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Mechanistic Approach to Analyzing and Improving Unconventional Hydrocarbon Production

(FWP-FE406-408-409)

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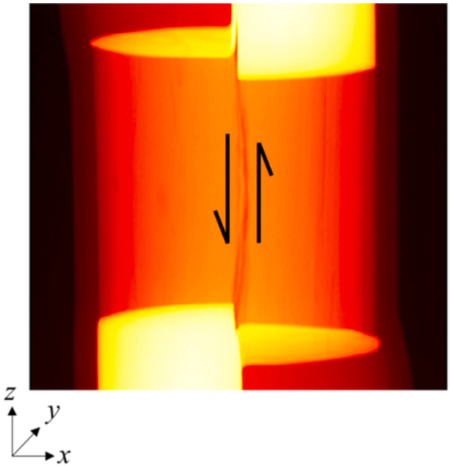
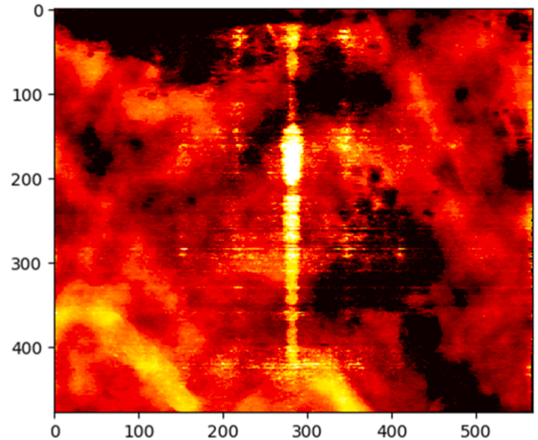


a. Radiograph showing fracture

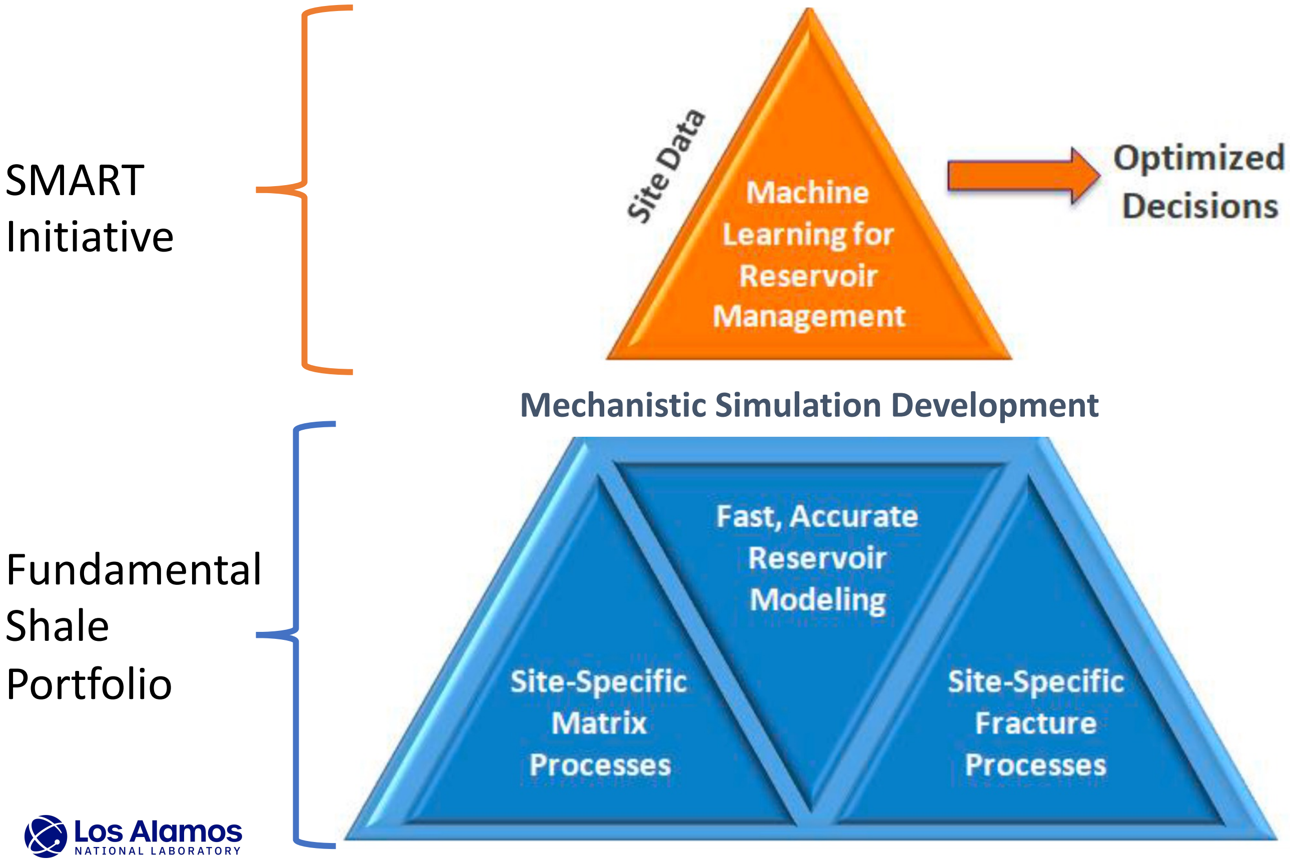


b. Effective normal stress = 3.2 MPa

Carbon Management and Oil and Gas Research Project Review Meeting
Oil and Gas Virtual Session
23-27 August 2021

Managed by Triad National Security, LLC, for the U.S. Department of Energy's NNSA.

Mechanistic Experimental and Computational Platform for Optimizing Production and Reducing Environmental Impacts of Unconventionals



SMART Initiative

Fundamental Shale Portfolio

Site Data

Machine Learning for Reservoir Management

Optimized Decisions

Mechanistic Simulation Development

Fast, Accurate Reservoir Modeling

Site-Specific Matrix Processes

Site-Specific Fracture Processes

Governing Hypotheses

- Efficient hydrocarbon recovery can be achieved by understanding and manipulating transport through the matrix to the fracture system
- Predictive tools based on measured physics can enable the virtual optimization of reservoir behavior

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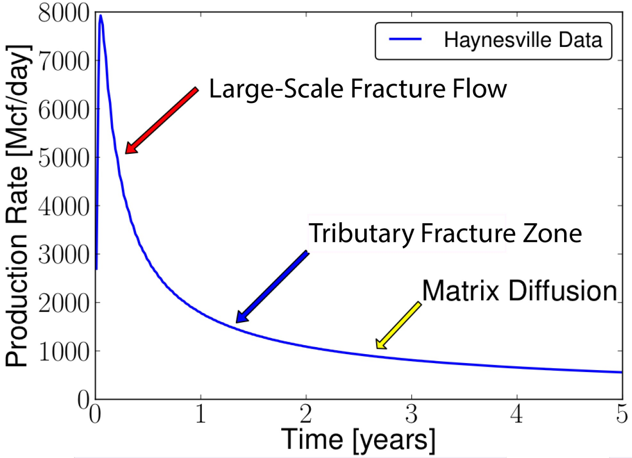
Outline: Research Highlights from Work Conducted at MSEEL

- Site-Specific Matrix Processes
  - Hydrocarbon-pore size distribution (Experimental)
  - Barite precipitation in fractures (Simulation)
- Site-Specific Fracture Processes
  - Stress-induced fracture closure (Experimental)
  - Pressure management at MSEEL (Experimental)
- Fast, Accurate Reservoir Modeling
  - Graph-based emulation of pressure management
  - Discrete fracture network modeling of fracture dissolution

Idealized Production Curve



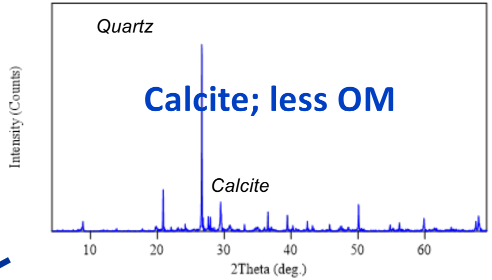
Impact of Pressure Management on Hydrocarbon Distribution

High-Pressure Small-Angle Neutron Scattering (HP-SANS)

"Light"

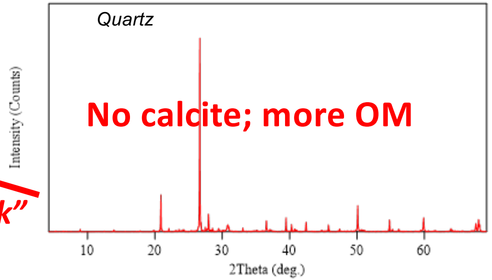
"Dark"

Wolfcamp "Light" Layer

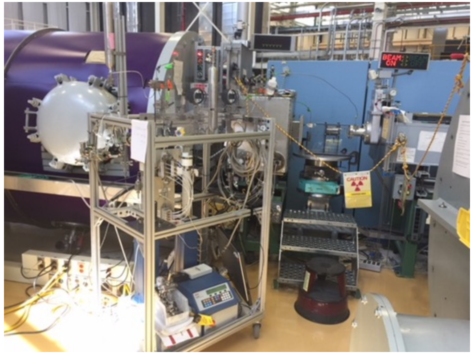


Calcite; less OM

Wolfcamp "Dark" Layer



No calcite; more OM



High-P SANS is a powerful capability

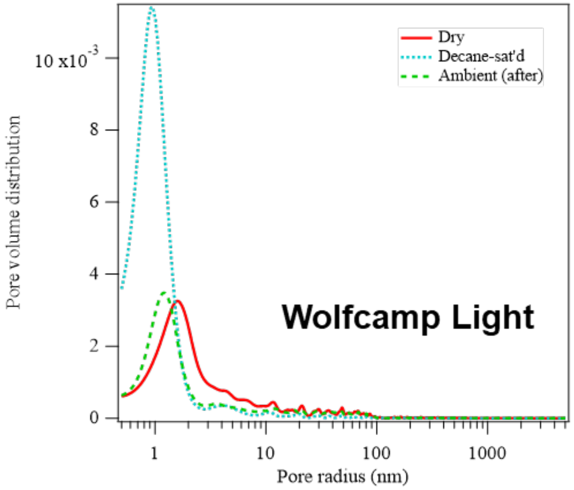
Pressure Cycling

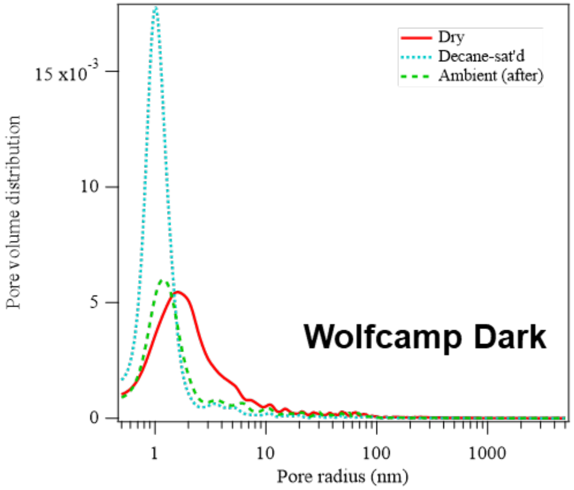
SANS measurement	Sample Condition	Pressure
1	Dry sample	Ambient
2	Decane-sat'd sample	Ambient
3		1500 psi of CD_4
4		3000 psi of CD_4
5		4500 psi of CD_4
6		6000 psi of CD_4
7		7500 psi of CD_4 *Max Pressure*
8		6000 psi of CD_4
9		4500 psi of CD_4
10		3000 psi of CD_4
11		1500 psi of CD_4
12		Ambient

Effects of shale mineralogy on recovery (decane removal)

Matrix-Scale

Pore Size Distribution (PSD) Changes with Production





- Both shales show decane uptake and removal after methane pressure cycling, causing shifts in PSD peaks.
- Very small pores were not accessible by decane; decane in 2-10 nm radius pores was not removable.

Similar pore size distributions for light and dark shales.

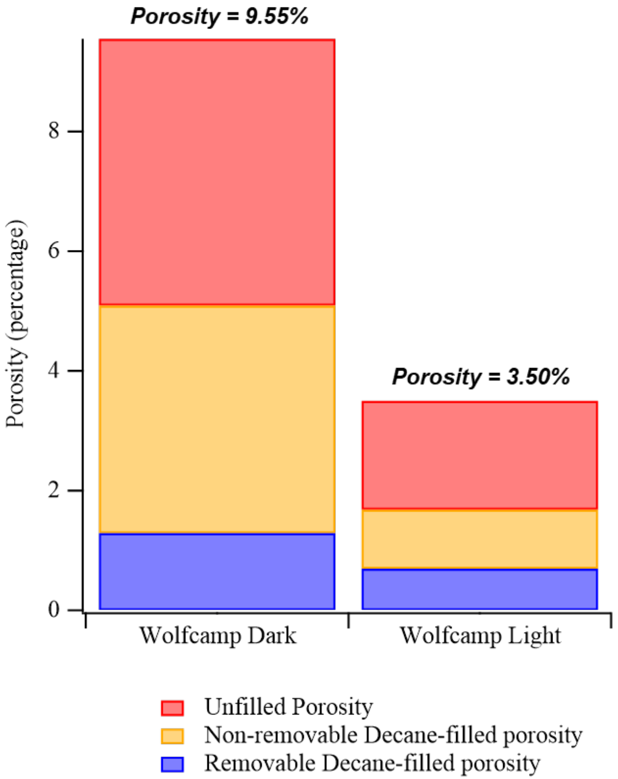
Matrix-Scale

Porosity Changes due to Production

- **Dark shale has a much higher porosity** than light shale
  - Likely due to more kerogen which hosts significant nanoporosity
- For both shales, ~50% of porosity was accessible to decane
  - 20% was recoverable for light shale and 13% was recoverable for dark shale
  - **Higher percentage of kerogen pores (oil wet) in dark shale**

First-of-its-kind experiments: pressure-induced production was greater from kerogen-rich shale

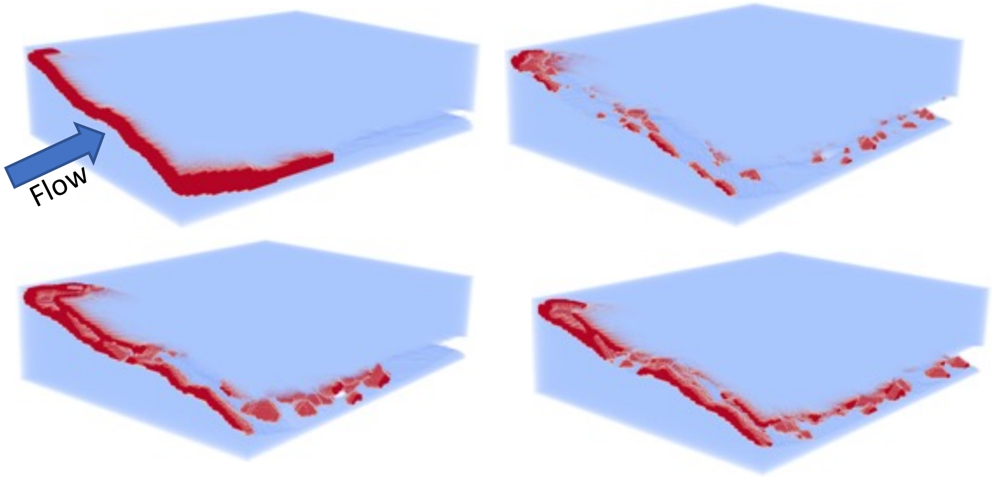
— Are there sweet spots for peak P, dP/dt, t, etc.?



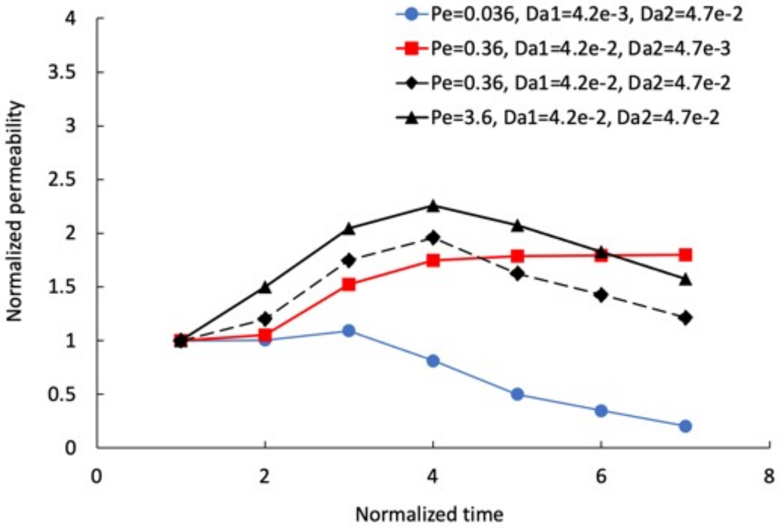
Neil et al. *in prep.*

Matrix-Scale

Pore-scale Simulation of Calcium Carbonate Dissolution and Barium Carbonate Precipitation in a Shale Fracture



Calcium carbonate dissolution and barium carbonate precipitation in a shale fracture at different combinations of Pe and Da numbers.



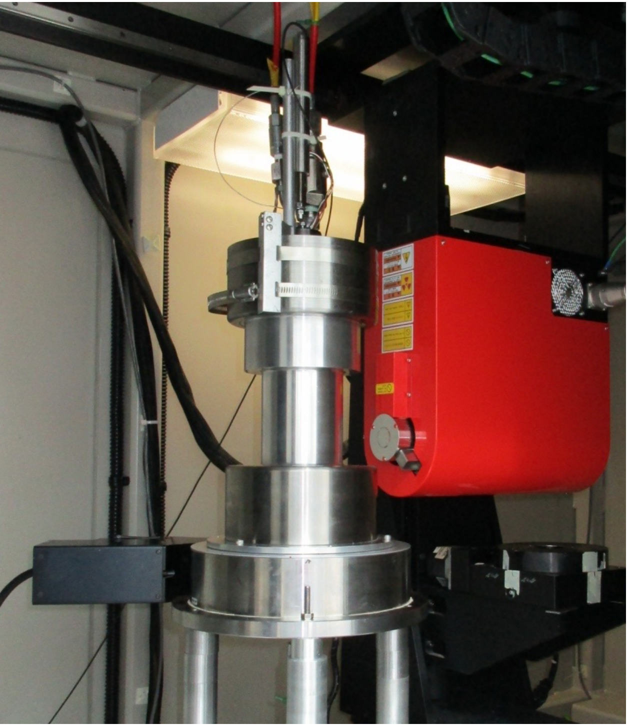
Permeability variation at different Pe and Da numbers

The trend of permeability change depends on the relative strength of advection, diffusion, dissolution, and precipitation as characterized by Pe and Da.

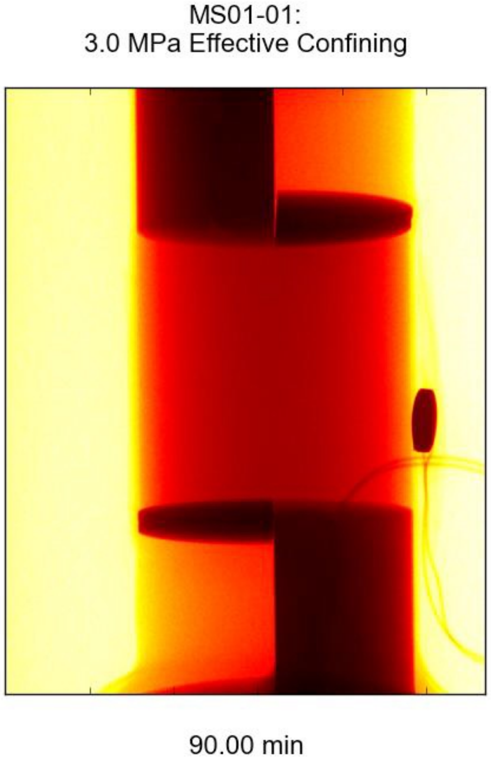
Matrix-Scale

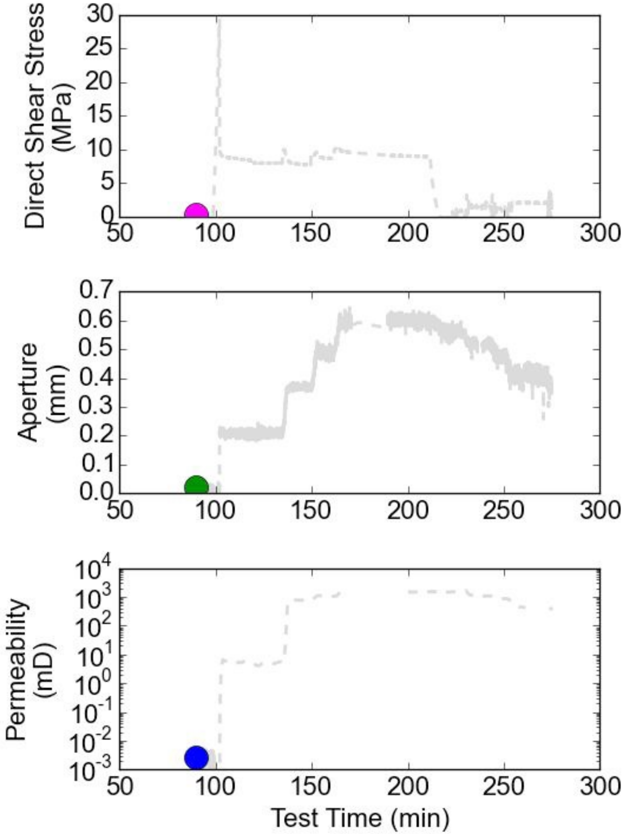
Experimental Measurement of Stress-Induced Fracture Closure

Triaxial Direct Shear with X-ray Radiography/Tomography



MSEEL

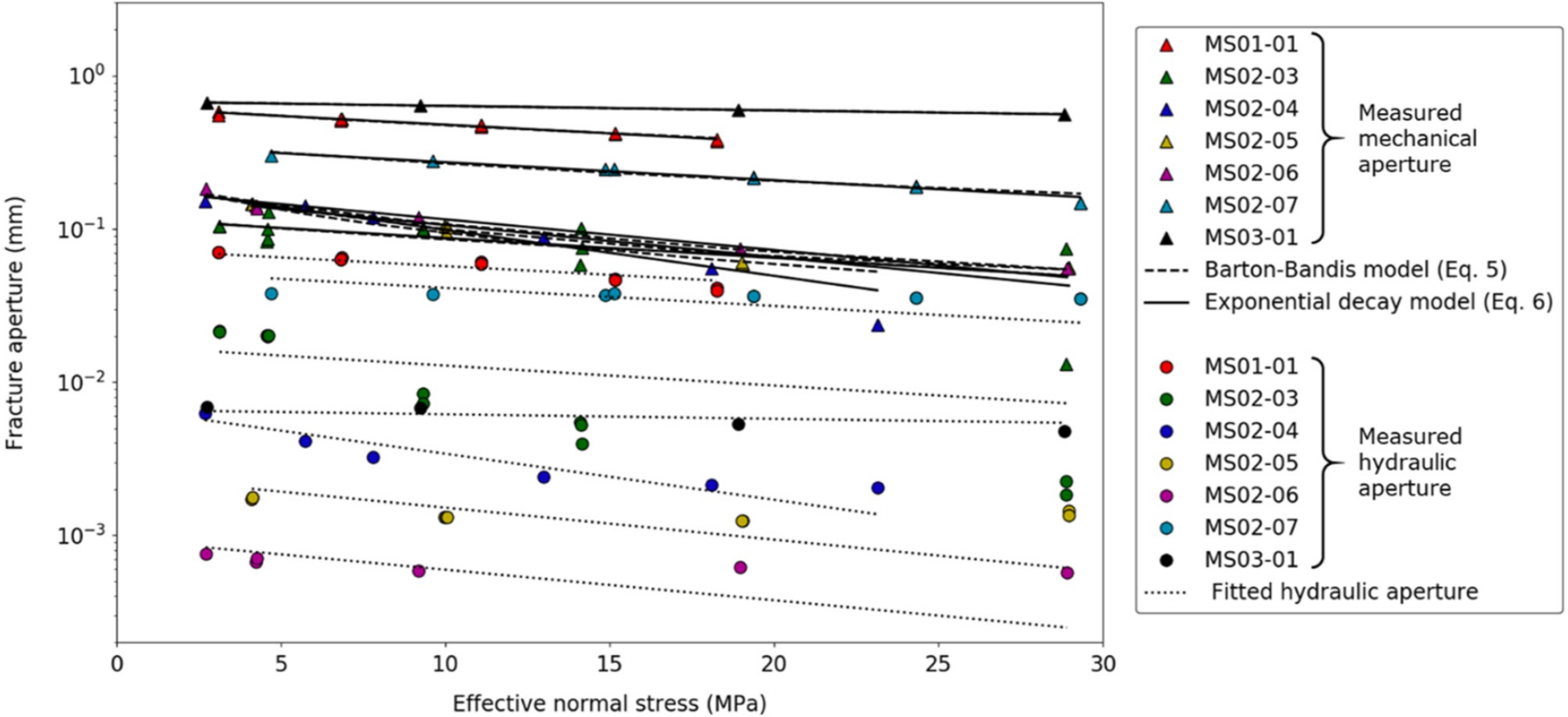




Fracture-Scale

Mechanical and Hydraulic Aperture Measurements

MSEEL Marcellus Shale

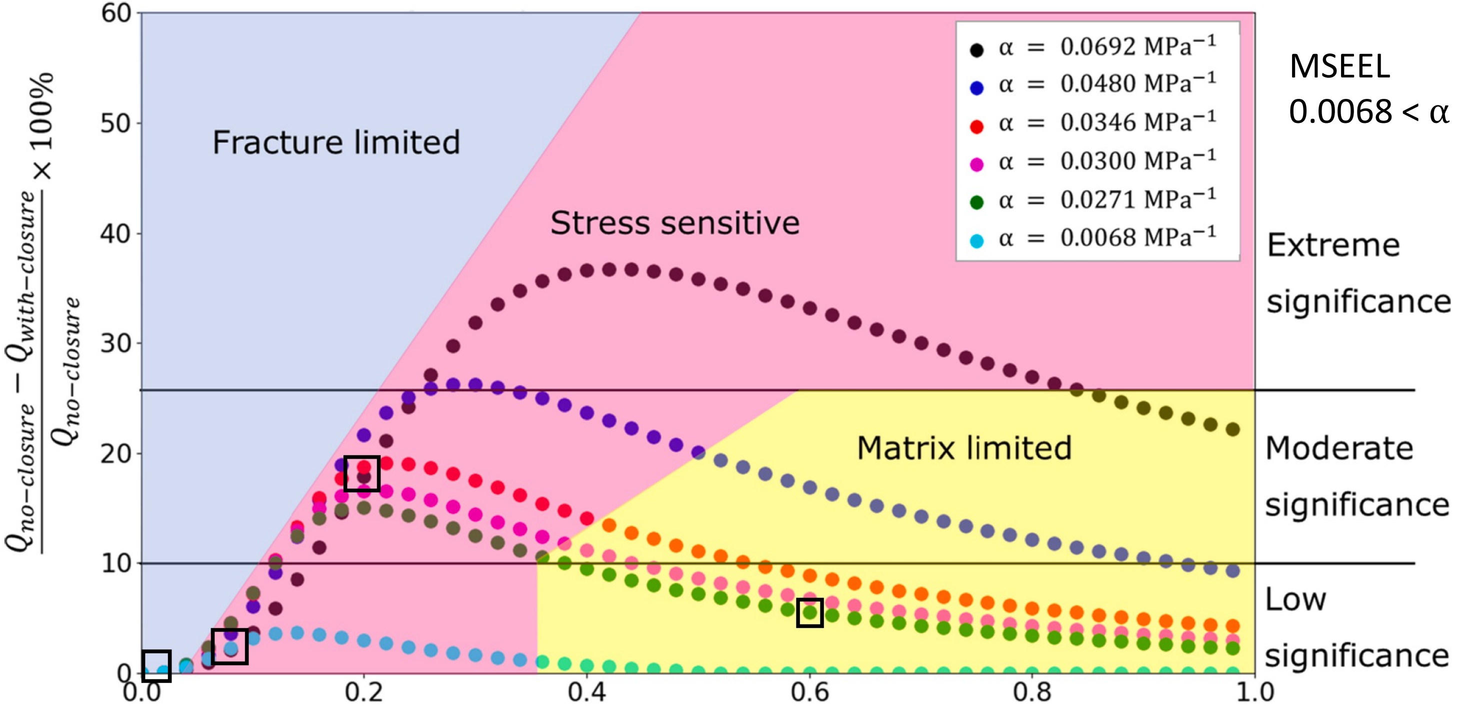


$N = b_h / b_m$ MSEEL $0.005 < N < 0.197$

Fracture-Scale

Significance of Fracture Closure on Production

(at Average Bottomhole Pressure in Field: 3000 psi; 21 MPa)



MSEEL
$0.0068 < \alpha < 0.0894$

$N = b_h/b_m$ MSEEL $0.005 < N < 0.197$

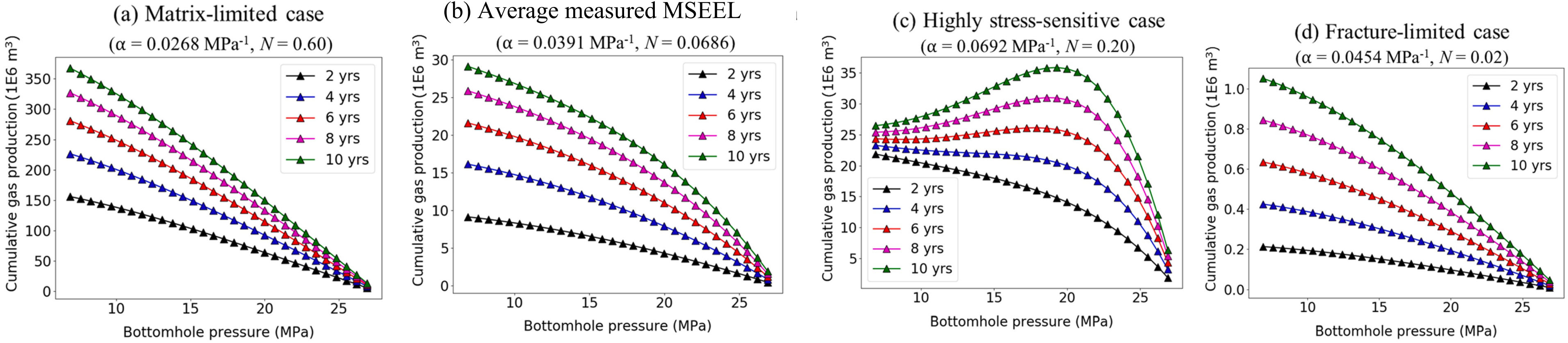
Fracture closure for average MSEEL fracture reduces production 3%

Li, W., Frash, L. P., Welch, N. J., Carey, J. W., Meng, M., and Wigand, M. (2021). Stress-dependent fracture permeability measurements and implications for shale gas production. Fuel, 290:119984.

Cumulative Production as a Function of Pressure Management and Fracture Properties

High k fractures

Low k fractures



(a) Matrix-limited case ($\alpha = 0.0268$ MPa^{-1}, $N = 0.60$)

(b) Average measured MSEEL ($\alpha = 0.0391$ MPa^{-1}, $N = 0.0686$)

(c) Highly stress-sensitive case ($\alpha = 0.0692$ MPa^{-1}, $N = 0.20$)

(d) Fracture-limited case ($\alpha = 0.0454$ MPa^{-1}, $N = 0.02$)

All simulations assume the same constant nano-Darcy matrix permeability

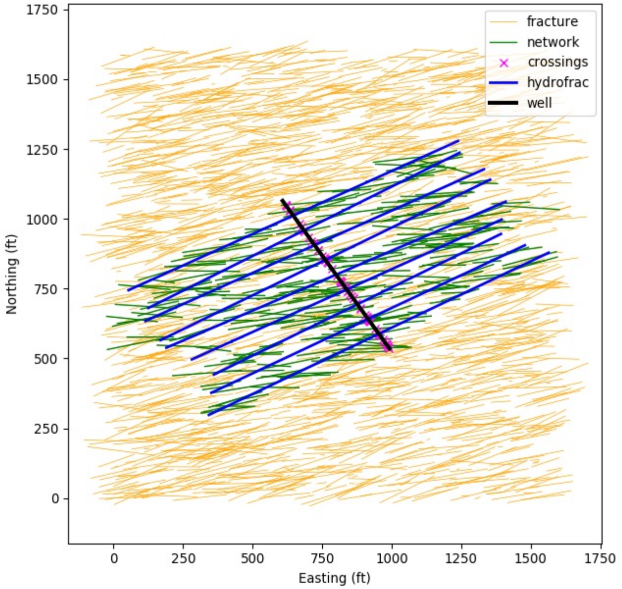
a) Greatest production comes from the “matrix-limited” case because fractures are quite permeable
b) The “average” MSEEL fracture is not sensitive to pressure drawdown
c) Individual fracture properties at MSEEL *are sensitive to Pressure Management*
d) Very limited production from the “fracture-limited” case because fractures are quite low permeability

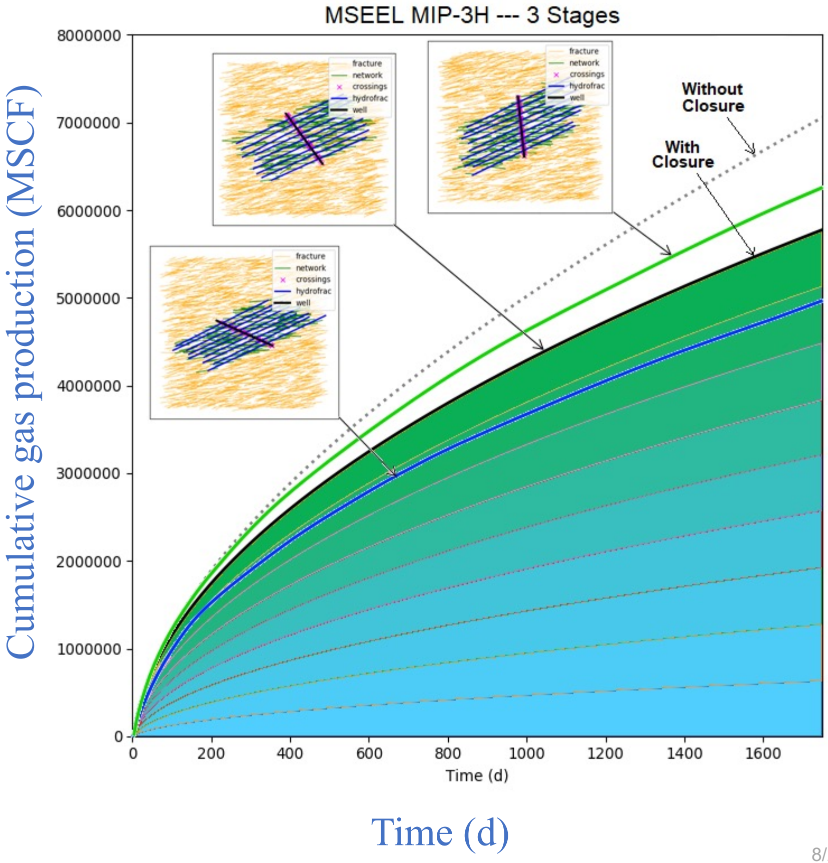
Li, W., Frash, L. P., Welch, N. J., Carey, J. W., Meng, M., and Wigand, M. (2021). Stress-dependent fracture permeability measurements and implications for shale gas production. Fuel, 290:119984.

Application of Fracture Closure to MSEEL

Motivational Questions

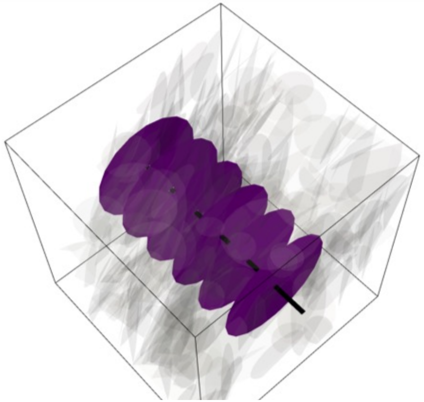
1. We wanted to see the conditions under which stress-closure of fractures is most likely to have an effect.
2. We wanted to see if wellbore orientation could affect production in naturally fractured reservoirs.
3. We wanted to see a basic production curve that used MSEEL data.



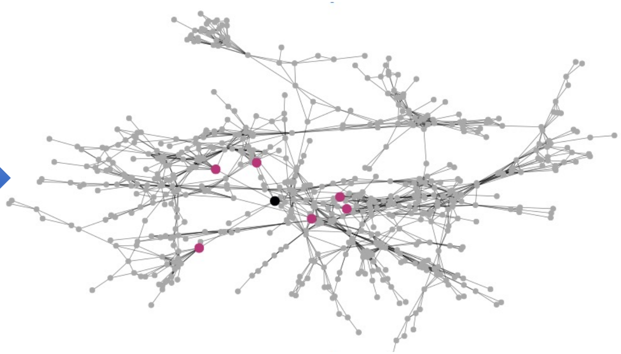


Fast, Accurate Transient Graph-Based Emulator for Pressure Management

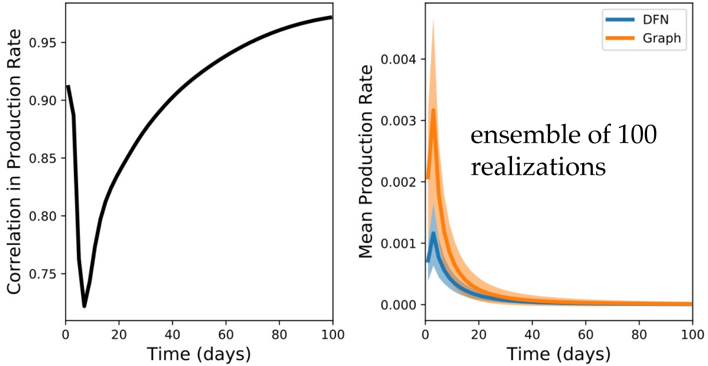
- Previously developed steady-flow graph emulator that was 10^4 times faster than high-fidelity DFN models was extended to transient flow
- Verification was performed against analytical solutions in a simplified system
- High correlation seen (>0.75) between graph emulator and high-fidelity DFN production estimates
- Graph-based emulator was used in uncertainty quantification workflows and in transfer learning for MSEEL-1 tasks



3D shale reservoir model



Equivalent graph



Solve flow and transport to get production

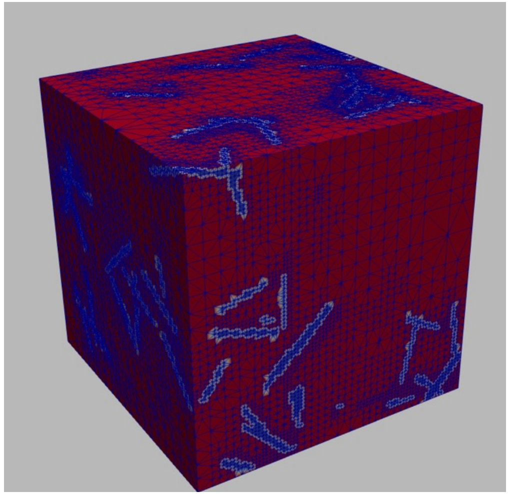
Srinivasan, S., O'Malley, D., Hyman, J.D., Karra, S., Viswanathan, H.S. and Srinivasan, G., 2020. Transient flow modeling in fractured media using graphs. *Physical Review E*, *102*(5), p.052310.

Reservoir-Scale

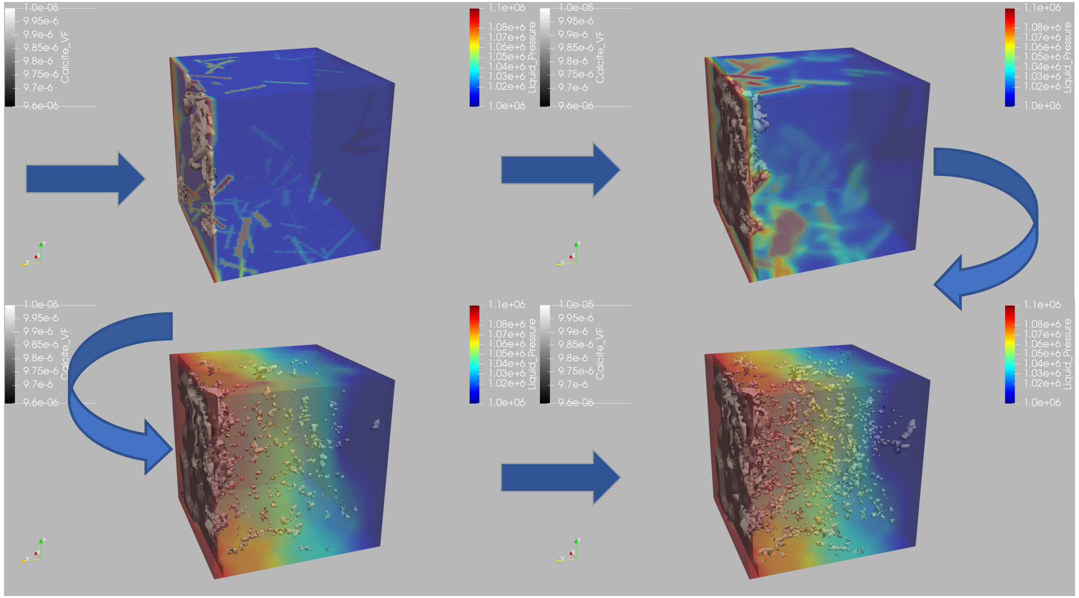
Influence of Acid Spearhead on Permeability and Production

- Collaboration with NETL and SLAC to study coupling of reaction and flow in complex fracture networks in shale
- Discrete fracture-matrix approach combines fracture network and matrix properties
- Calcite dissolution is shown below with acidic fluid injected through the left face
- Colors are pressure; speckles are the calcite that has been dissolved
- Currently using this approach to study the effect of fracture configuration and reactive transport on overall permeability

Discrete fracture matrix model



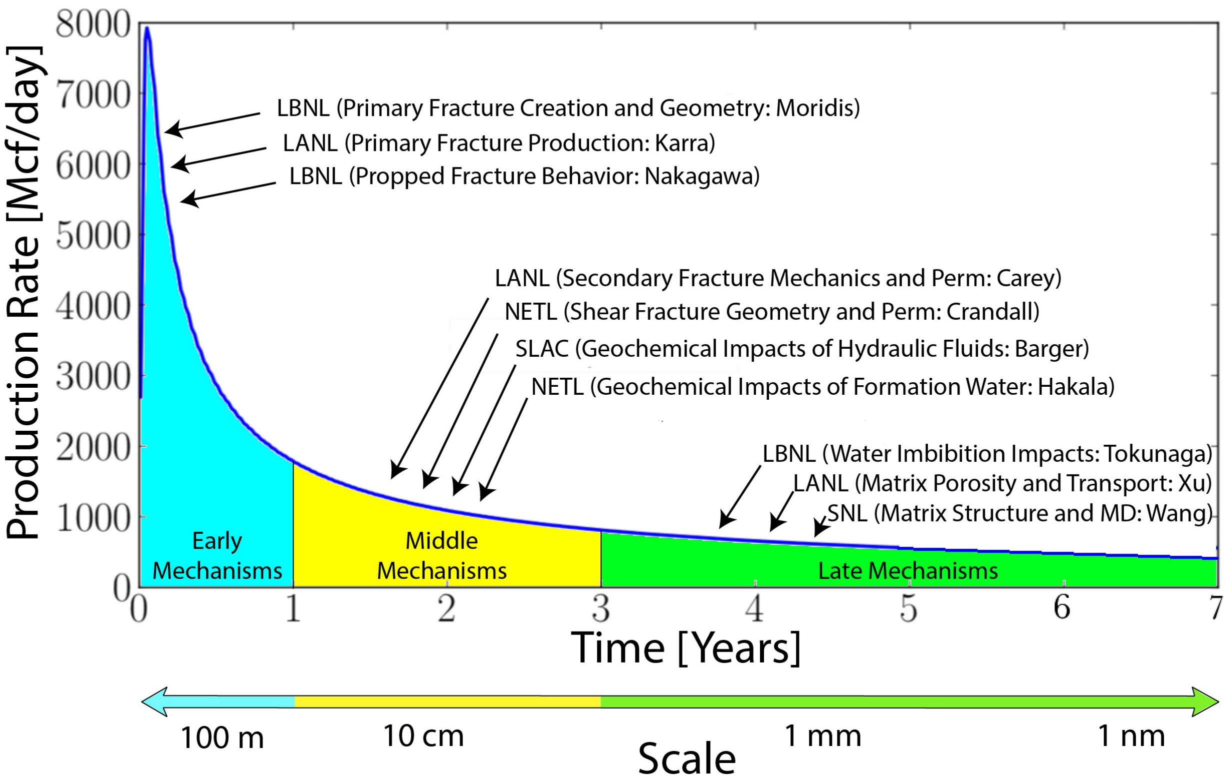
Acid Spearhead



Time Evolution of Amount of Calcite and Injection Pressure Field

Reservoir-Scale

DOE's Hydraulic Fracture Program Addresses Key Features Needed for more Efficient Production and Reduced Environmental Impacts Through Reduced Wells



Conclusions

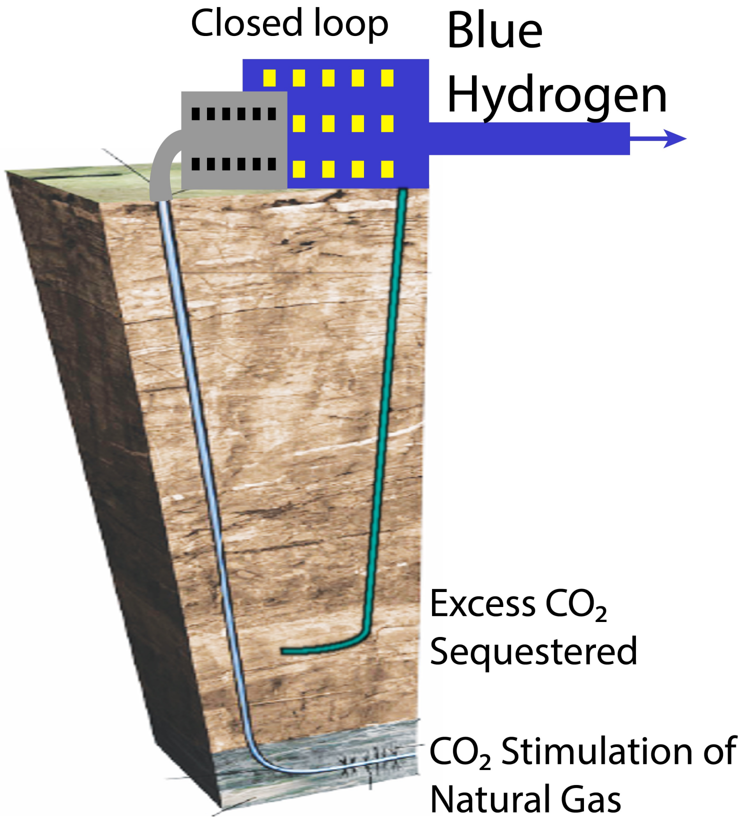
- Improved understanding of matrix and fracture processes provides strategies to optimize production efficiency
- More efficient production = better stewardship of resources
- More efficient production = fewer wells
- More efficient production = reduced environmental impacts

Acknowledgements

- DOE's Fossil Energy & Carbon Management Oil and Gas program
- Guidance from Bruce Brown, Steve Henry, Jared Ciferno, Elena Melchert
- Fruitful collaborations with colleagues at NETL, LBNL, SLAC, SNL, LLNL

Future Work: Use of Natural Gas to Enable a Transition to Renewables

Natural gas plays a critical role: Enables renewable use on the grid; generates blue hydrogen



Grand challenge: Reduced environmental impact of natural gas production

1. Reduced water usage
   - ✓ Recycle water
   - ✓ Recover NORMs & metals
   - ✓ Benign, effective water chemistry
2. Fewer wells
   - ✓ Enhanced fracturing methods (in-zone/better penetration)
   - ✓ Alternative fracture fluid chemistry (efficient recovery)
3. Eliminate fugitive methane
   - ✓ Improved well integrity
   - ✓ Improved monitoring of surface ops