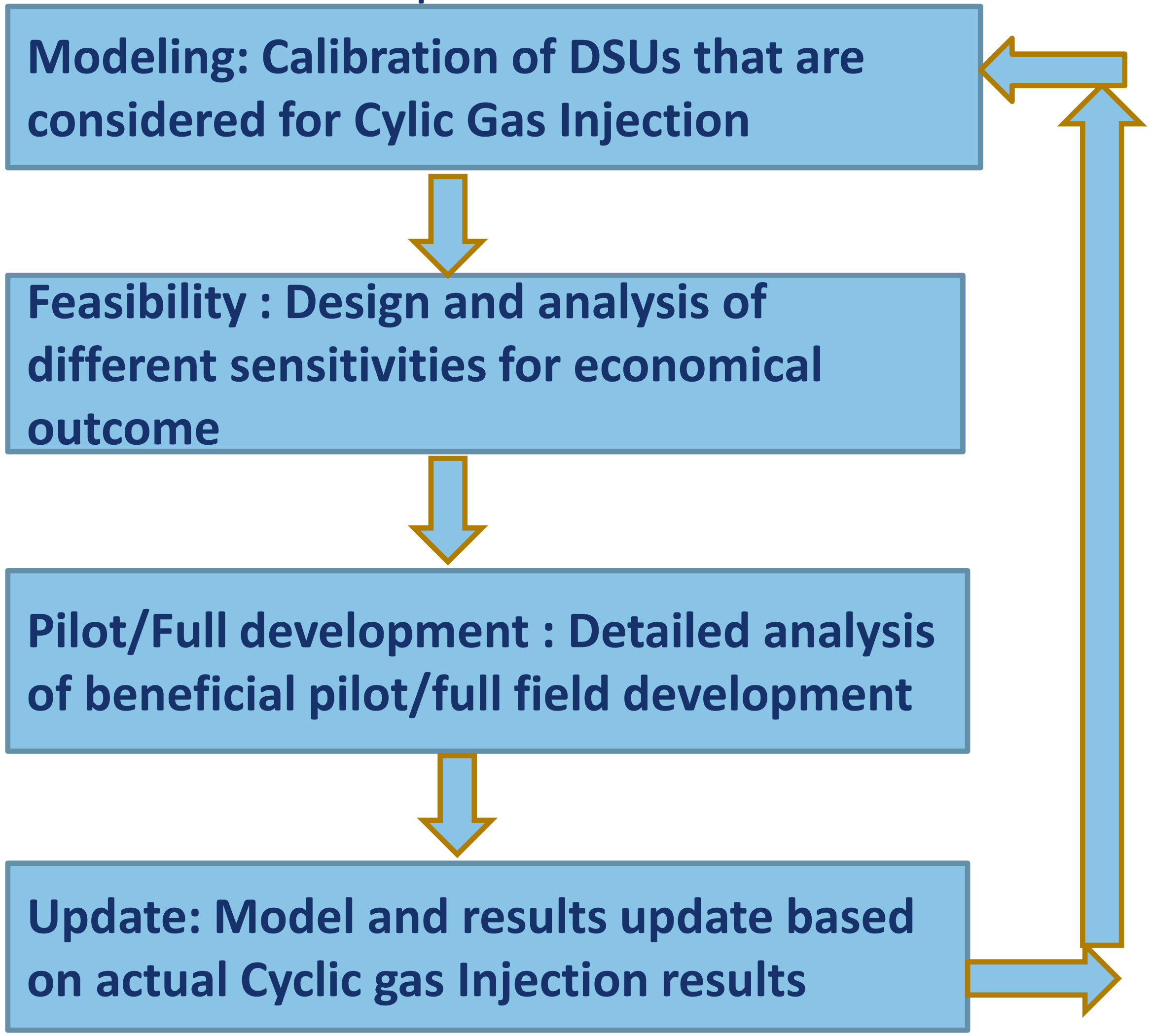
## Study Stages Prior to Pilot and Full Field Development



# Modeling: Calibration of DSUs that are considered for Cyclic Gas Injection

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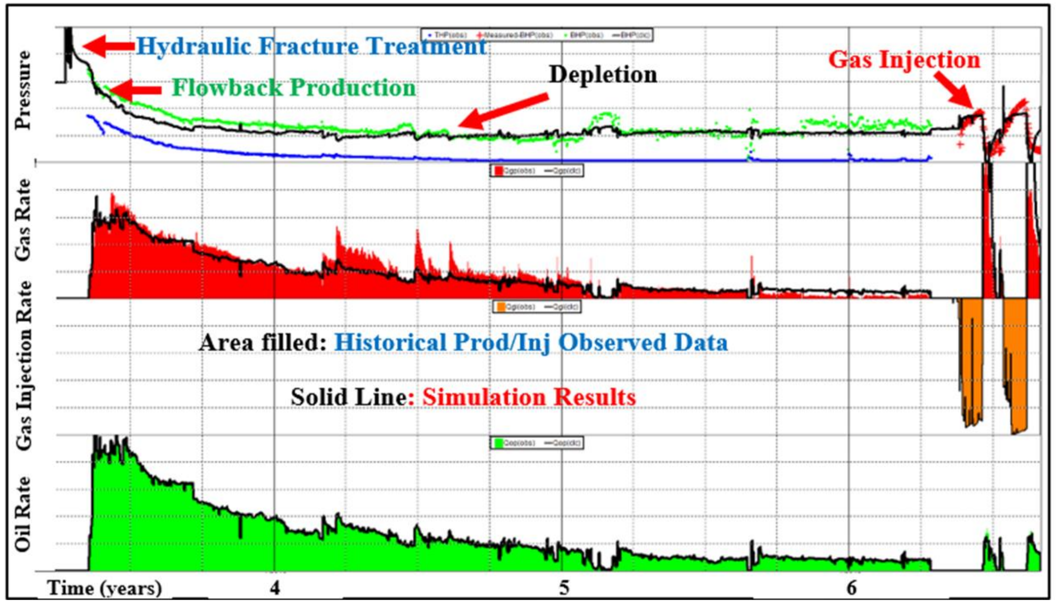
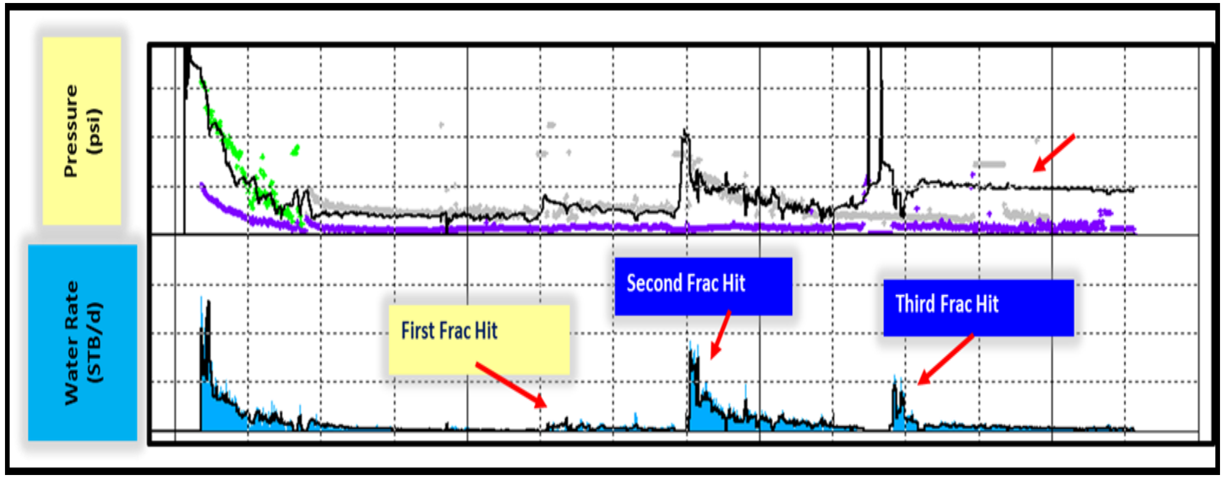
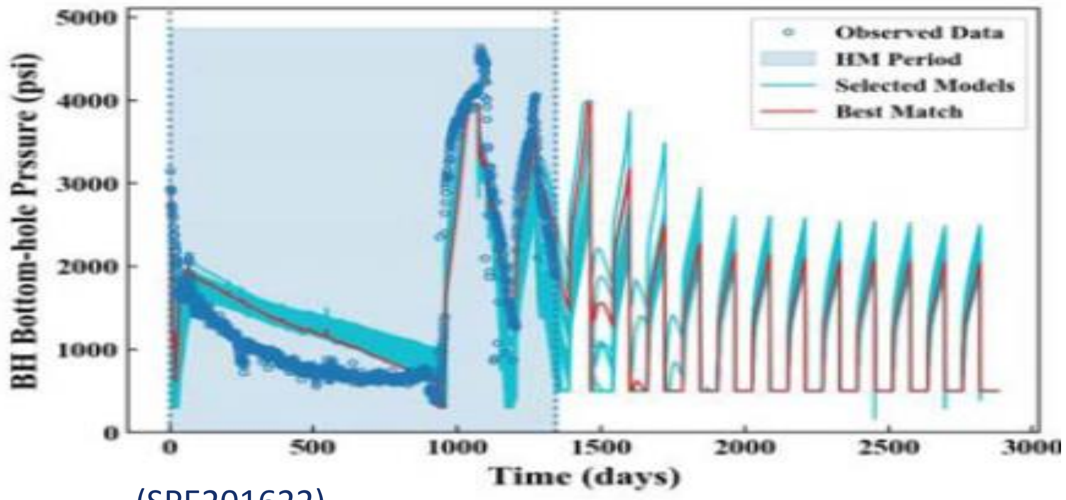



(SPE 200430)




(SPE201622)

Calibration is in the center of modeling.

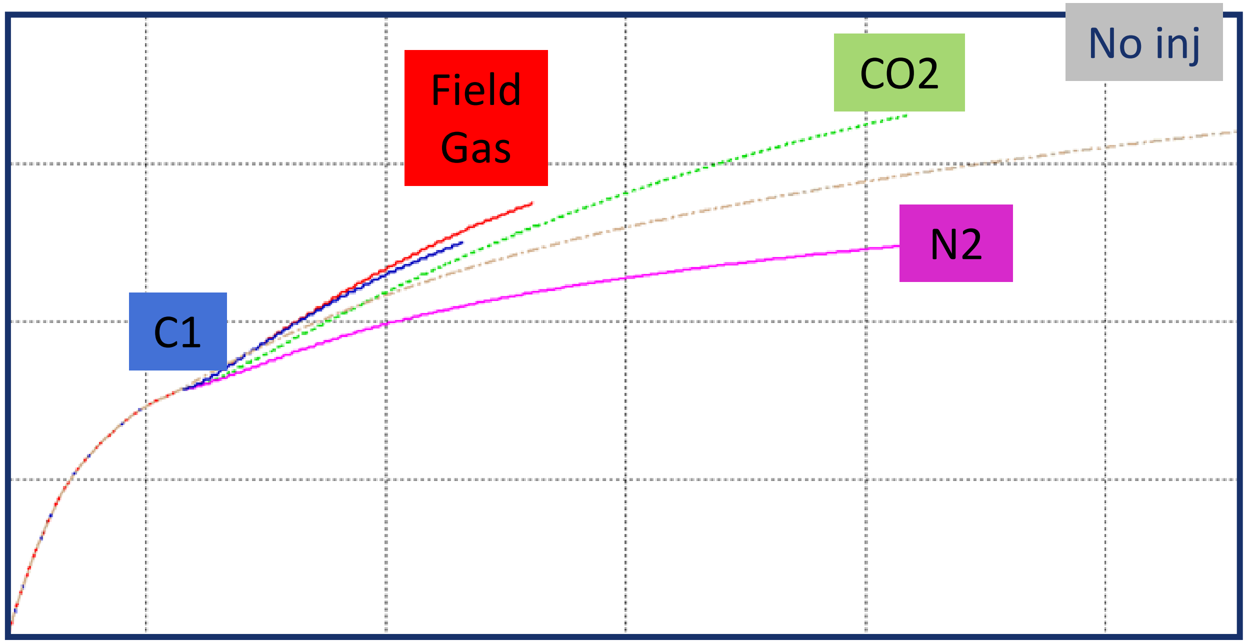
Calibration should include all the wells within the DSU and capture fracture interactions to understand the connectivity

**Single well models will be misleading and most likely optimistic due to lack of well communication**

# Feasibility : Design and analysis of different sensitivities for economical outcome

## Injectant Selection

- Usually picked based on availability
- Most commonly produced gas
- Performance of each gas depends on the oil composition
- In general CO2 is a better solvent
  - Not available everywhere and expensive
  - Carbon credit or zero emission pledges may make it feasible



# Feasibility : Design and analysis of different sensitivities for economical outcome

## Diminishing Returns on Injection Rate

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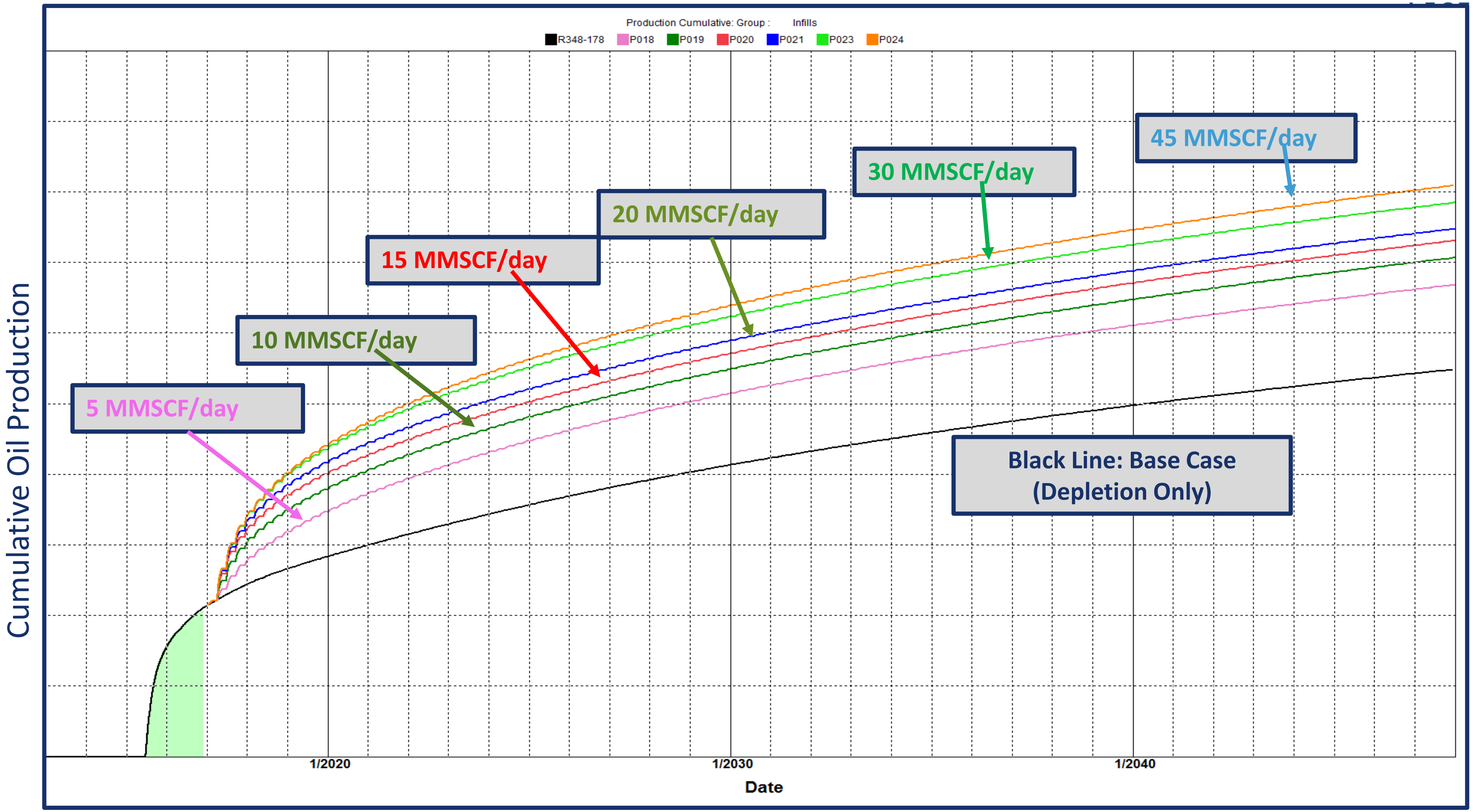
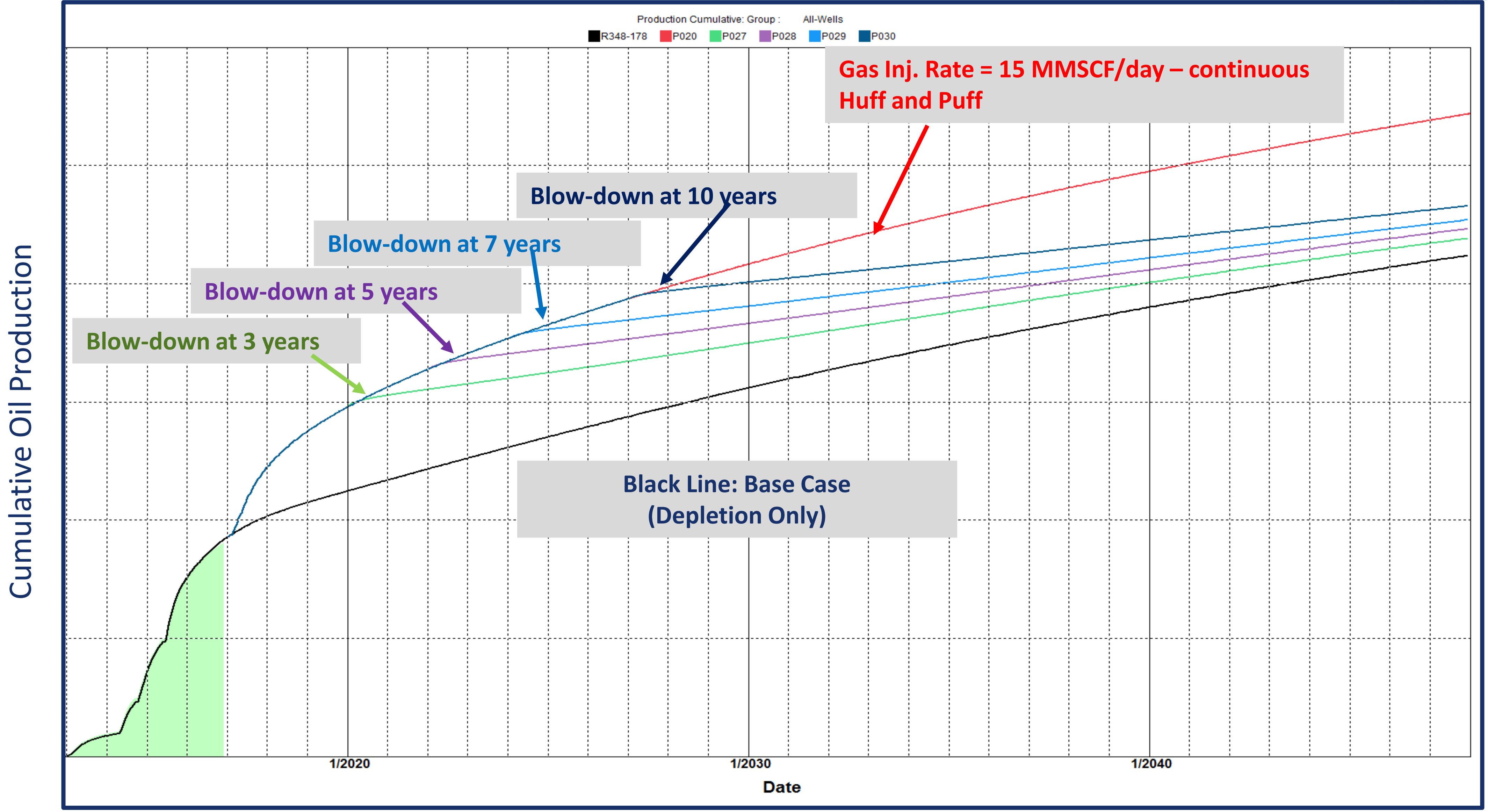


# Feasibility : Design and analysis of different sensitivities for economical outcome

## Blow-down Date Impacts Recovery

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# Feasibility : Design and analysis of different sensitivities for economical outcome

## Impact of Injection Time – Earlier Injection may be beneficial

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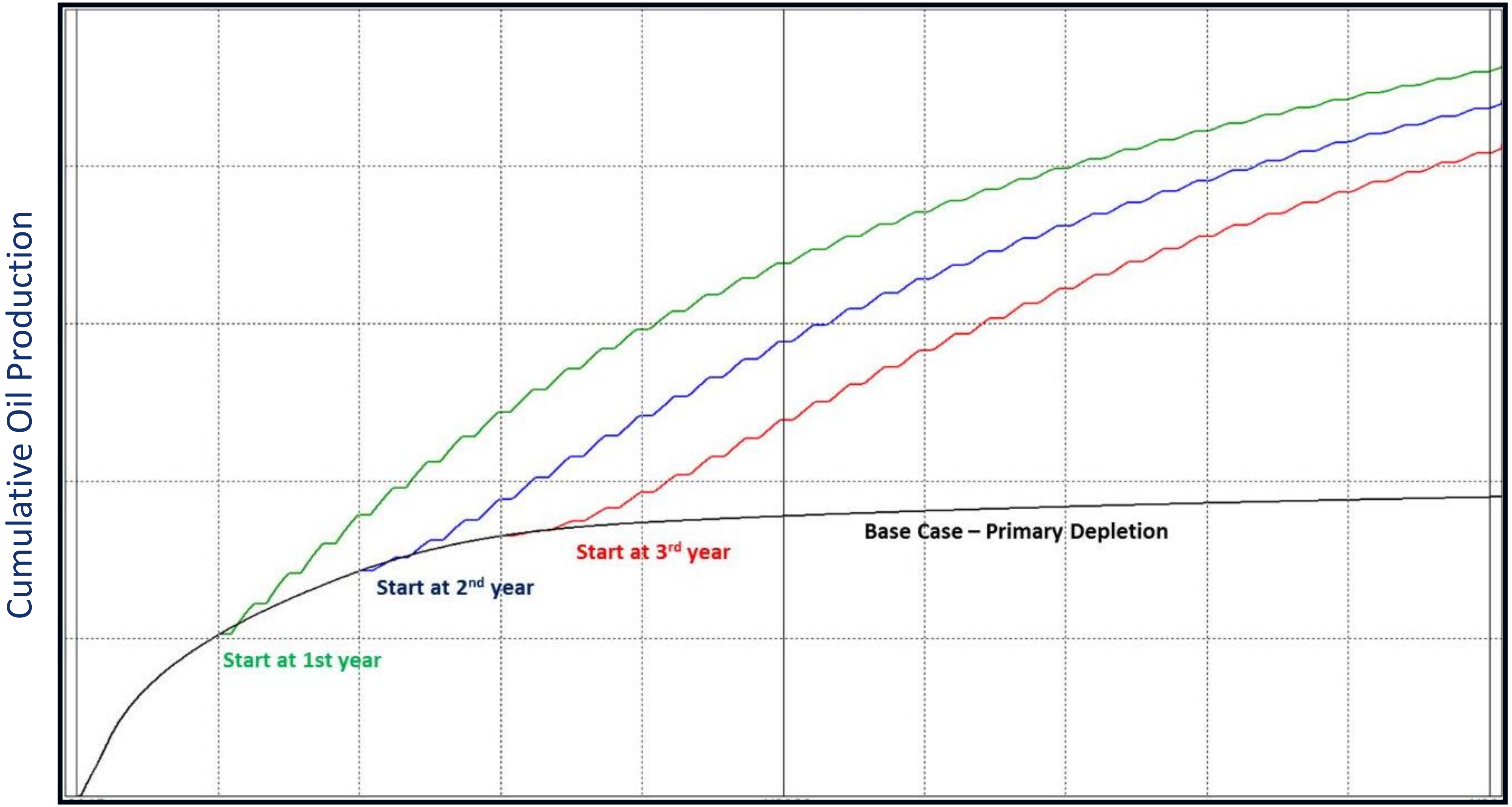
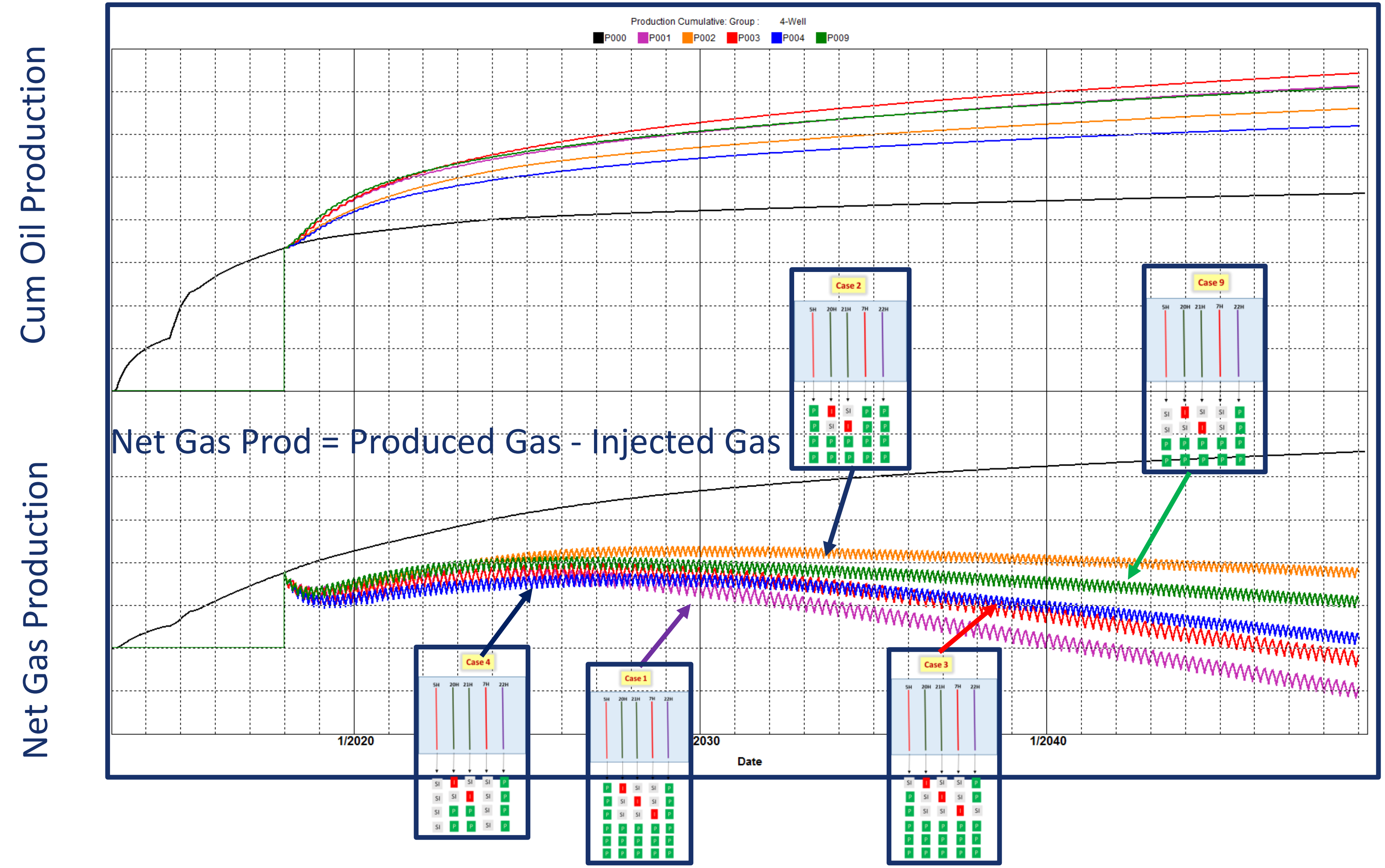


# Feasibility : Design and analysis of different sensitivities for economical outcome

## Well Scheduling Impacts Oil Recovery and Net Gas Purchase




Same injection rate
Wells operated differently

- Injector
- Producer
- Shut-in

Needs less gas purchase

# Conclusions

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- The injection pattern should include the entire DSU for pilots
- To account for the gas and to contain it capture wells should be considered.
- Wells with complex fractures are better candidates for a successful cyclic gas injection design.
- High pressure, high rate injection leads to better cyclic gas injection performance.
- Feasibility studies should be based on physics-based models.
- Multi well physics-based models should be calibrated to capture the communication paths using fracture interactions. Single well models may be misleading
- Dynamic nature of connectivity needs to be captured to model the gas movement correctly.
- While investigating feasibility both oil production and gas requirements should be taken into account for an economical project.