Environmentally Prudent Stewardship

NATIONAL ENERGY TECHNOLOGY LABORATORY

Minimizing and mitigating environmental impacts from oil and gas development. With consideration to an environment where CO_2 is injected and in support of FOA Field Labs.

Offshore R&D

Remediation and Reuse of Onshore Resources

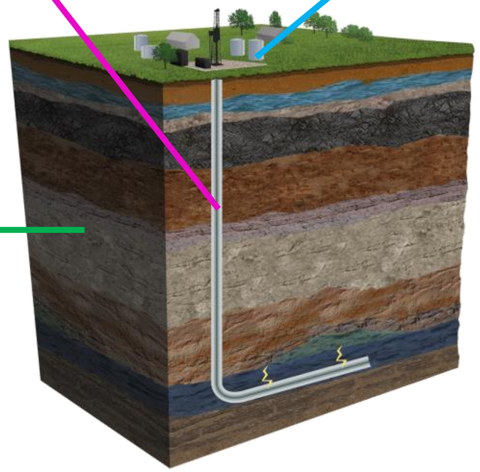
Well Integrity: Limiting Unwanted Emissions and Fluid Migration from Wells

Task 24: Ensuring well plugging materials and approaches reduce leakage and ensuring well plugging placement limits subsurface gas migration.
Task 25: Identifying controls on unwanted migration of fluids between active and abandoned wells.

CO_2 EOR: In Support of the Field Labs
Task 30 (NEW): Identify why pilot tests are not successful at enhanced oil recovery with CO_2 injection.

Produced Water: Minimizing Freshwater Use and Maximizing Successful Produced Water Management

Task 27: Quantifying role of reservoir organic reactions on composition of, and ability to treat/use, produced water.



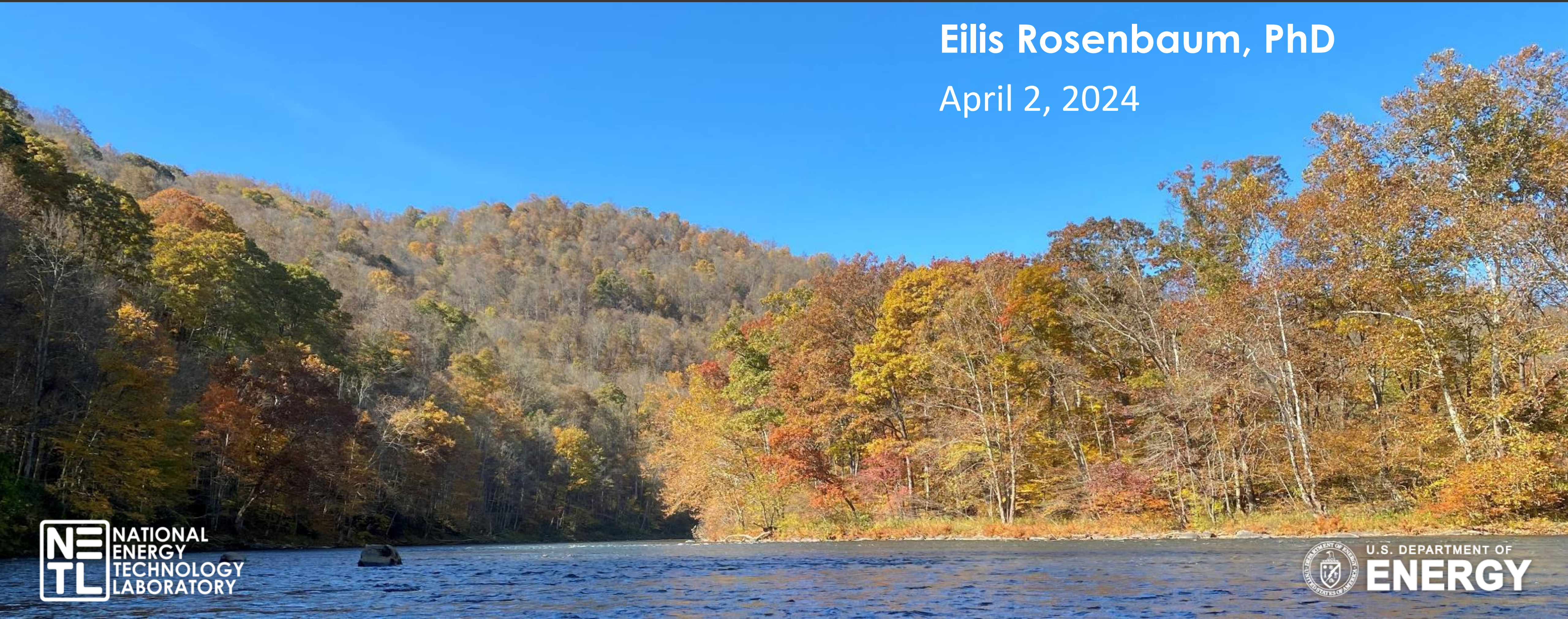
Offshore Infrastructure Integrity: Identify and Prevent Offshore Hazards

Task 6: Infrastructure and Metocean Technology – Analytical models to characterize and prevent seabed and metocean hazards to infrastructure.
Task 8: Thermodynamic Modeling of Mineral Scale at HTHP
Task 10: Smart Infrastructure Integrity Models to Support Remediation and Inform Safe Use Strategies – Evaluate infrastructure and evaluate operational and environmental risks.
Task 12: Signatures of Kicks to Inform Drilling, Operations, and Safety

Well Integrity and Improved Plugging

Eilis Rosenbaum, PhD

April 2, 2024



NATIONAL ENERGY TECHNOLOGY LABORATORY

U.S. DEPARTMENT OF ENERGY

Project Overview
Task 24.0 Well Integrity and Improved Plugging

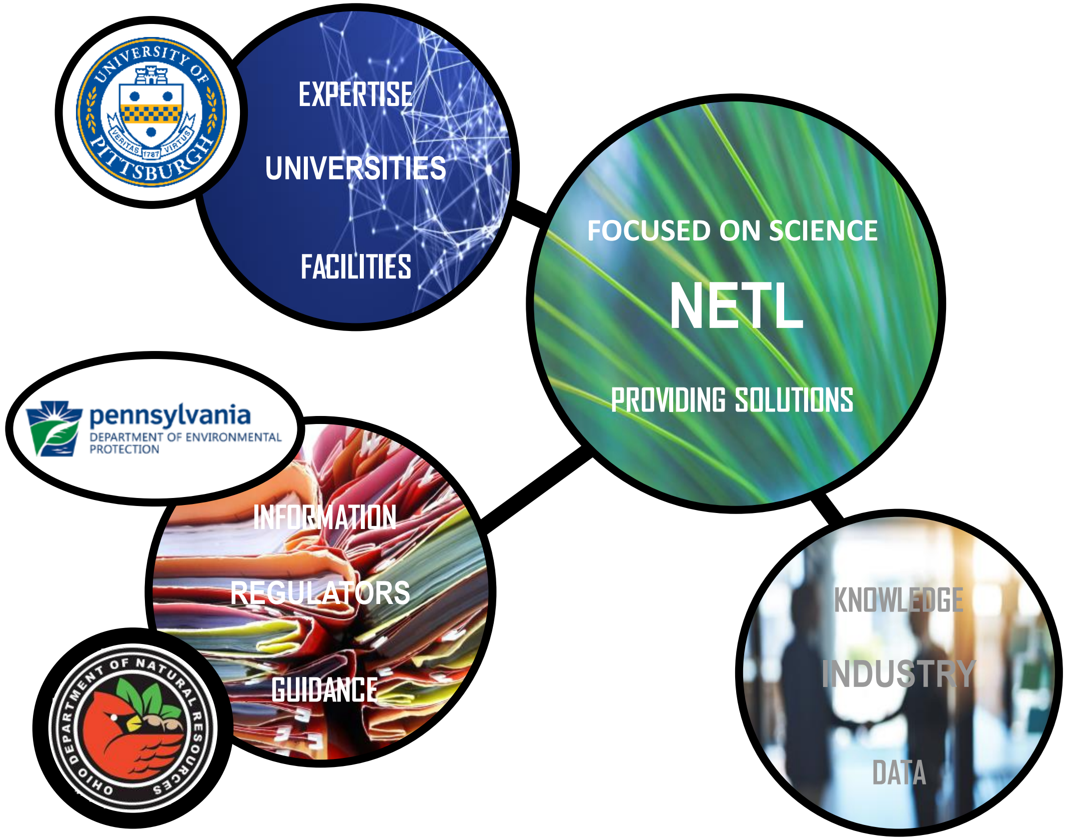
TIMELINE	EY 2021	EY 2022	EY 2023	EY2024	EY2025	EY2026

How do we ensure that wells maintain integrity and are not leaking?

Need: Many current code requirements <u>do not provide</u> long-term plugging and leak mitigation. Experiments and testing can be conducted to establish new requirements.

Project Team:

Key Personnel:
NETL: Eilis Rosenbaum (PI), Richard Spaulding, Igor Haljasmaa, Justin Mackey, Phillip McElroy, James Fazio, University of Pittsburgh: Julie Vandenbossche, Anthony Iannacchione, John Brigham, Carlos A. Garcia Verdugo (PhD Student)



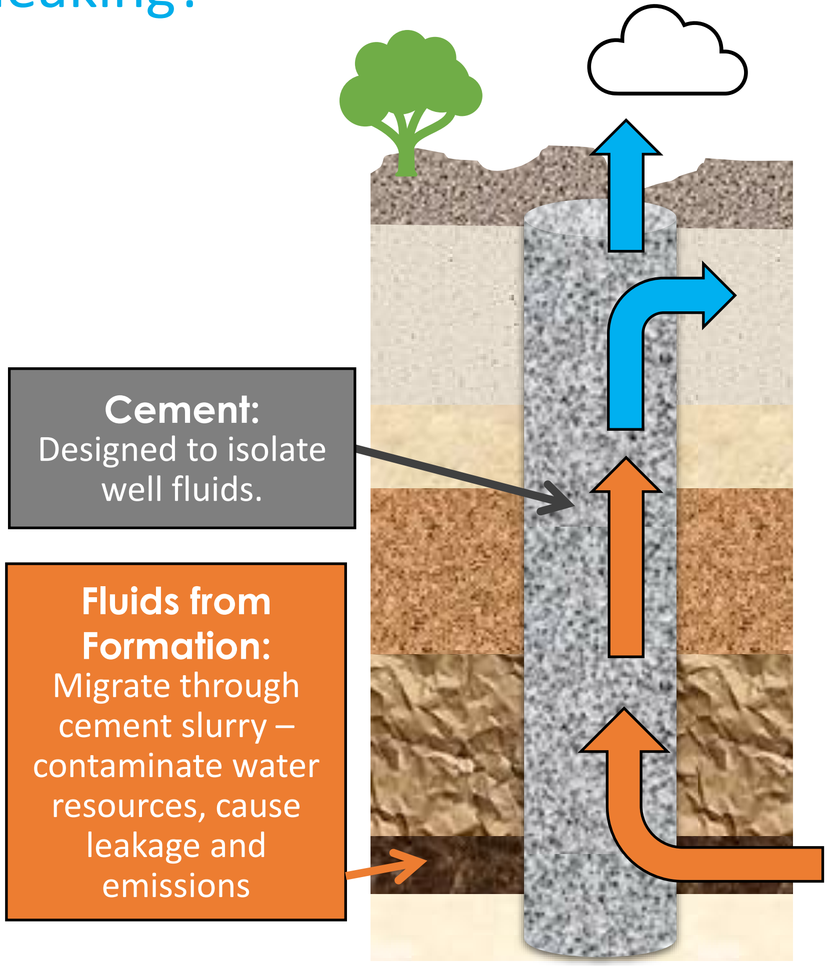
Crosscutting: Methane emissions, Undocumented wells, EPA MERP Technical Assistance

Stakeholders: State Regulatory Agencies, National oil and gas regulatory agencies, and oil and gas companies.

Zonal Isolation

How do we ensure that wells maintain integrity and are not leaking?

- Ensure plugging and well materials meet or exceed code requirements through research and testing.
- Characterize and test materials under relevant conditions.
- Improve material performance with additives.
- Develop innovative materials.
- Remediate leakage pathways.
- Etc.



Sharifi, Vandenbossche, Iannacchione, Brigham, Rosenbaum, 2023

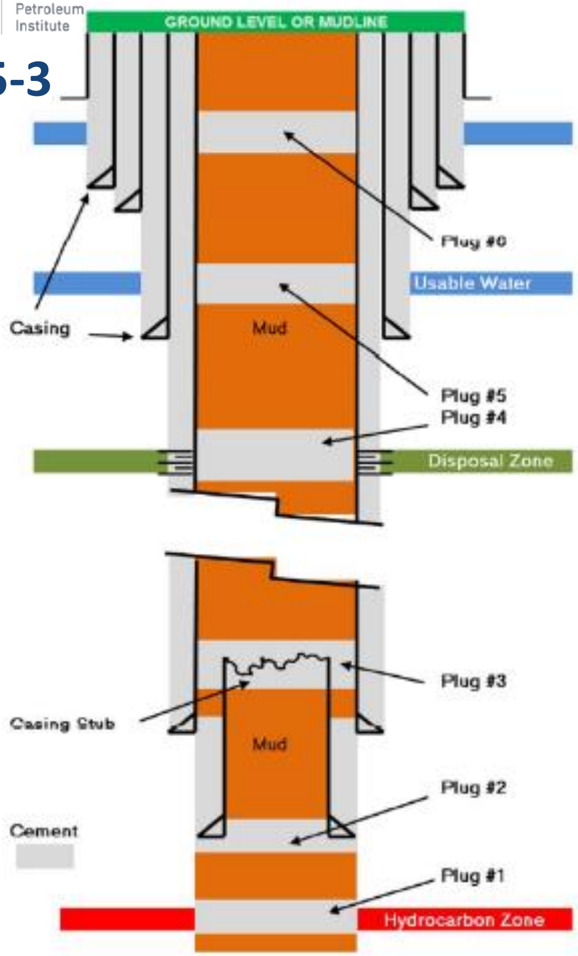
Background: Plugging Practices in PA and Appalachian Basin

Well Plugging and Oil and Gas Codes

- API Recommended Practice 65-3 (2021)
- PA Chapter 78.71 (1987)
  - Hydrocarbon-producing intervals plugged with Portland cement.
  - Non-producing intervals – slurry composed of no less than 4% bentonite and water “gel”.
- WV Code R. 35-4-14
  - Class A Ordinary Portland cement with no greater than 3% $CaCl_2$ and no other additives.
  - All non-porous materials used in conjunction with plugging shall be at least 6% bentonite gel.
- Field Study by PA DEP found:
  - Higher incidence of leakage in wells plugged with cement + gel.

American Petroleum Institute

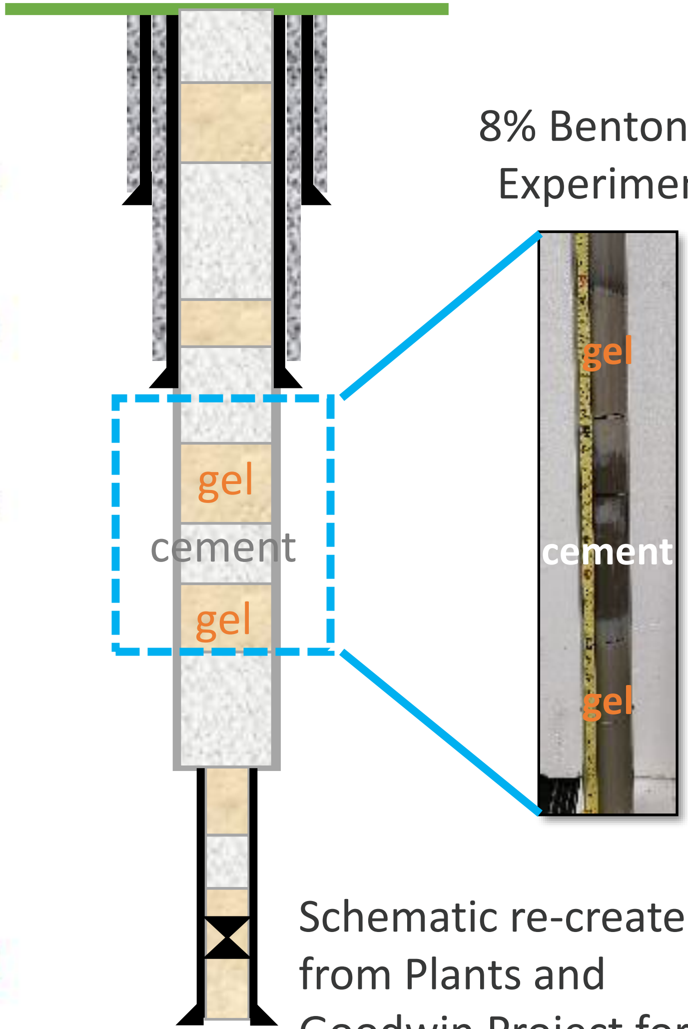
RP 65-3



NOTE 1 Plug #1 may cover all open hole length in several cases.
NOTE 2 Plug #3 is commonly called a casing stub plug or "T" plug.
NOTE 3 Plug #6 is commonly called a surface or environmental plug.
NOTE 4 Top of cement in casing strings can vary depending on well construction.

Figure 1—Example Schematic of a Permanent Well Abandonment

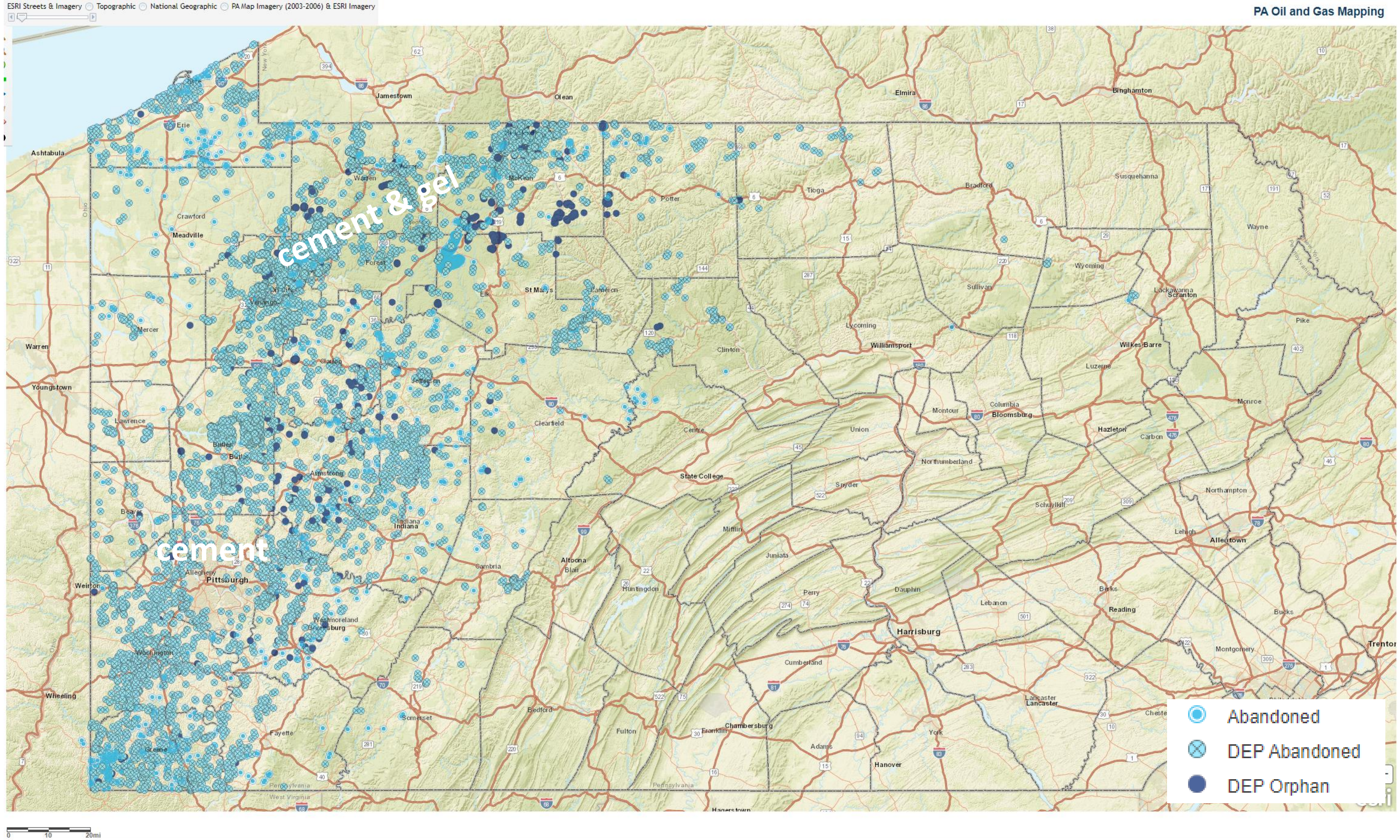
8% Bentonite Experiment



Schematic re-created from Plants and Goodwin Project for well plugged in NY

Background: Plugging Practices in PA and Appalachian Basin

Well Plugging in PA



"The number of plugged wells will grow in time, but plugging does not always represent the last chapter in a well's life."

-PA DEP

Cement $ > Bentonite $

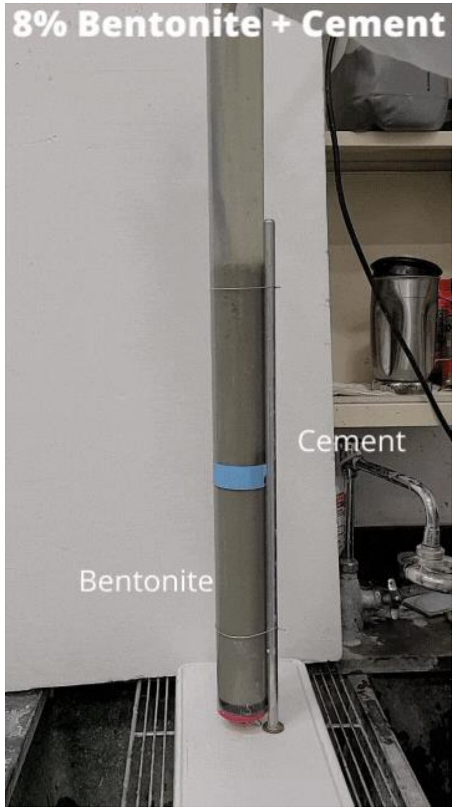
Rig time is the greatest impact on costs

Plugging with Cement and Bentonite

Tests Conducted in 2" Simulated Well

"Gel" – allowed by current PA code requirements

4% bentonite in water gel cannot support cement placement



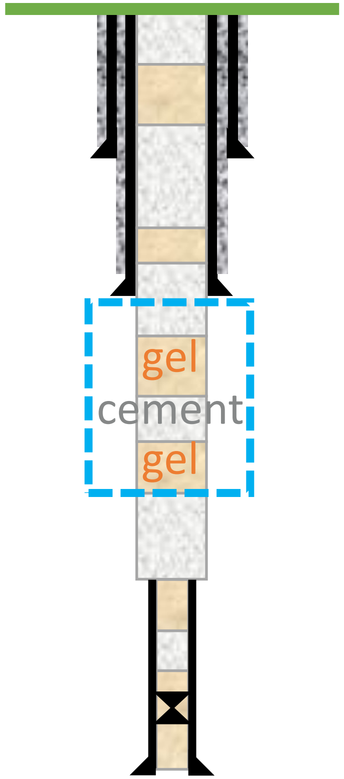
NETL recommended bentonite concentration and process

Provided efficient process recommendations and gel concentration

Scaled up

Tests Conducted in 6" Simulated Well

**Preliminary results and could change with additional tests.*

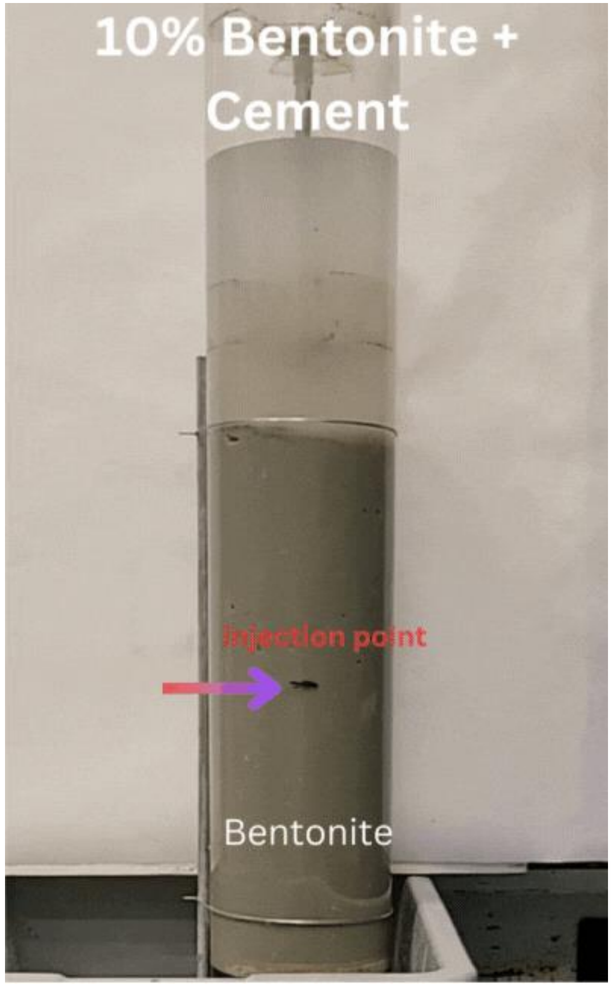


Rig time is the greatest impact on costs

Plugging with Cement and Bentonite

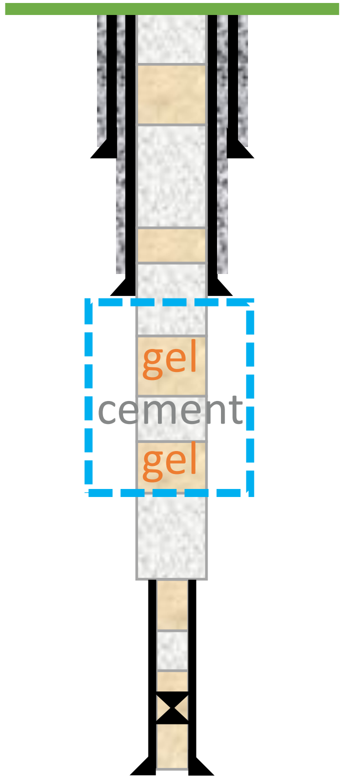
Tests Conducted in 6” Simulated Well

**Preliminary results and could change with additional tests.*



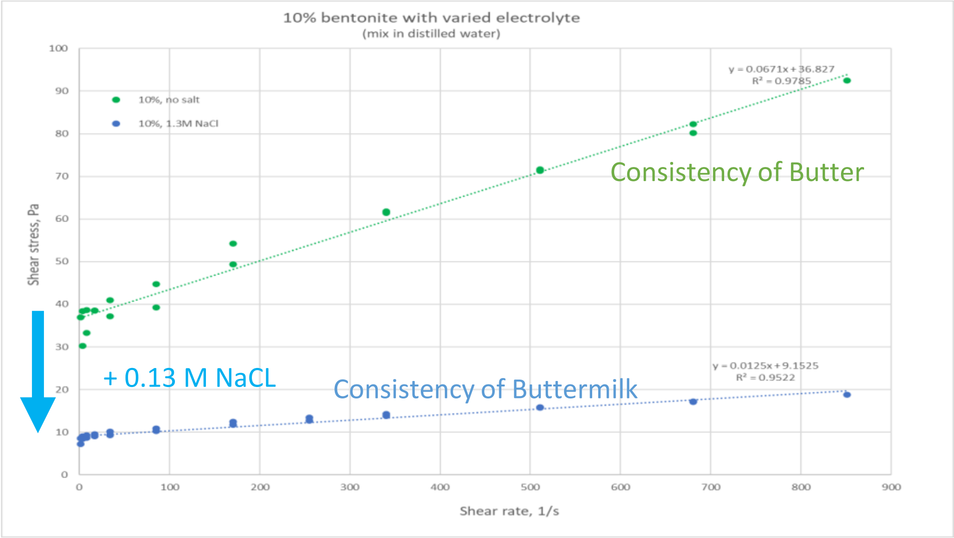
*NETL is recommending using 10% bentonite in water for larger diameter wells**

**Preliminary results and could change with additional tests.*

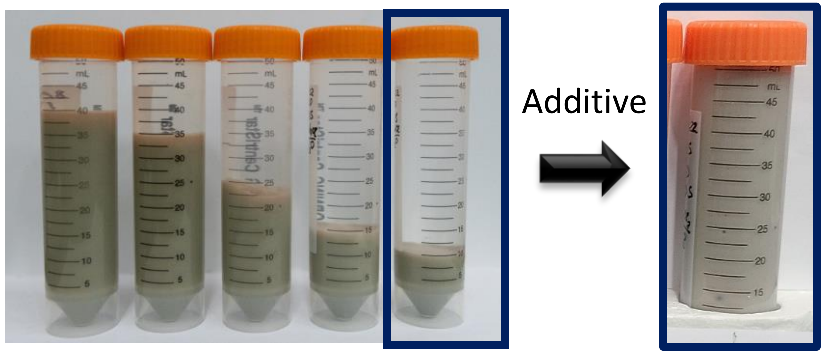


Plugging with Cement and Bentonite

The effects of salt on bentonite stability

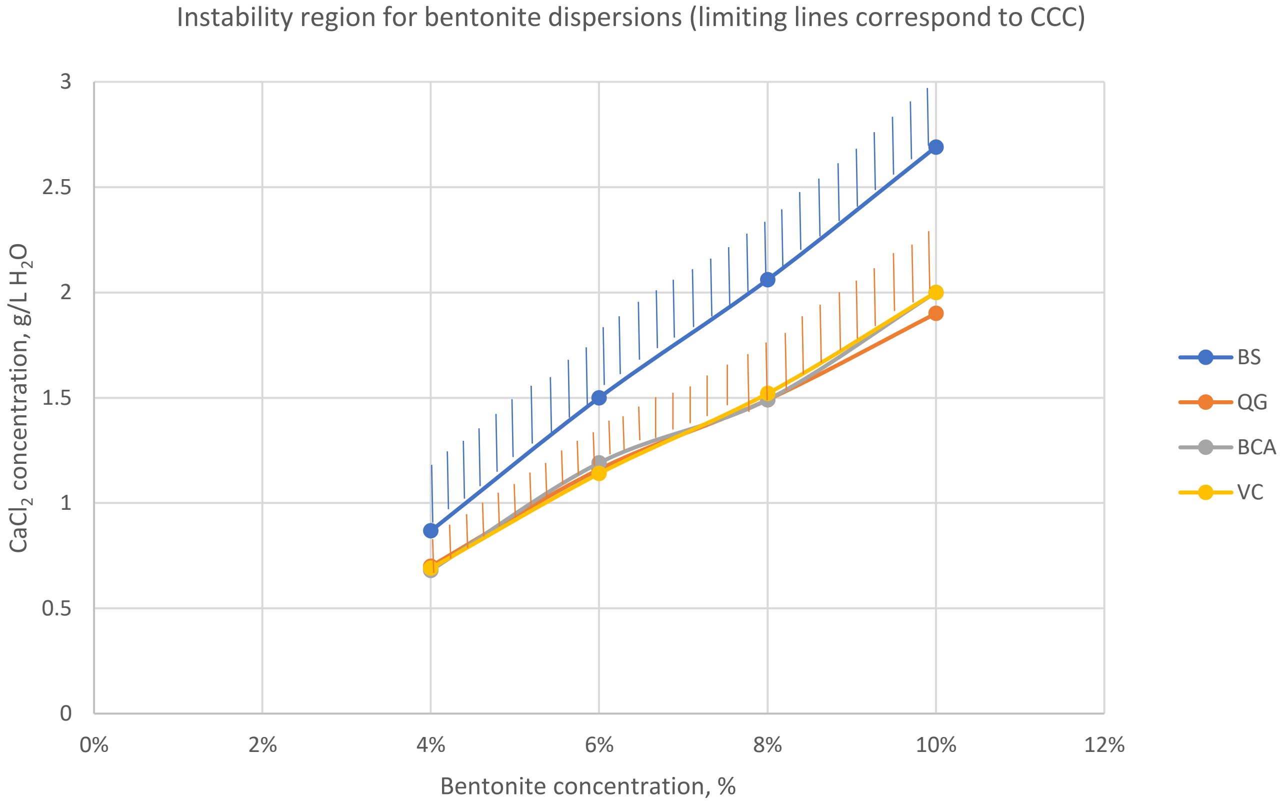


Established instability levels of salts on spacer gel
Developed material mixes to combat plug instability



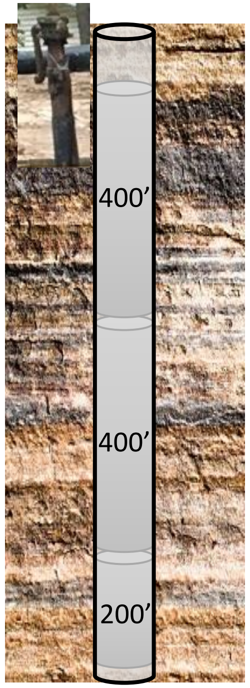
Unstable – reduced effectiveness

Stable



Modeling Plugging Material Placement

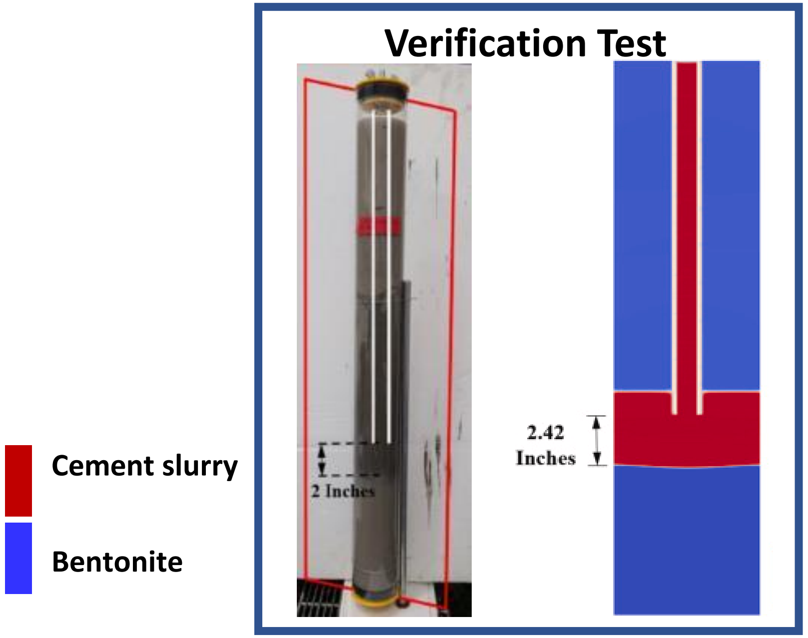
Field Conditions

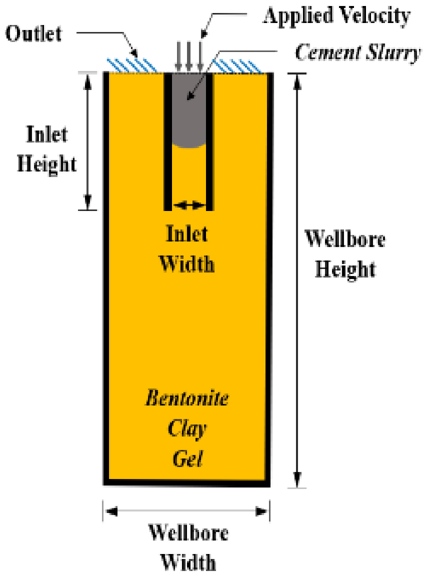


Plugging Example

	Field	Lab
Well Length	1000’ to 2000+’	3’ to ~6’
Plug Interval Length	200’ to 400’	0.5’ to 3’
Injection Rate	106 gal/min (2.5 barrels/min)	3 gal/min
Pressure	100’s psi	0 psi
Well Diameter	4” to 10”	Up to 6”
Formation	Formation	Idealized
Water source	Potable	distilled
Cement	Type IL (density 14.5-15.6 ppg)	Class H (16.4 ppg)

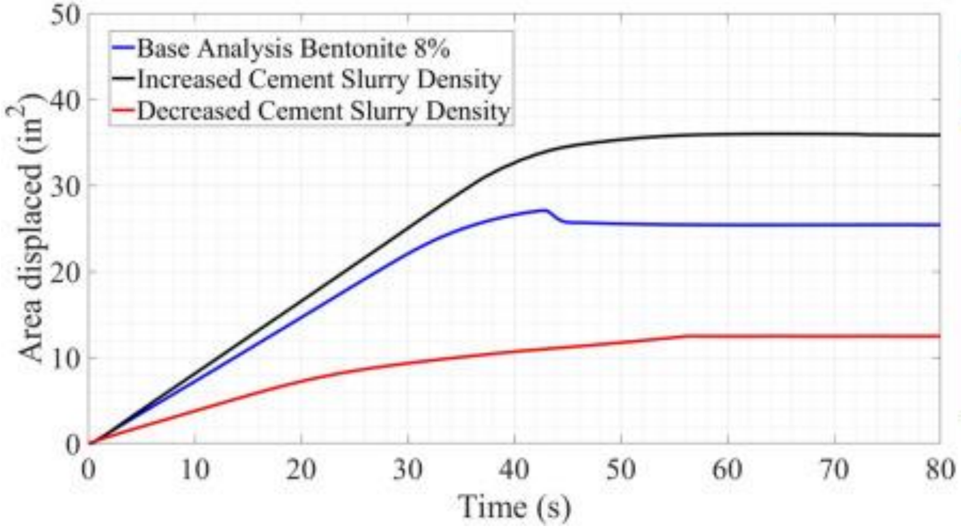
Lab Conditions

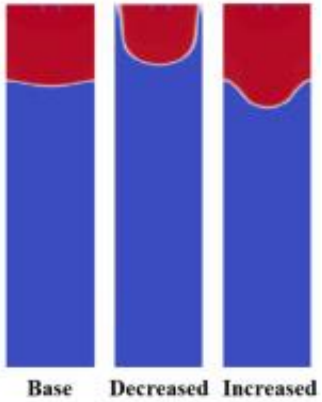




Bentonite 8% Concentration
Density: 0.0383 lbs/in^3
Yield Stress: 8.70 x 10^{-4} psi
Plastic Viscosity: 10.0 cP

Cement Properties
Density: 0.0708 lbs/in^3
Yield Stress: 3.2 x 10^{-4} psi
Plastic Viscosity: 220 cP





Garcia, Rosenbaum, Spaulding, Haljasmaa, Sharifi, Vandenbossche, Iannacchione, Brigham, 2023 https://doi.org/10.1016/j.geoen.2023.212047

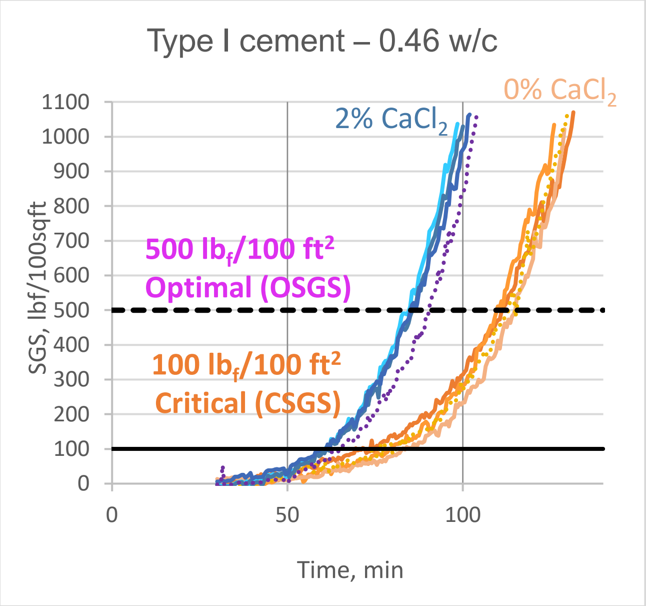
Plugging and Completions with Portland Cement – Addressing Gas Migration

Tests in Wellbore Simulation Chamber (WSC)

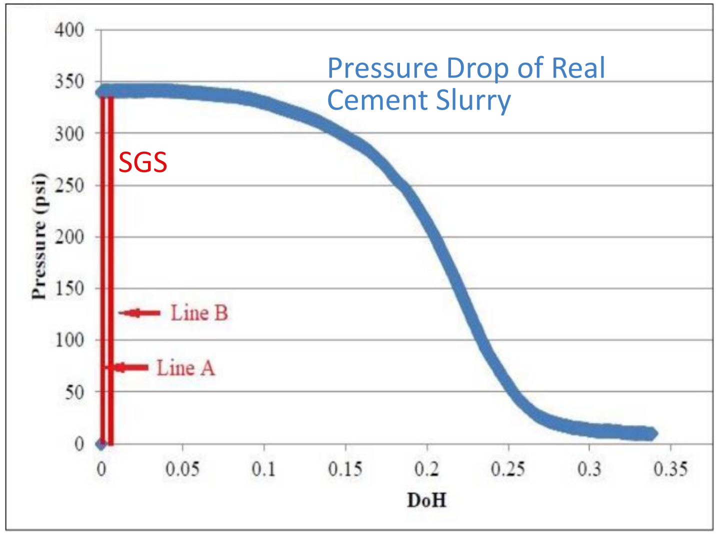
Test cements under real well conditions → Identify when cements are gas tight

Static Gel Strength (SGS) – API, Oil and Gas Industry Standard Method

SGS - single material property



SGS Values Occur early in the hydration process

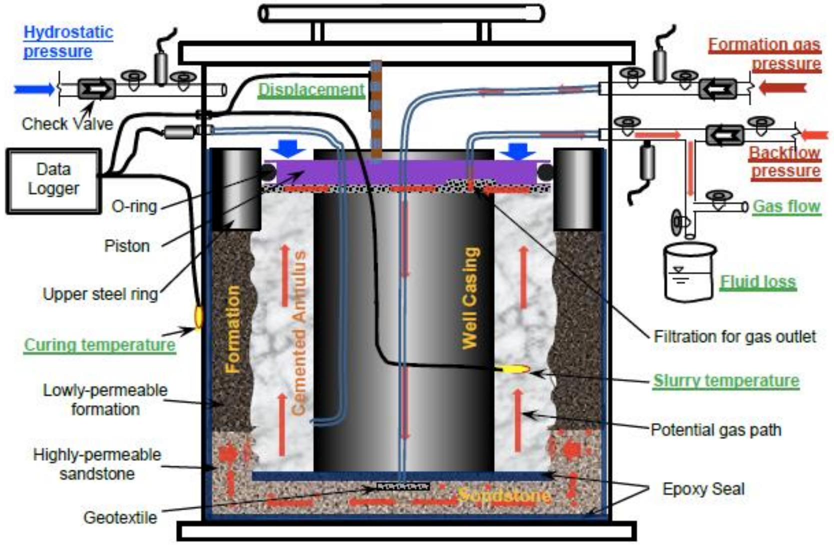


Pressure drop vs. degree of hydration

Line A: CSGS 100 lb_f/100ft^2, 80 min, 0.0004 DoH

Line B: OSGS 500 lb_f/100ft^2, 115 min, 0.005 DoH

Wellbore Simulation Chamber (WSC)



"Slice" of the wellbore

Plugging and Completions with Portland Cement – Addressing Gas Migration

Tests in Wellbore Simulation Chamber (WSC)

Cement slurry placement

Initial Time

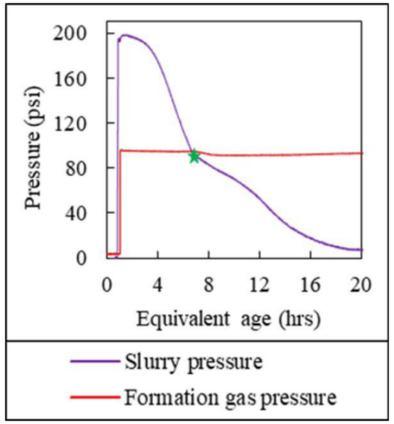
Gas migration occurs between initial time and end time

End Time

No gas migration | Vulnerable to gas migration | No gas migration | ***time***

Type I Cement, w/c 0.46

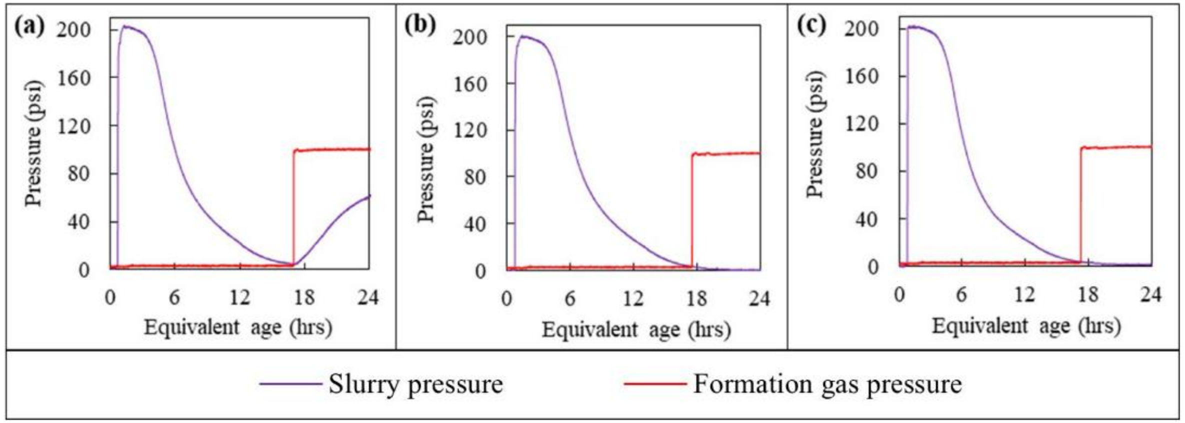
Initial Time



6 hrs 30 min

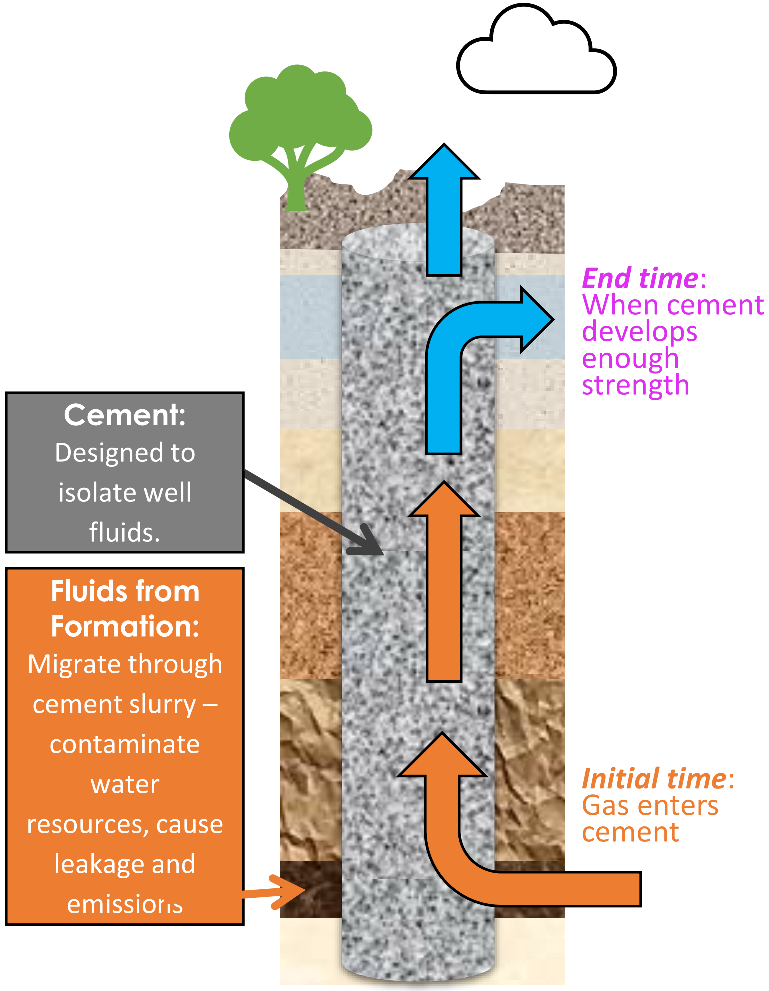
500 lb$_f$/100 ft^2 ~1 hr 20 min
Optimal (OSGS)

End Time – requires multiple tests



(a) 17 hrs – gas migration, (b) 17 hrs 30 min – no gas migration, (c) 17 hrs 15 min – no gas migration

100 lb$_f$/100 ft^2 ~1 hr 55 min
Critical (CSGS)



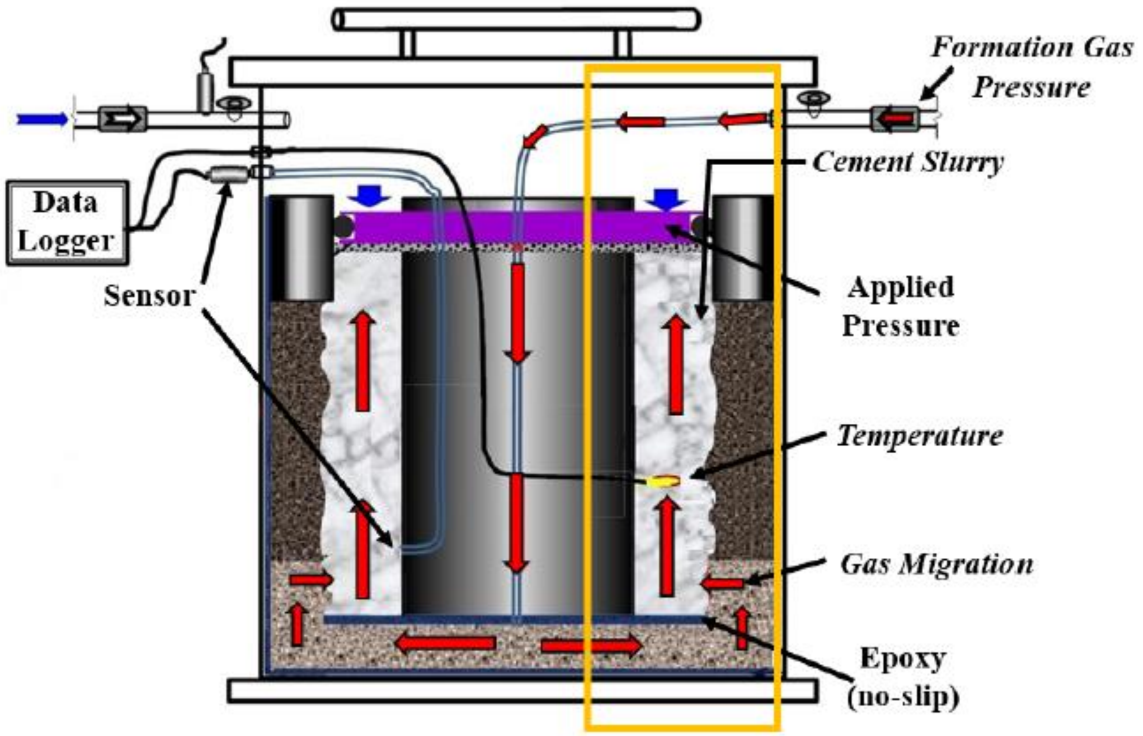
Sharifi, Vandenbossche, Iannacchione, Brigham, Rosenbaum, 2023

Plugging and Completions with Portland Cement – Addressing Gas Migration

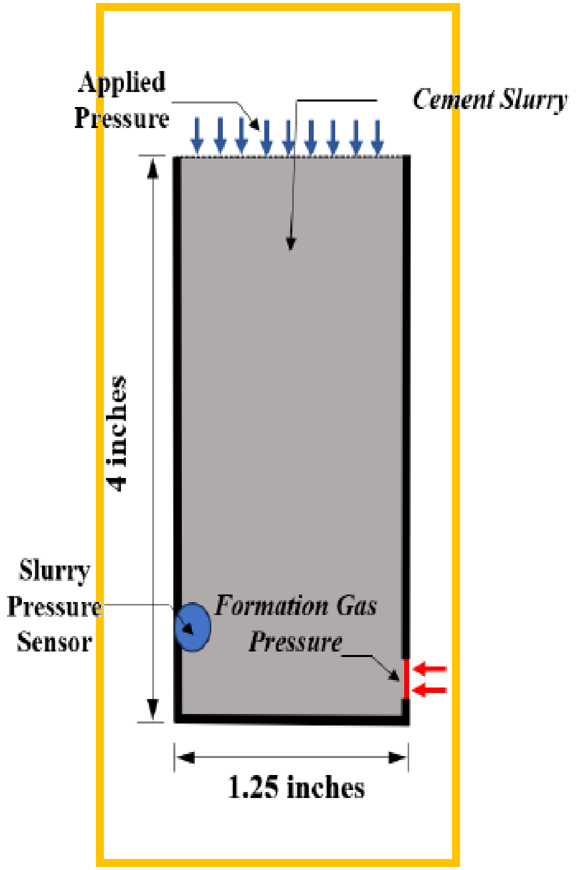
Lattice Boltzmann Simulation

Multi-Component/Multi-Phase Lattice Boltzmann Method

Simulated two fluids interacting: cement slurry and formation gas

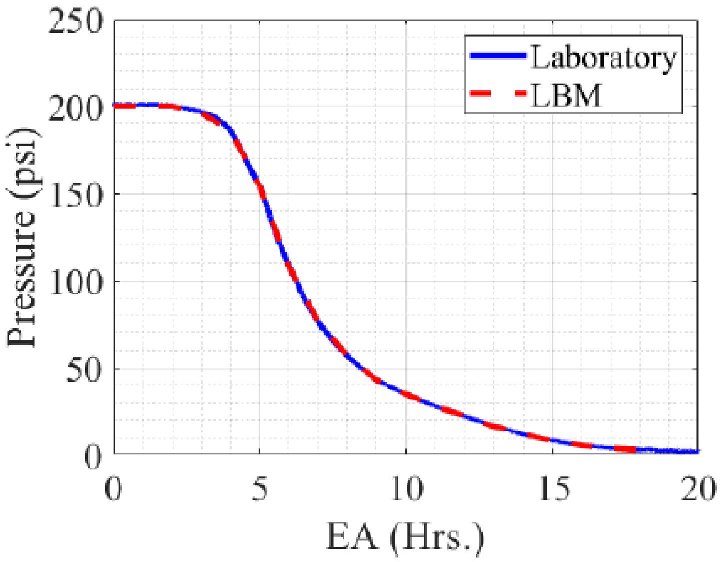


Wellbore Simulation Chamber (WSC)



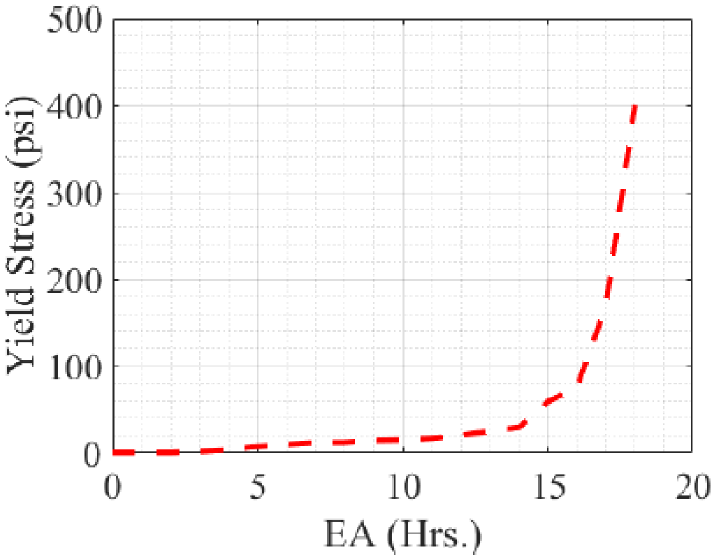
2D Simulation
Representing Experiments from WSC

Plugging and Completions with Portland Cement – Addressing Gas Migration



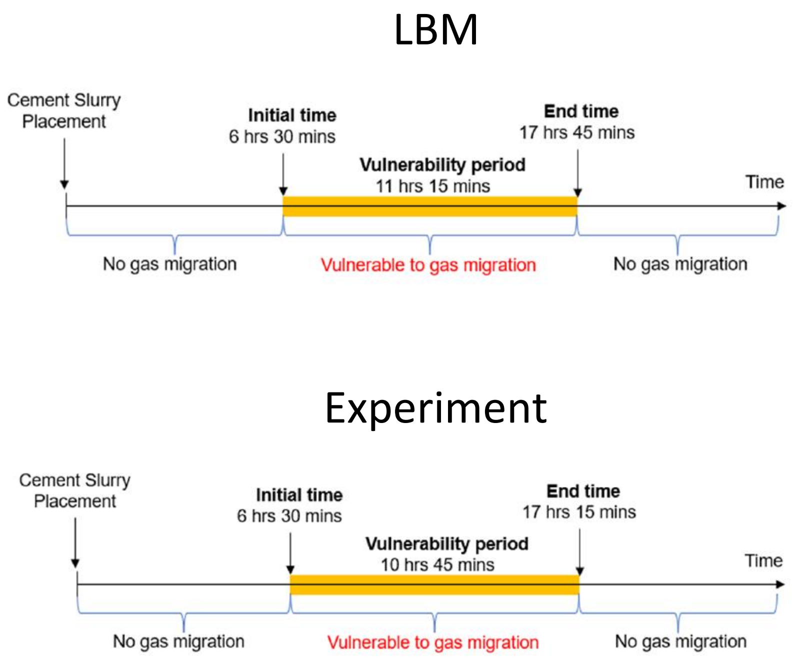
Pressure vs. Equivalent Age

Experimentally measured pressure (bottom of the cement slurry domain) and estimated pressure from the LBM simulation after calibration of the cement slurry yield stress.



Yield-stress vs. Equivalent Age

Estimate of the cement slurry yield stress with respect to equivalent age.

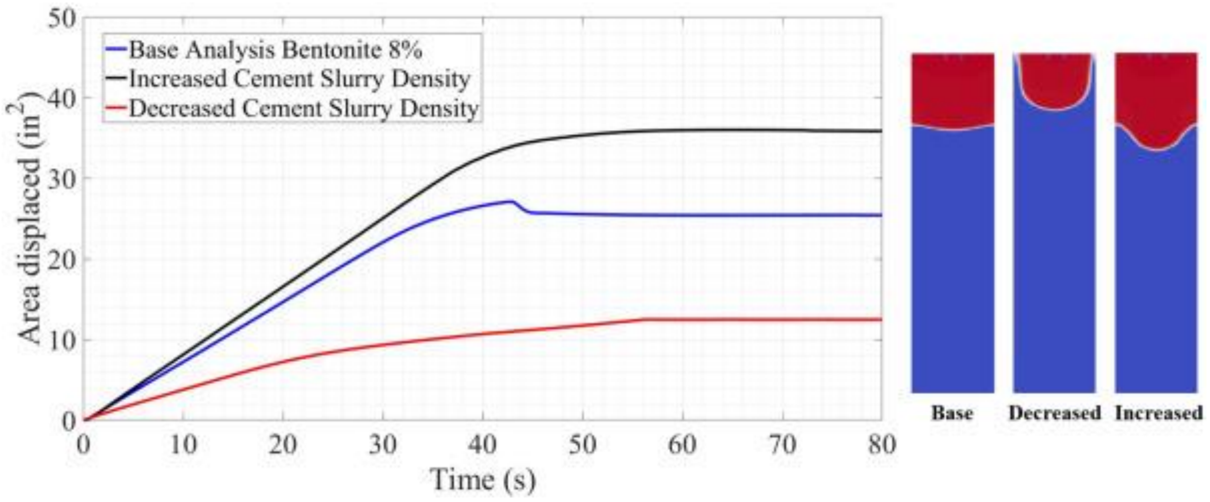


Garcia, Rosenbaum, Grasinger, Vandenbossche, Iannacchione, Brigham, "Simulation of Gas Migration Enhancing Wellbore Integrity and Zonal Isolation using the Lattice Boltzmann Method", Submitted for Publication.

Summary

Recommendations for New Process/Code Requirements

- At least 8% bentonite mix concentration (tested for: powdered sodium bentonite cement additive, Quik Grout, Ben Seal) was shown to support the cement for diameters up to 4 inches. 10% Bentonite Concentration for well diameters over 4 inches.
- *Recommended Process* for plugging with gel spacer: Fill the well with bentonite mix first, allow it to hydrate, then inject the cement in the producing zones. → Reduces rig time and cost.
- Brine water in the well was not shown to impact bentonite plug unless thoroughly mixed with bentonite – e.g. in mix water.
- Gas migration can be predicted for specific slurry and pressure conditions. LBM simulations verified to give results that match experiments → Can be used to efficiently test different conditions.



Bentonite 8% Concentration
Density: 0.0383 lbs/in^3
Yield Stress: 8.70 x 10^{-4} psi
Plastic Viscosity: 10.0 cP

Cement Properties
Density: 0.0708 lbs/in^3
Yield Stress: 3.2 x 10^{-4} psi
Plastic Viscosity: 220 cP

Thank You

For more information, please contact me:
eilis.rosenbaum@netl.doe.gov

Muse Well #1 (top)
Cementing (bottom)

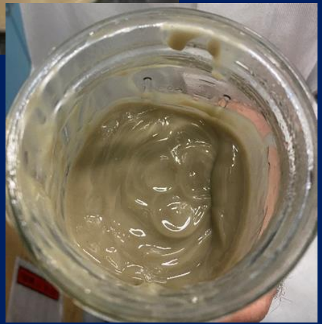
Standard Well and Plugging Materials Disadvantages

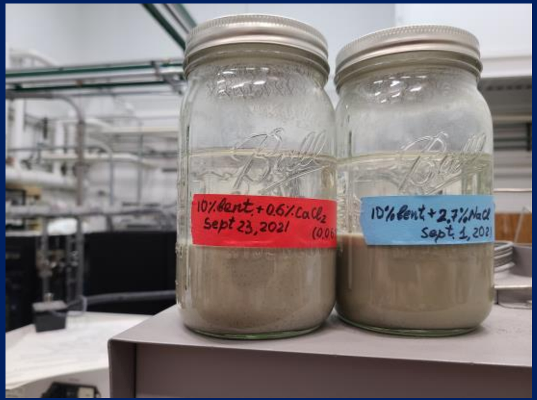
Portland Cement:

- Prone to Shrinkage
- Gas migration during hydration
- Properties altered with additives
- Hydration products and other properties of cement mixes not always known
- Production: ~8% CO_2 emissions

Sodium Bentonite Gel:

- Prone to precipitate and destabilize when mixed with small amounts of salt (mix water, brine in well, etc.)
- Supply?
- Gas migration?



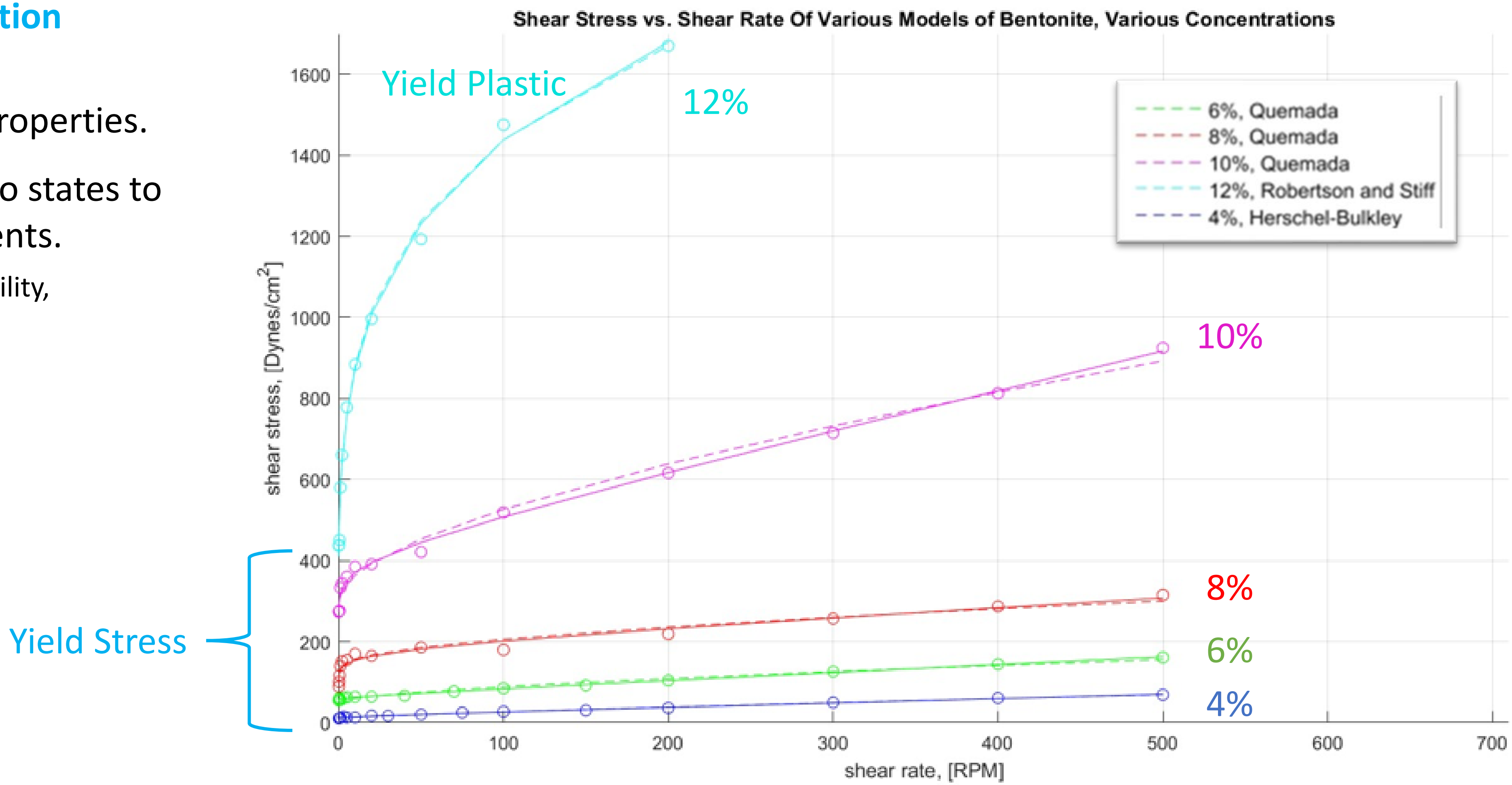


Plugging with Cement and Bentonite

Plugging Material Characterization

- Identify required material properties.
- Provide recommendations to states to develop plugging requirements.
    - e.g. viscosity, density, permeability, compressive strength, etc.

10% Bentonite in water



Headrick, E.; Spaulding, R.; Rosenbaum, E.; Massoudi, M.; Kutchko, B. The Effects of Conditioning and Additives on the Viscosity Measurement of Cement Slurries; DOE.NETL-2022.3352; NETL Technical Report Series; U.S. Department of Energy, National Energy Technology Laboratory: Pittsburgh, PA, 2023; p 32. DOI: https://doi.org/10.2172/1987484