

**SMALL SCALE FIELD TEST DEMONSTRATING CO₂
SEQUESTRATION IN ARBUCKLE SALINE AQUIFER AND
BY CO₂-EOR AT WELLINGTON FIELD
SUMNER COUNTY, KANSAS
DE-FE0006821**

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National Energy Technology Laboratory

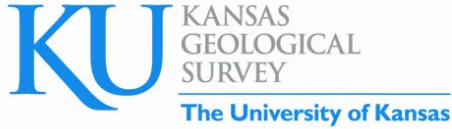
Morgantown, WV
Monday, March 20, 2017



U.S. DEPARTMENT OF
ENERGY



Project Team



**DOE-NETL Contract
#FE0006821**



Project established November 2011

David Cercone, P.M.

L. Watney (Proj. Manager, Joint PI), Y. Holubnyak (Joint PI),
J. Hollenbach (Asst. Project Manager), T. Bidgoli, B. Campbell,
J. Doveton, M. Fazelalavi, D. Newell, John Victorine
*(static & dynamic modeling, petrophysics, well test analysis,
install/maintain seismometer array, Structural, geochemical,
geomechanical analysis, project management)*



Dana Wreath, Adam Beren
(field operator and operations)



Tom Daley, Barry Freifeld
(CASSM, U-Tube for Arbuckle Class VI geosequestration)



CO₂ supplier



T. Birdie *(aquifer modeling, EPA Class VI permit)*

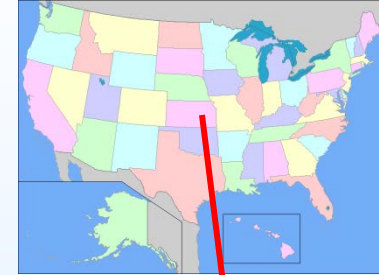


Jennifer Roberts, Leigh Sterns, George Tsoflias,
B. and K. Graham, A. Nolte, D. Schwab, B. Norwood
InSAR-cGPS, active and passive seismic, geochemistry

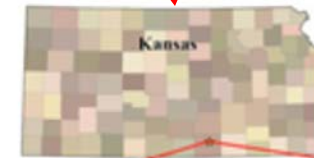


Presentation Outline

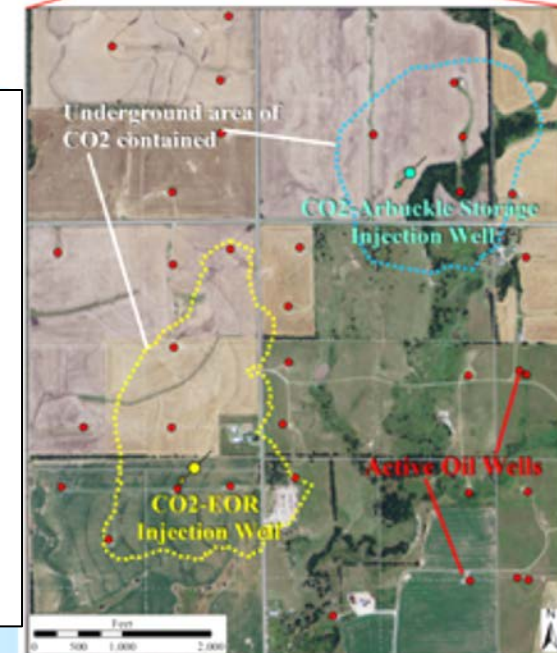
1. Project Overview
2. Benefits to the Program
3. Technical Status
4. Future Plans and Expectations



Wellington Field Sumner County Kansas



- Oil field in rural area operating since 1929
- 55 wells, 21 million barrels produced, 46,000 barrels annually
- Effective waterflood, ready for CO₂-EOR
- **Phase I** – Completed June 21, 2016 → 20,000 tonnes CO₂ injected into Mississippian dolomite for EOR
- **Phase II** – 26,000 tonnes CO₂ into Arbuckle saline aquifer, pending Class VI permit (2017)



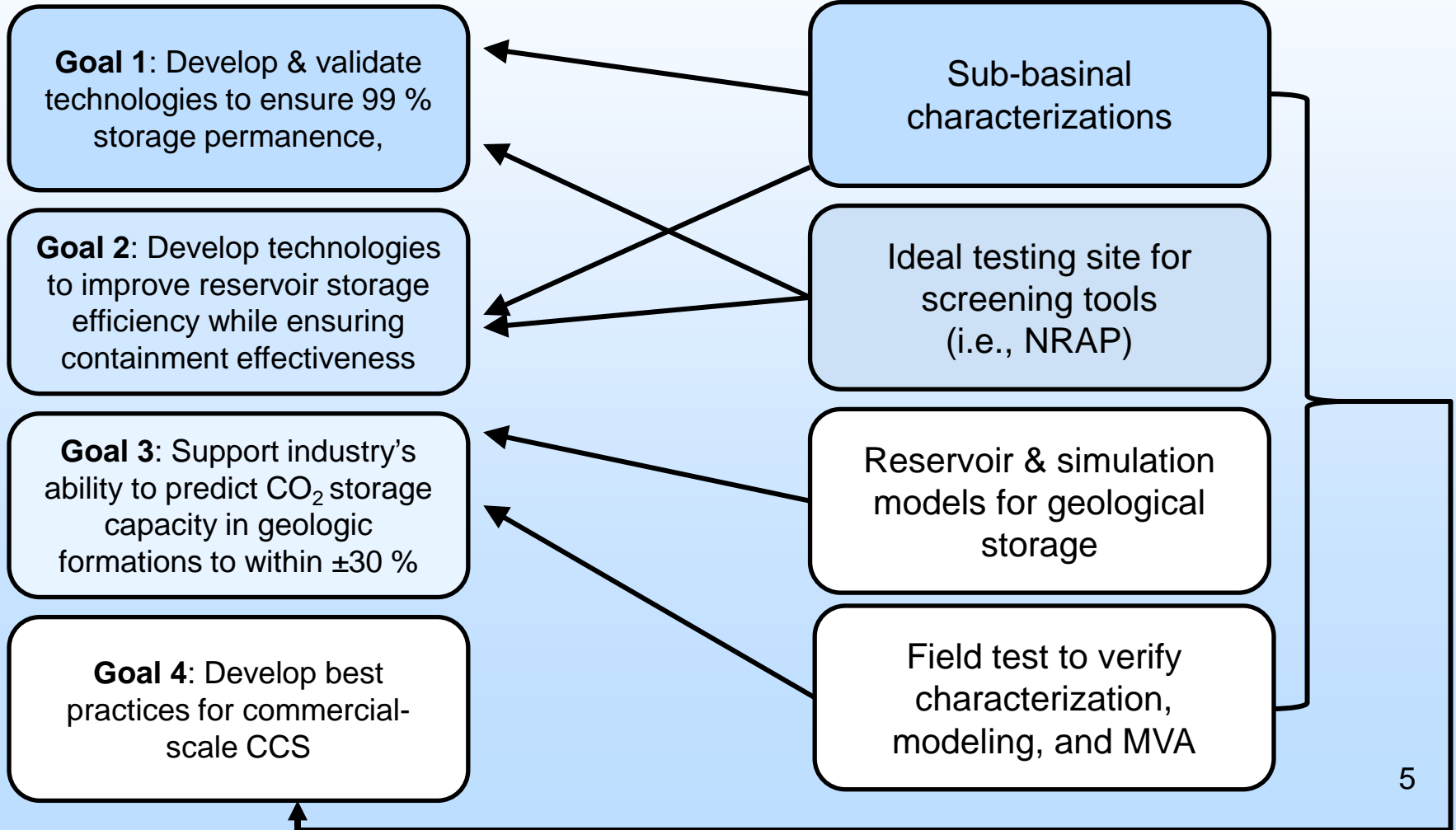
Project Objectives

- Test Monitoring, Verification, and Accounting (MVA) technologies - partially addressed
 - National Labs tools:
 - U-Tube
 - Continuous Active-Source Seismic Monitoring (CASSM)
 - Other methods:
 - Surface and reservoir water analysis
 - 18- seismometer array for passive seismic
 - cGPS and InSAR
 - 2D and 3D Seismic
- CO₂ storage through EOR and saline aquifer
- Commercialization plan
- Technology transfer
- US EPA UIC Class VI permit application – added by Brian Dressel
- Suggested new objective: test NRAP tools – suggested by Brian Dressel

Benefits to the Program

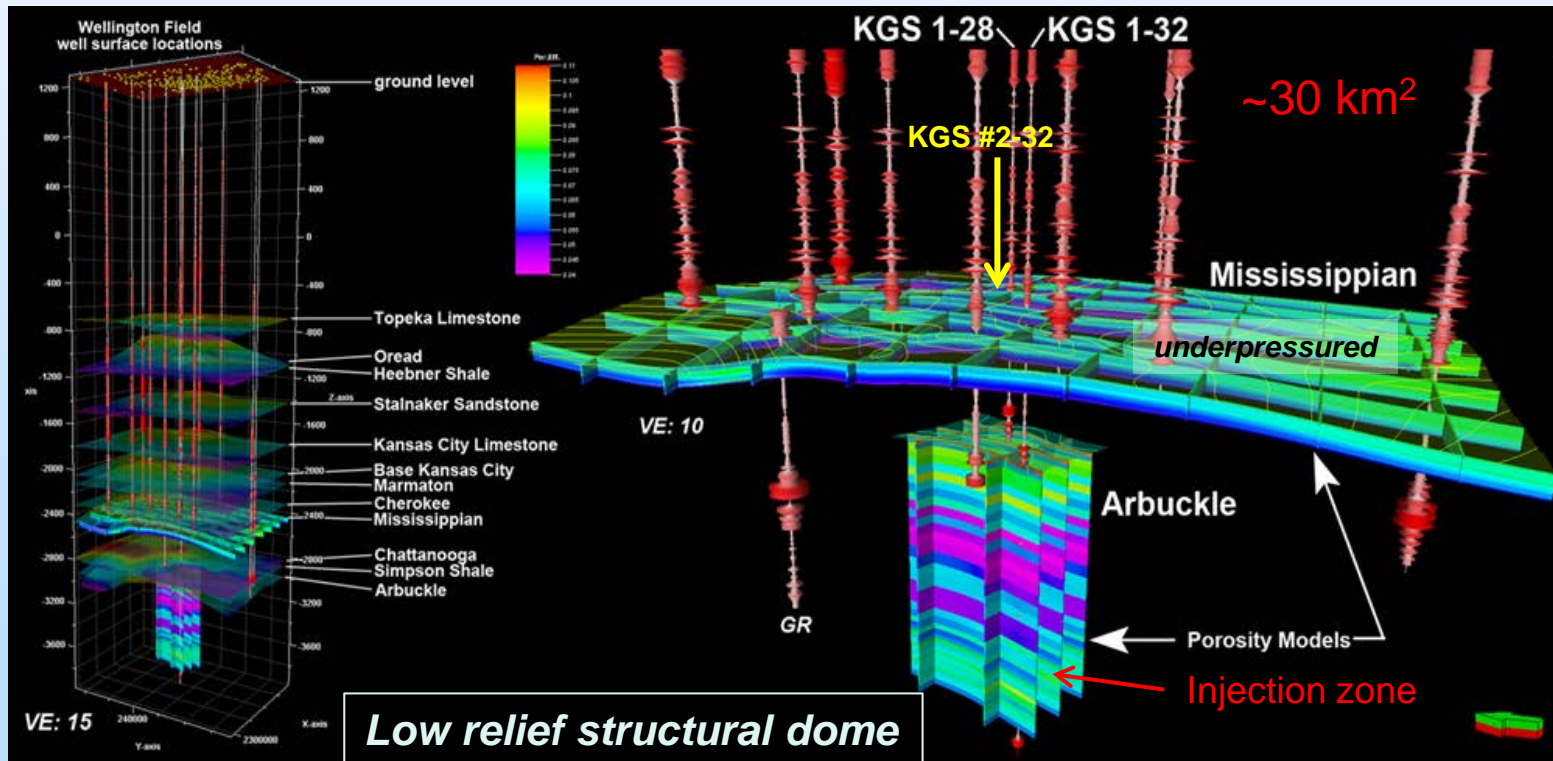
DOE Program Goals

This Study



Benefits to the Program

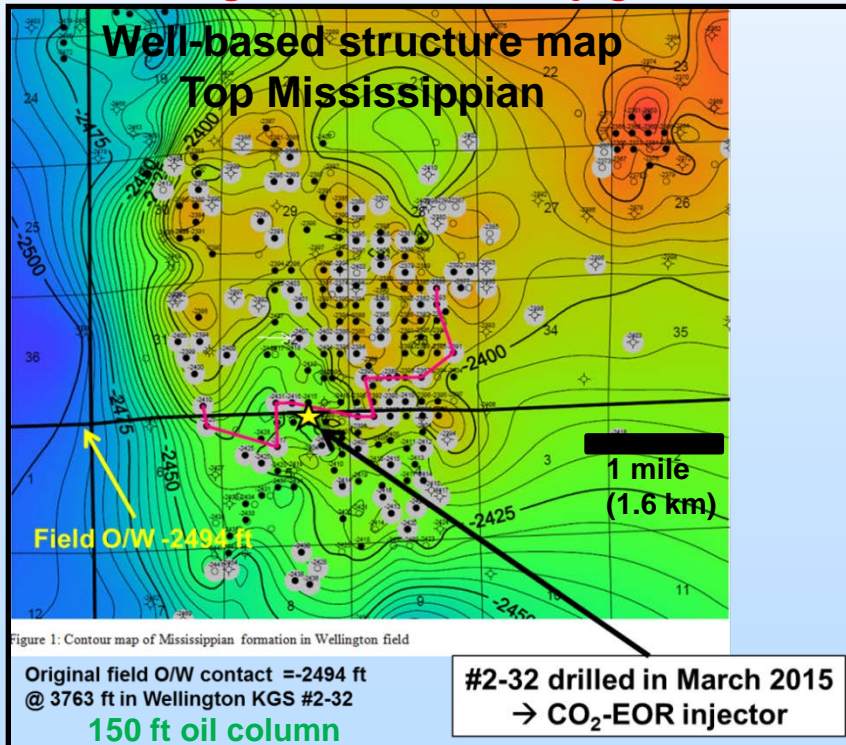
- **Demonstrate that 99 percent permanence of injected CO₂**
 - 20,000 metric tons tonnes injected into KGS #2-32 into *Late Mississippian siliceous dolomite reservoir* between January 9 and June 21, 2016 → CO₂ plume and EOR response as forecast by model (**Class II UIC permit**)
 - 20,000 metric ton injection into underlying *Lower Ordovician Arbuckle Group dolomitic saline aquifer* (**Pending Class VI UIC permit**)
- **Demonstrate reliable and cost effective MVA (monitoring, verification, and accounting) tools and techniques**
- **Develop best practices for effective and safe CO₂-EOR and CO₂ saline storage**



Technical Status

Task 15. Evaluate Potential to Move Oil and Optimize for Carbon Storage

- Begin CO₂ injection into KGS #2-32 on January 9, 2016
- Completed injection on June 21, 2016
- 1,101 truckloads, 21,784 US tons, 19,803 metric tons, average of 120 tonnes per day, approximately 374,000 MCF of CO₂
- Total expenditures for purchasing CO₂ were \$1,964,000. Our overall price for CO₂ was \$90.16 per US ton from *Linde Group*
- **Behaving as forecasted by gemodel/simulation**

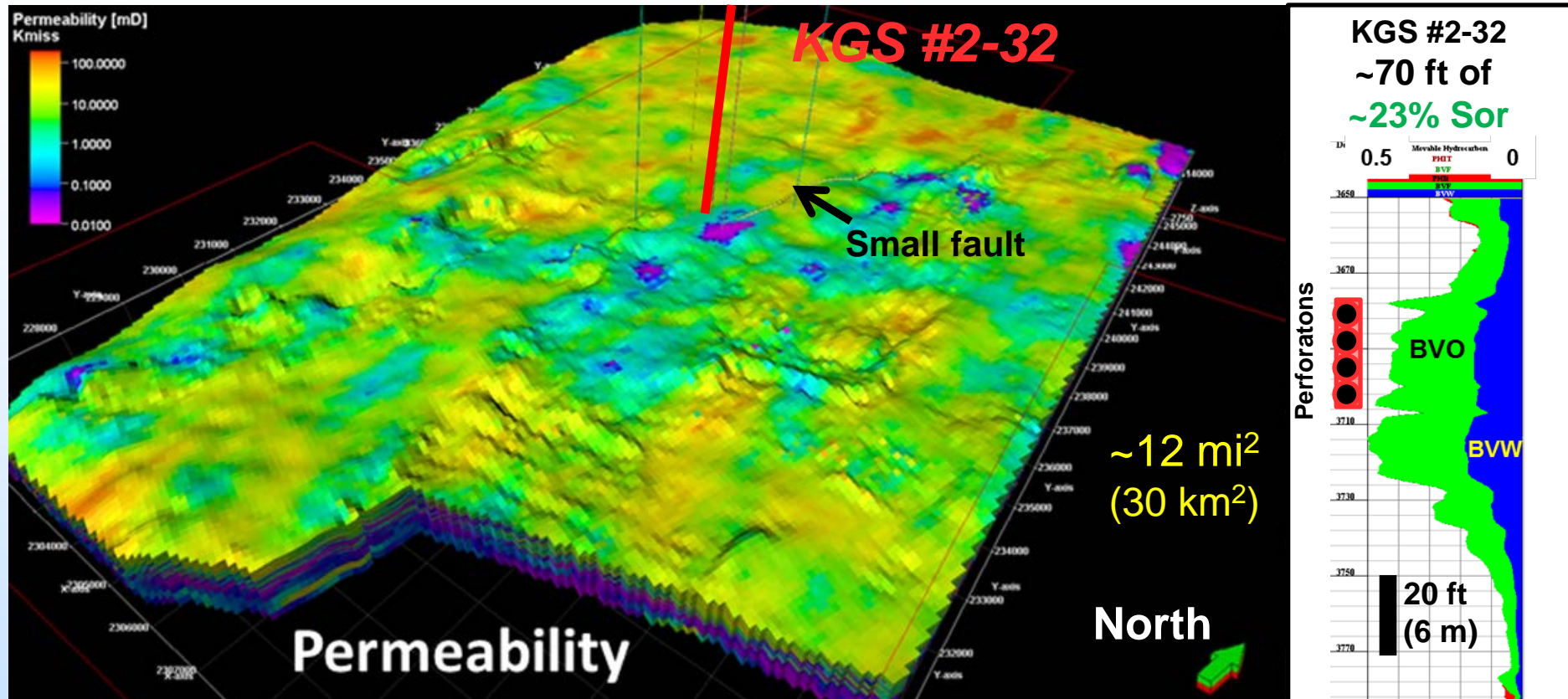


Monitoring technologies during Class II injection

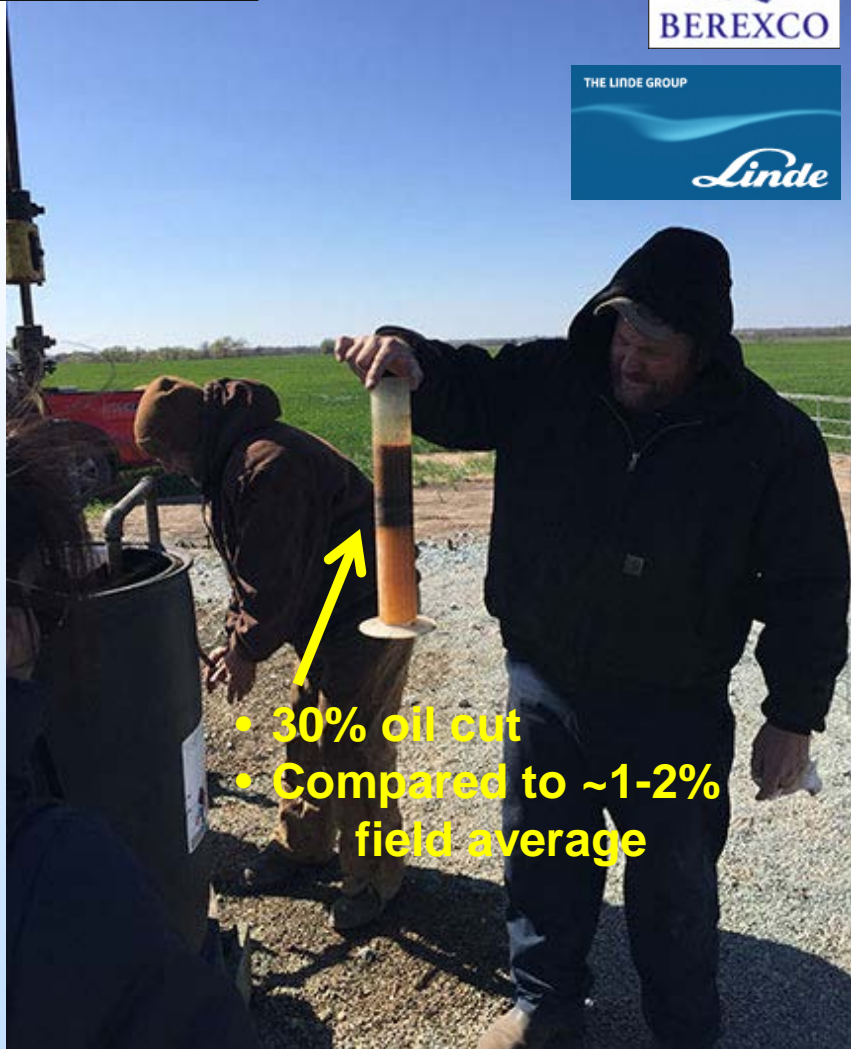
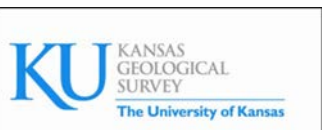
- 1) Surface water analysis
- 2) 18- seismometer array for passive seismic
- 3) cGPS and InSAR
- 4) Weekly analysis of 17 wells surrounding injector
- 5) Repeat 2D seismic survey (July 2016)
- 6) Post-CO₂ injection well performance around Class II well
- 7) Arbuckle pressure monitoring since April 2016



Targeted area → High CO₂-EOR potential



- Petrel map of permeability distribution in the Mississippian dolomite
- CO₂ injection well is red vertical line
- Lower permeability noted east and south of the injection well, Berexco Wellington KGS #2-32
- Residual oil saturation in cored injection well averages 23%



- 30% oil cut
- Compared to ~1-2% field average

Wellington Field small scale CO₂-EOR
Jason Bruns above (Caanon Well Services) and Dana Wreath upper right (VP Berexco, LLC) with KGS staff



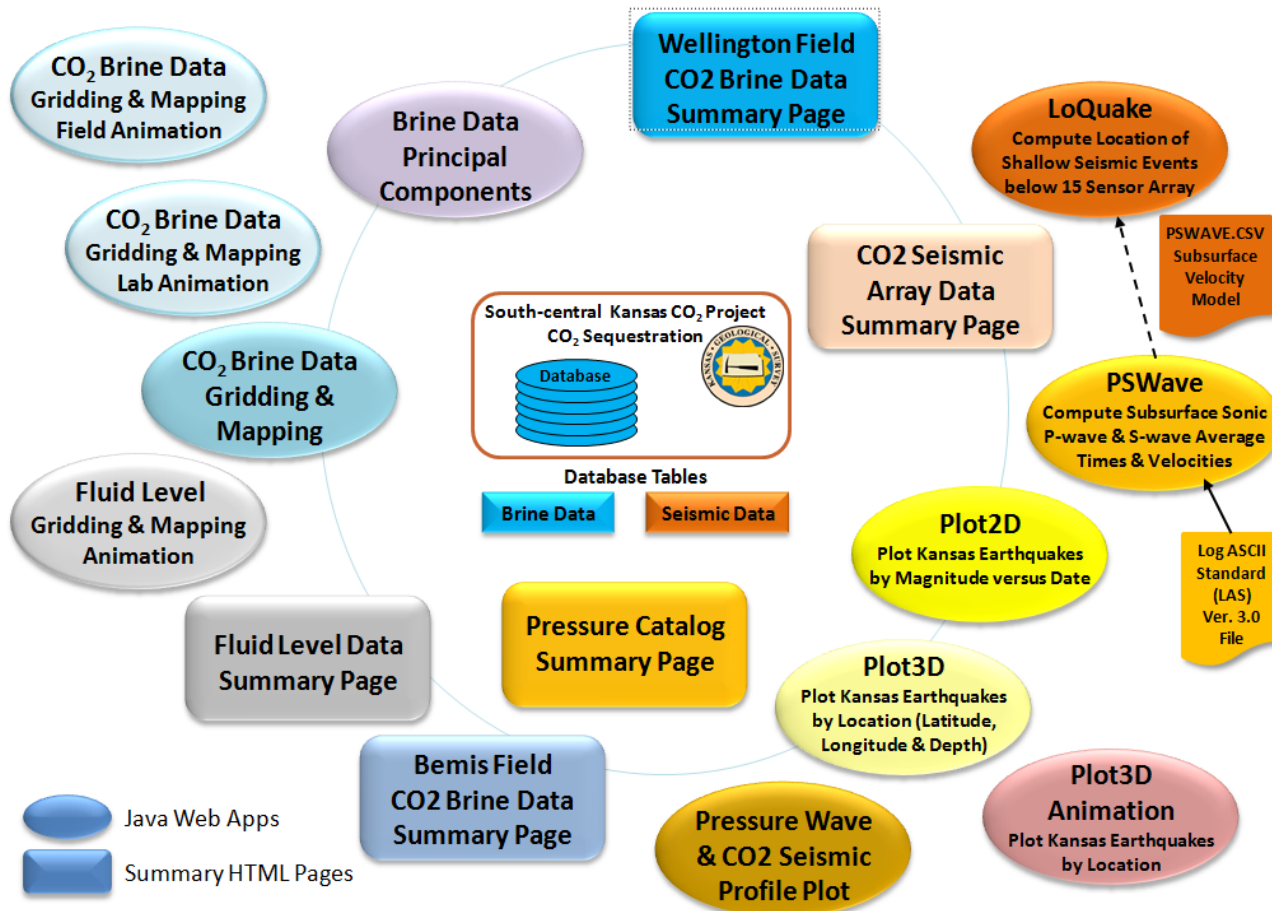
SCADA System installed on wells

Web Applications Built to Display and Analyze Data “in Real-Time” by the Team During Monitoring → time lapse maps, cross plots, analytical tools, csv download

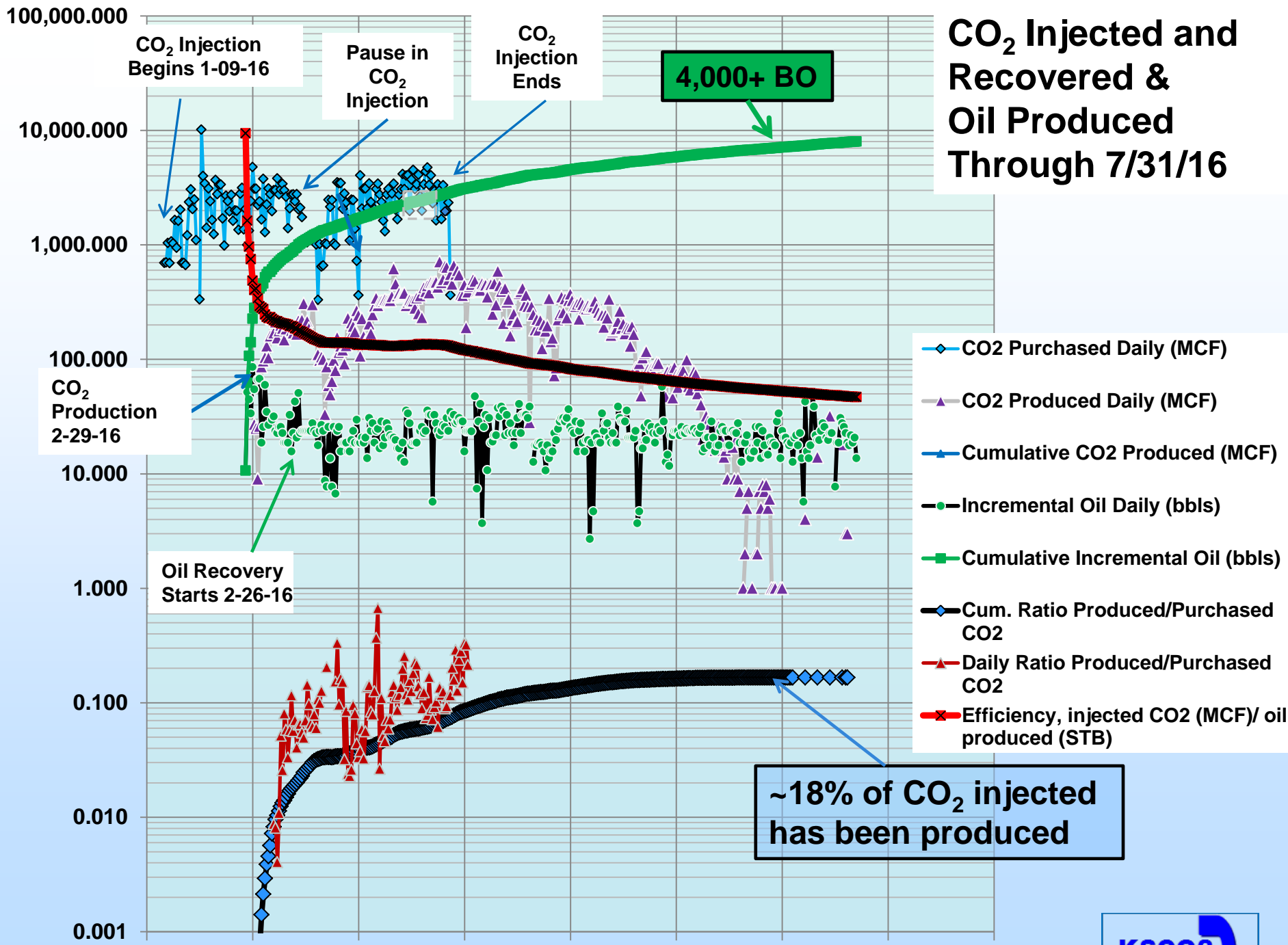


South-central Kansas CO₂ Project CO₂ Sequestration Summary Pages and Web Apps

Select the bubble button below to display respective module.



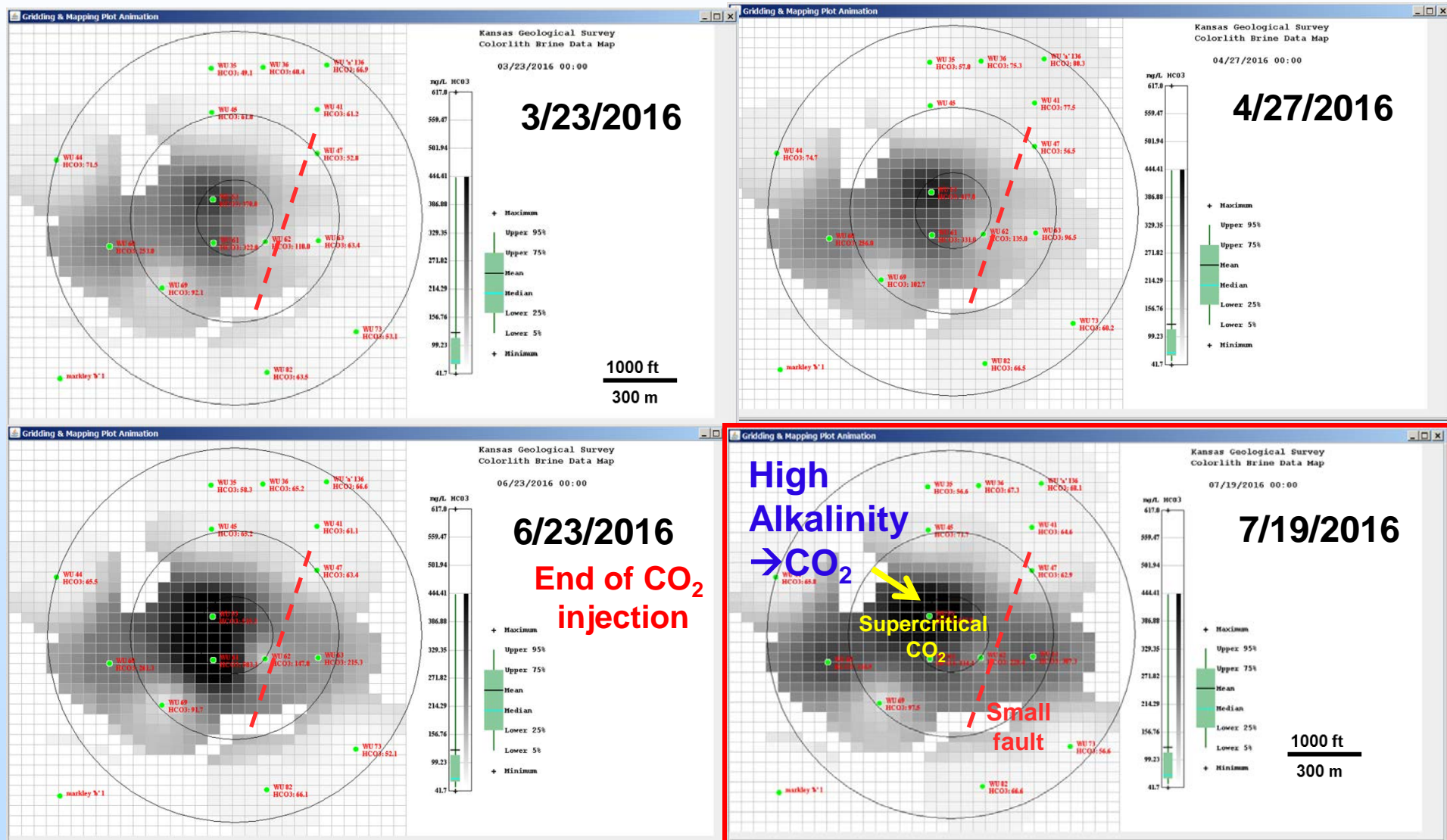
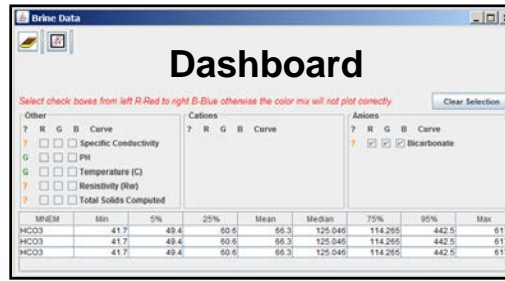
CO₂ Injected and Recovered & Oil Produced Through 7/31/16



- ◆ CO₂ Purchased Daily (MCF)
- ▲ CO₂ Produced Daily (MCF)
- ▲ Cumulative CO₂ Produced (MCF)
- Incremental Oil Daily (bbls)
- Cumulative Incremental Oil (bbls)
- ◆ Cum. Ratio Produced/Purchased CO₂
- ▲ Daily Ratio Produced/Purchased CO₂
- × Efficiency, injected CO₂ (MCF)/ oil produced (STB)

Time Lapse Alkalinity

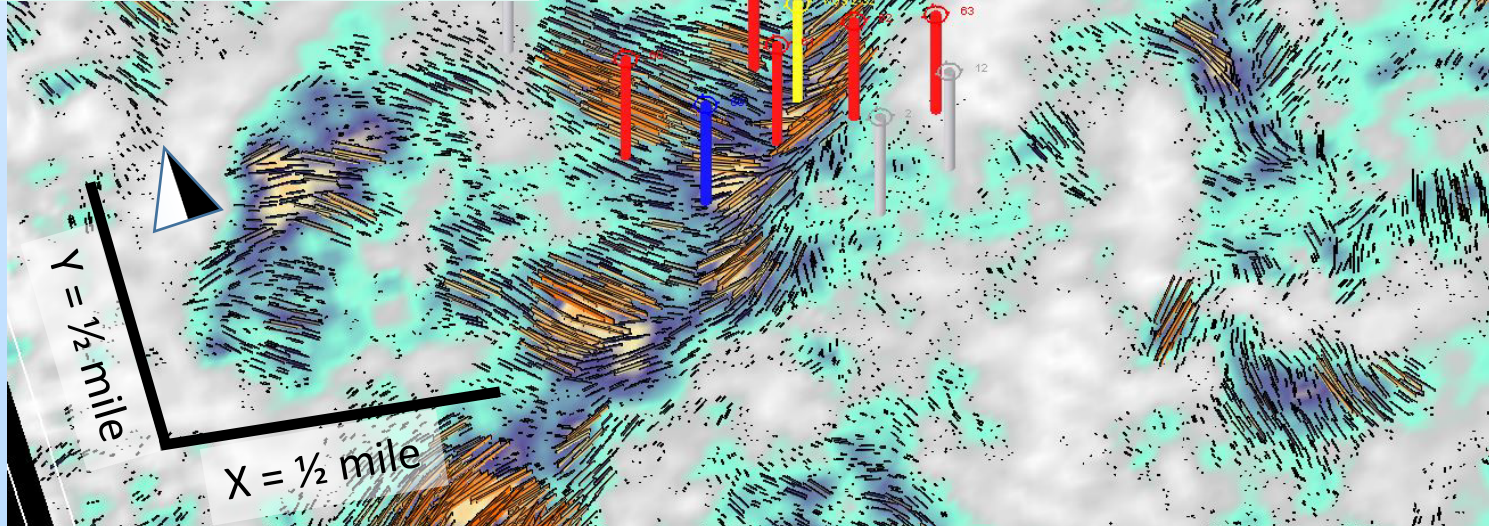
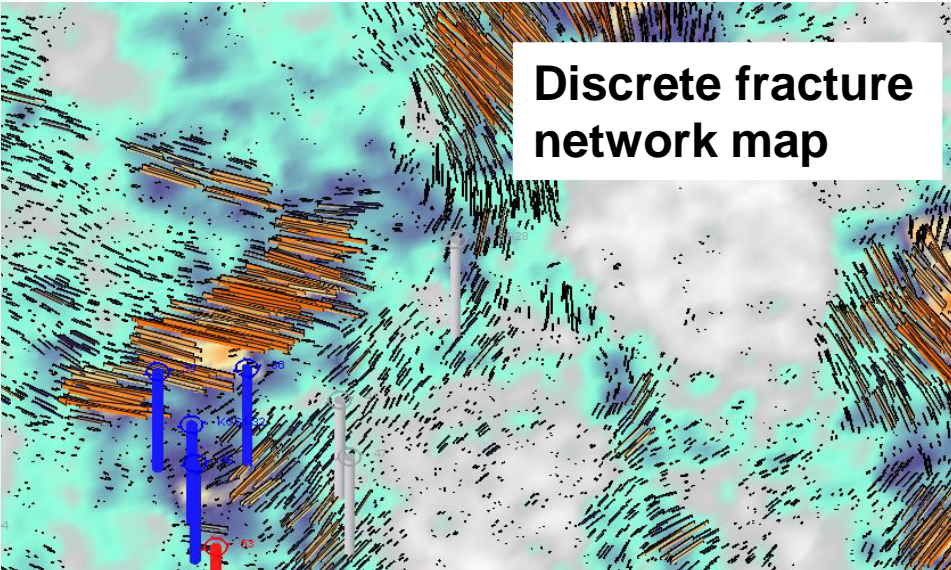
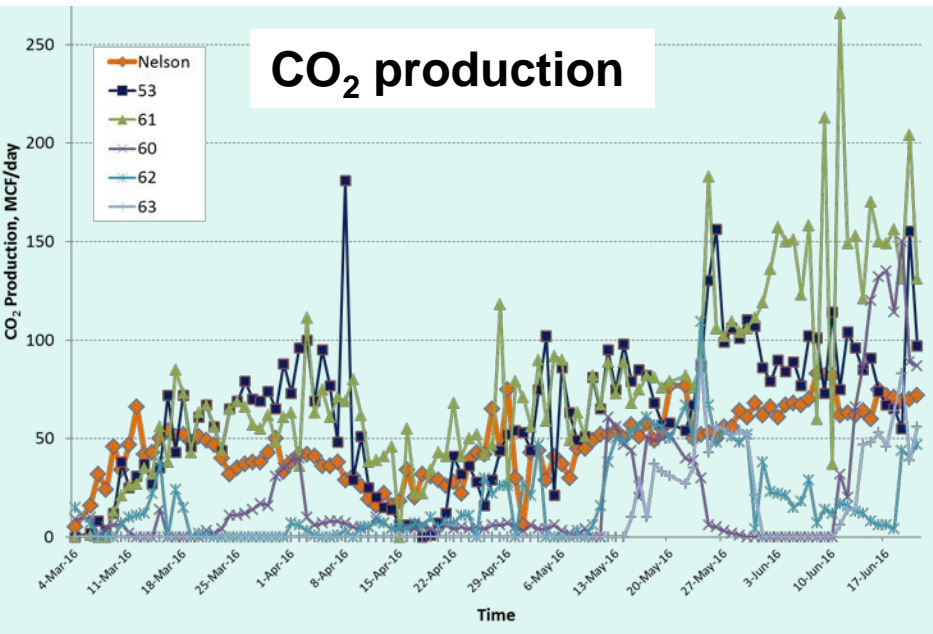
-- During and Post CO₂ Injection



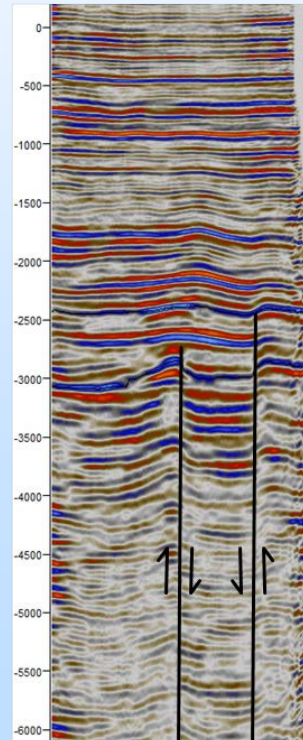
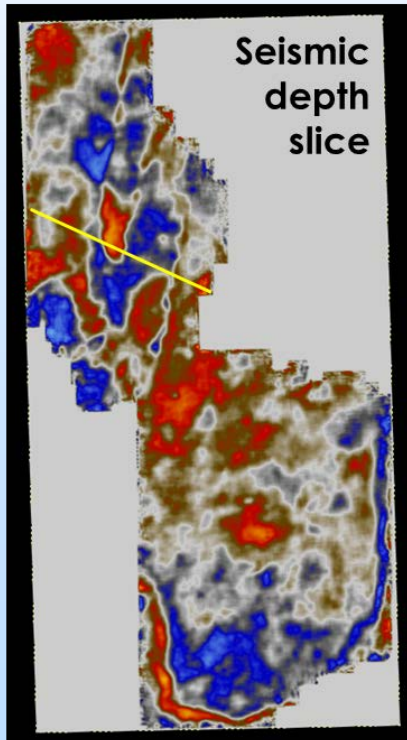
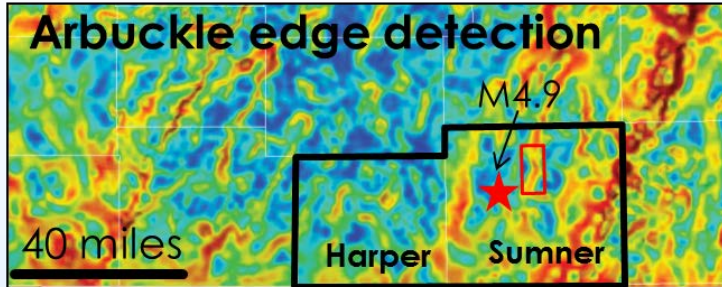
Re-processed 3D seismic analysis: discrete fracture network vs. field CO₂ MVA data

T₅ = June 17, 2016

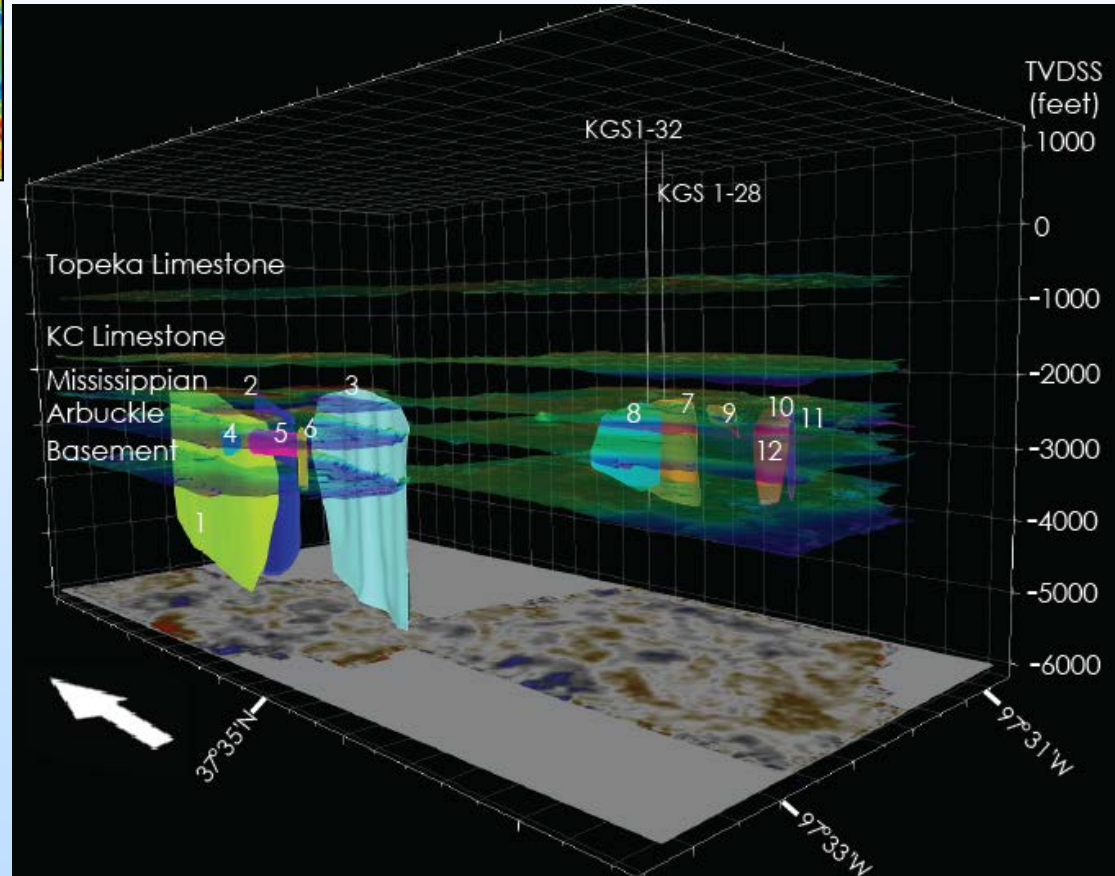
- █ KGS 2-32 Injection well
- █ Significant CO₂ production
- █ Detection of CO₂
- █ No detection of CO₂



Faults cut Mississippian, Arbuckle, and basement



Wellington-Anson Bates Fields, Sumner Co.



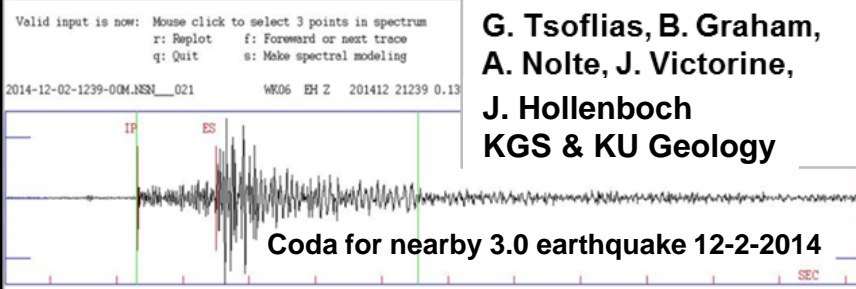
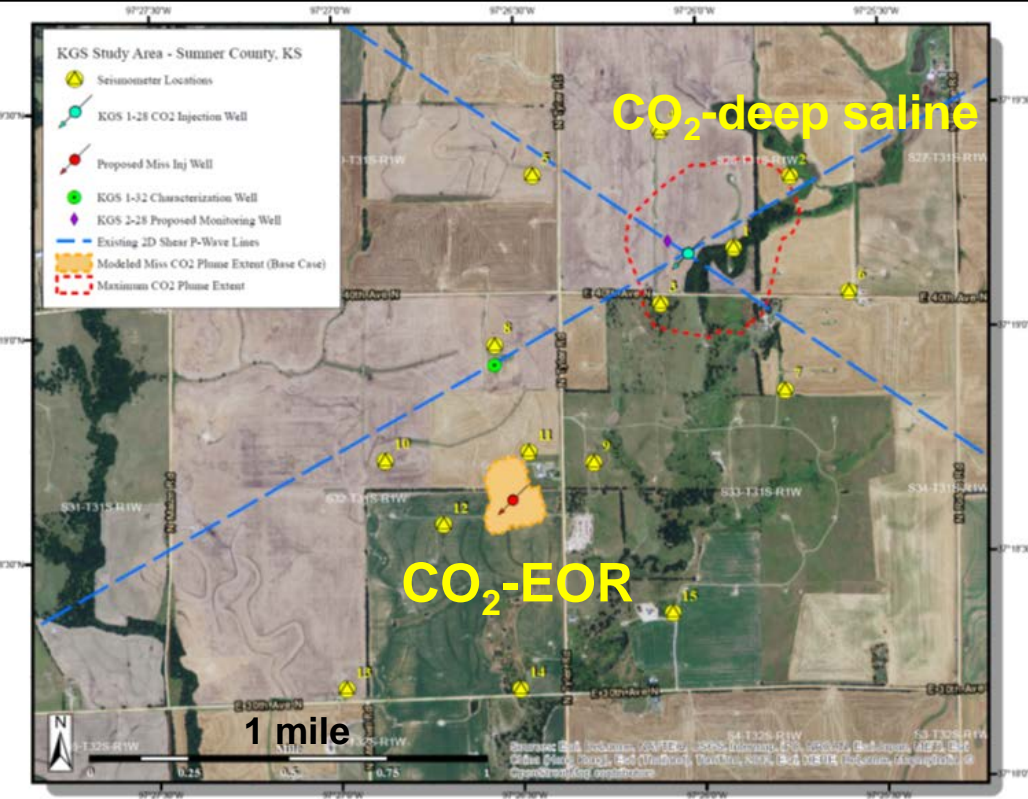
Milestone 3. Pre-injection MVA baseline recording

- ❑ 18 seismometer array since Fall 2014
- ❑ cGPS and inSAR for processing since August 2014
- ❑ Five shallow monitoring wells around KGS #1-28 and domestic wells in vicinity
- ❑ Weekly baseline geochemistry and production data from 17 wells during CO₂-EOR
- ❑ Static bottom hole pressure in lower Arbuckle from KGS #1-28 since April 2016

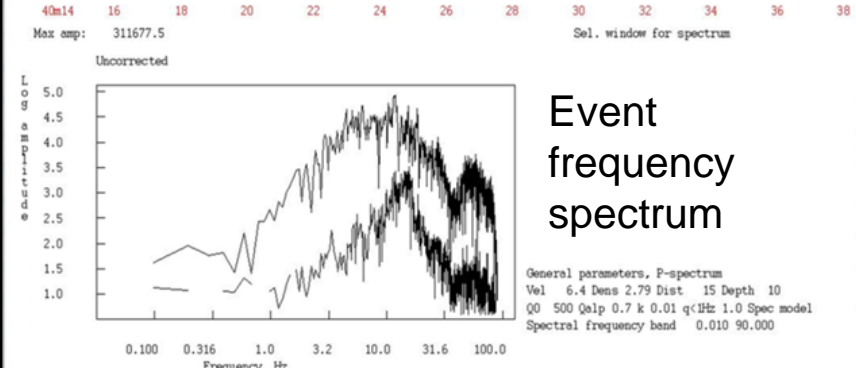


Housing setup for Sercel (Mark Products) L-22D-3D sensors, ~5 ft below surface to minimize surface noise; installed below frost line in bedrock

R. Miller & S. Petrie, KGS installation

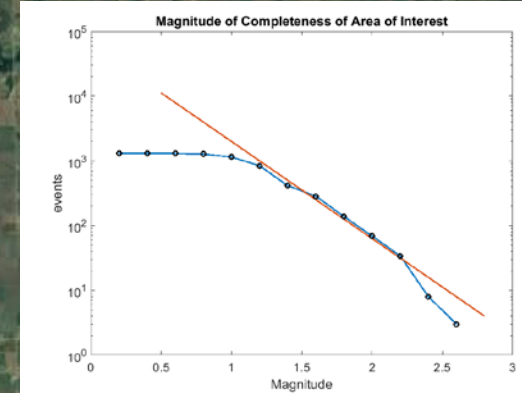
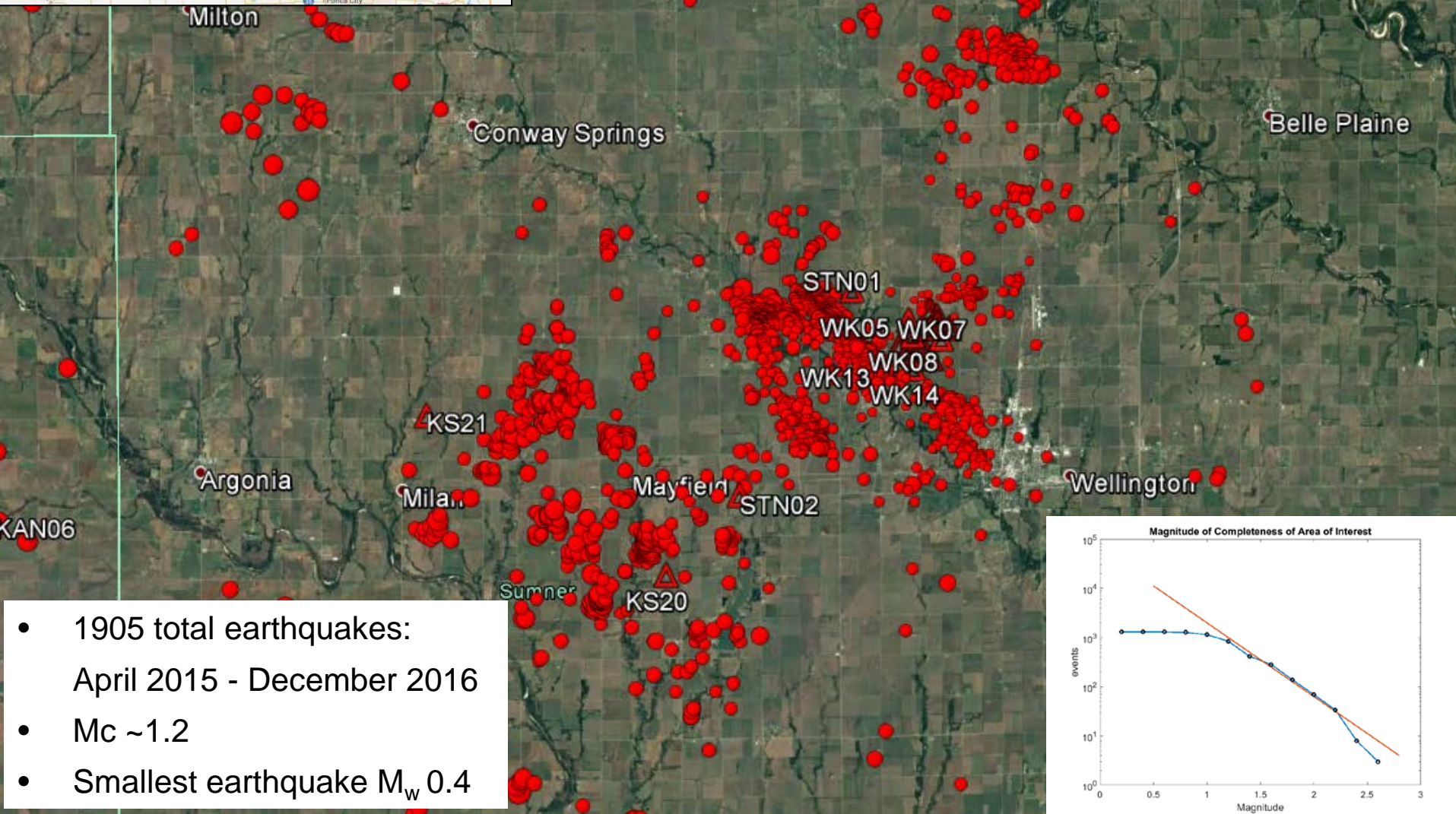


G. Tsoflias, B. Graham,
 A. Nolte, J. Victorine,
 J. Hollenboch
 KGS & KU Geology



Earthquake Catalog

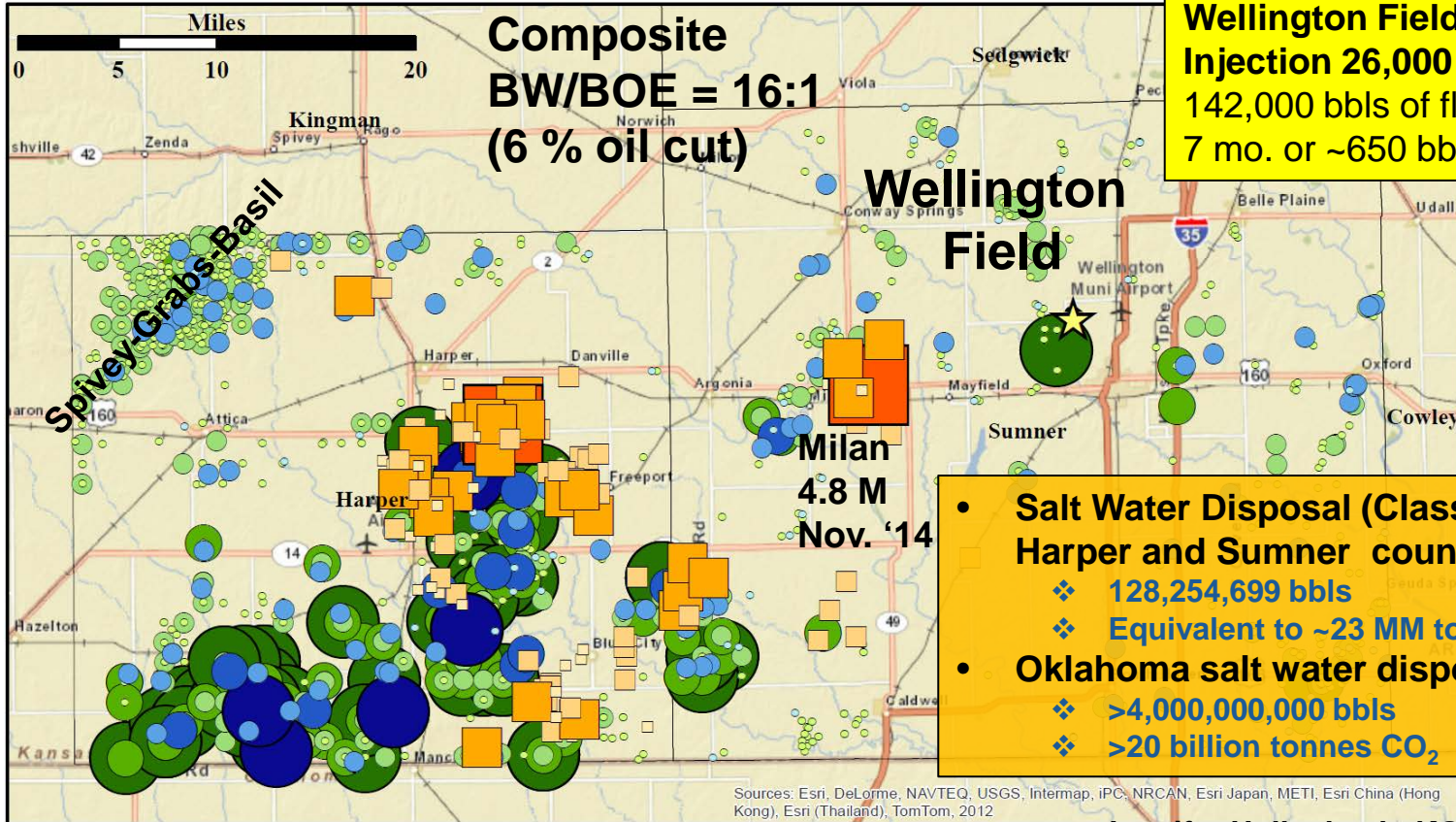
No earthquake has been detected within Wellington field in association with the CO₂ injection in KGS #2-32



- 1905 total earthquakes:
April 2015 - December 2016
- $M_c \sim 1.2$
- Smallest earthquake M_w 0.4

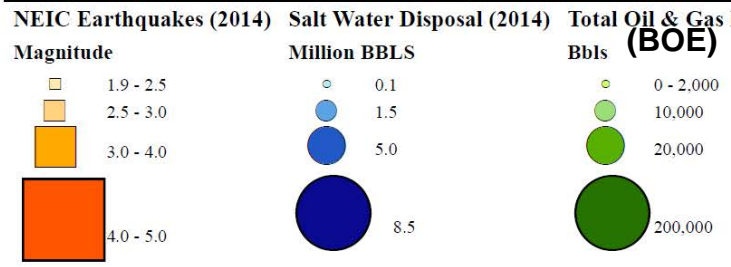
Induced Seismicity Southwest of Wellington Field

Total salt water injected by well (●), BOE produced by oil lease (●) and earthquakes (■) in 2014, Harper and Sumner Counties, Kansas

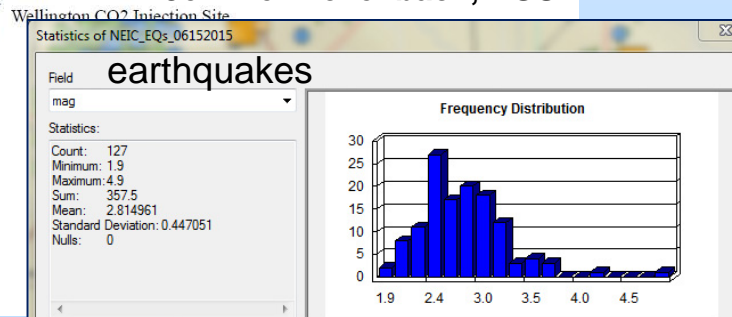


- **Salt Water Disposal (Class II) in Harper and Sumner counties in 2014**
 - ❖ 128,254,699 bbls
 - ❖ Equivalent to ~23 MM tonnes CO₂
- **Oklahoma salt water disposal in 2014**
 - ❖ >4,000,000,000 bbls
 - ❖ >20 billion tonnes CO₂

Jennifer Hollenbach, KGS

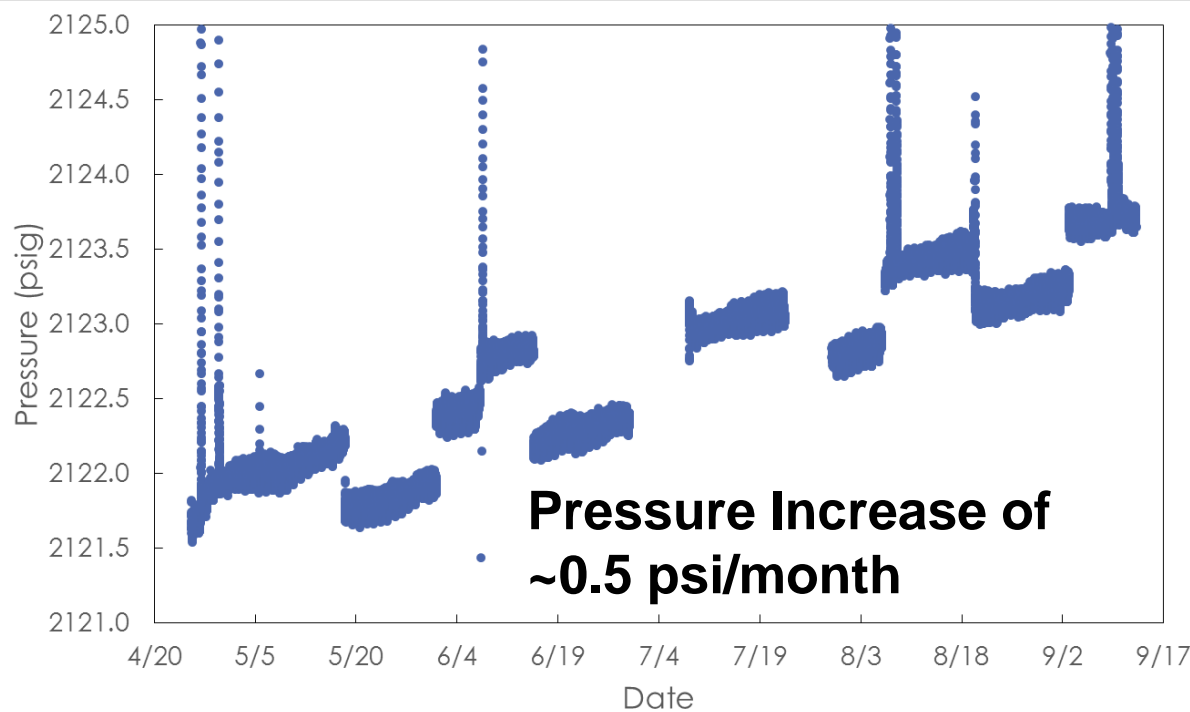


★
Min 1.9
Max 4.8
Mean 2.8
127 earthquakes in 2014

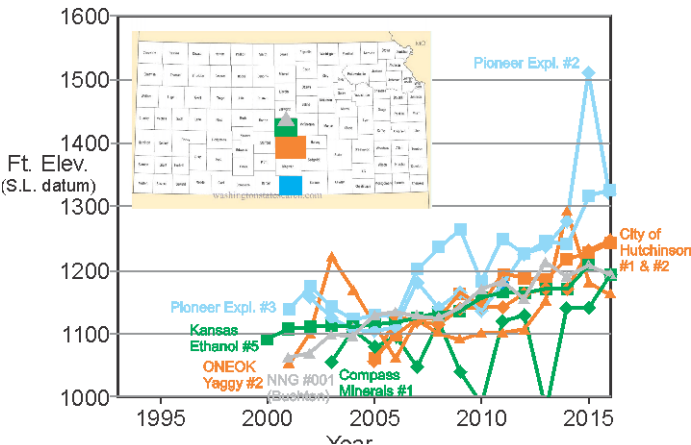


Kansas Regional Pressure Increase

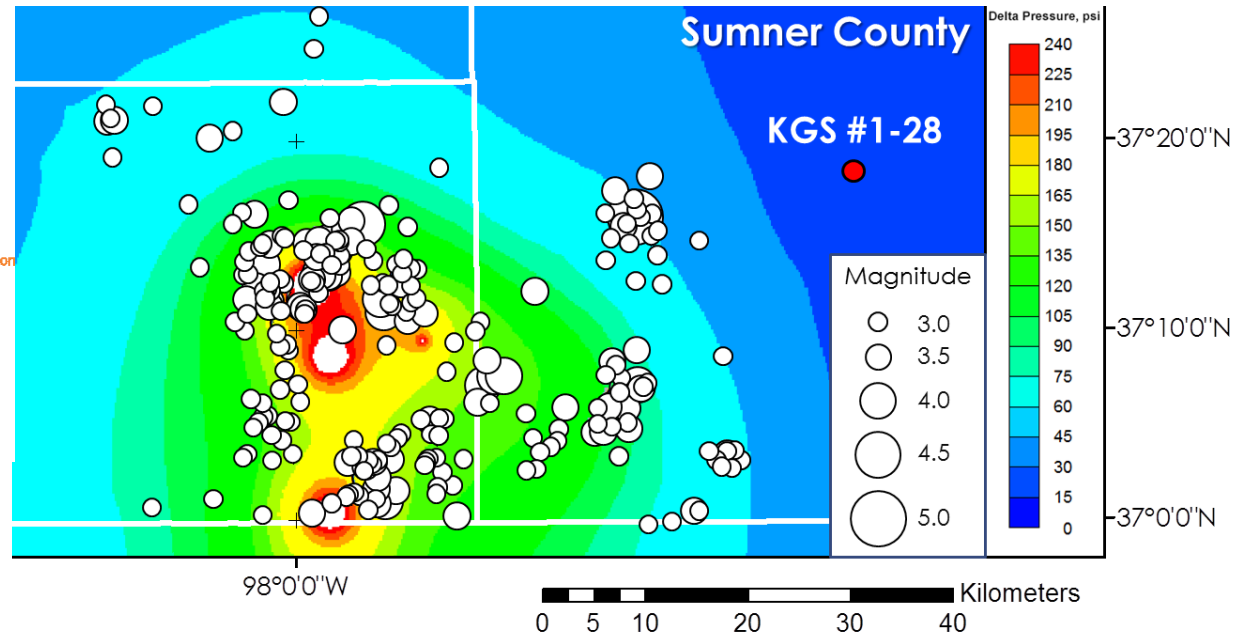
- On 4-25-16, BHP in lower Arbuckle was **+31.4 psig** higher than what was recorded on 8/23/11.
- Since April, 2016 the pressure has risen to **+32.9 psi** → 1.5 psi (0.0147 psi/day or **0.44 psi/mo**).
- Increase in pressure forecast by simulation of 2-county brine disposal
- **Regulators express concerns about storage capacity**



CLASS-I-WELL FLUID LEVELS central KS, north-south comparison



Simulation model: Δ pressure (psi)



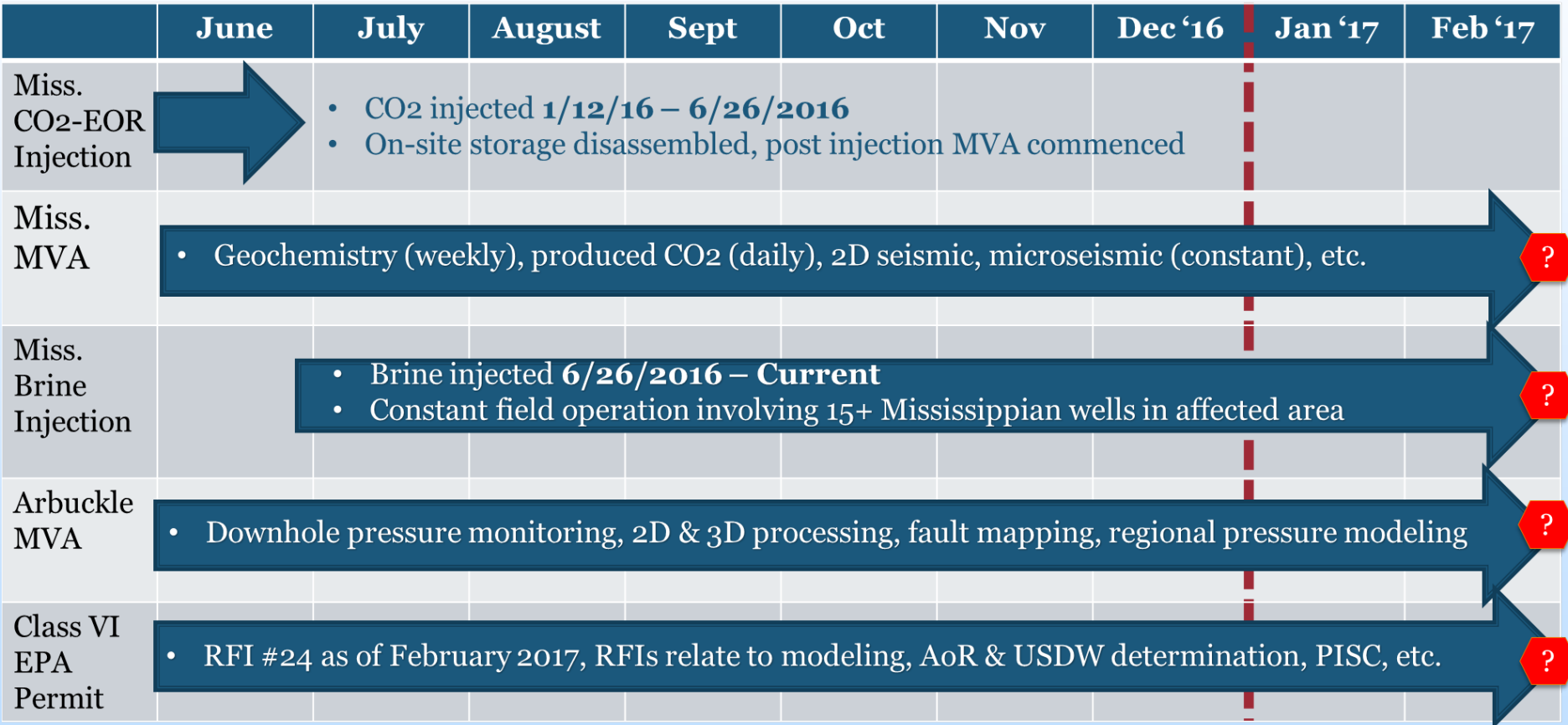
- Pressure increase without changes to injection rate

Accomplishments of the Wellington Project during BP2

ACTIVITIES CARRIED OUT TO DATE BY THE KANSAS TEAM

- Successful CO₂ injection in the Mississippian carried out by Berexco, LLC, Wichita, KS
- Injection done in a highly controlled and monitored environment
- Linde Group, a leader in CO₂ capture and supply, an excellent partner for the project, provided steady supply of CO₂
- Assisting in defining safe disposal and economic potential for Kansas reservoirs
- Rapid-response detection & mitigation procedures being tested are as part of a comprehensive operation & risk management plan
- Advanced monitoring technologies
- Wellington Field is proving to be a viable field laboratory

Current Timeline

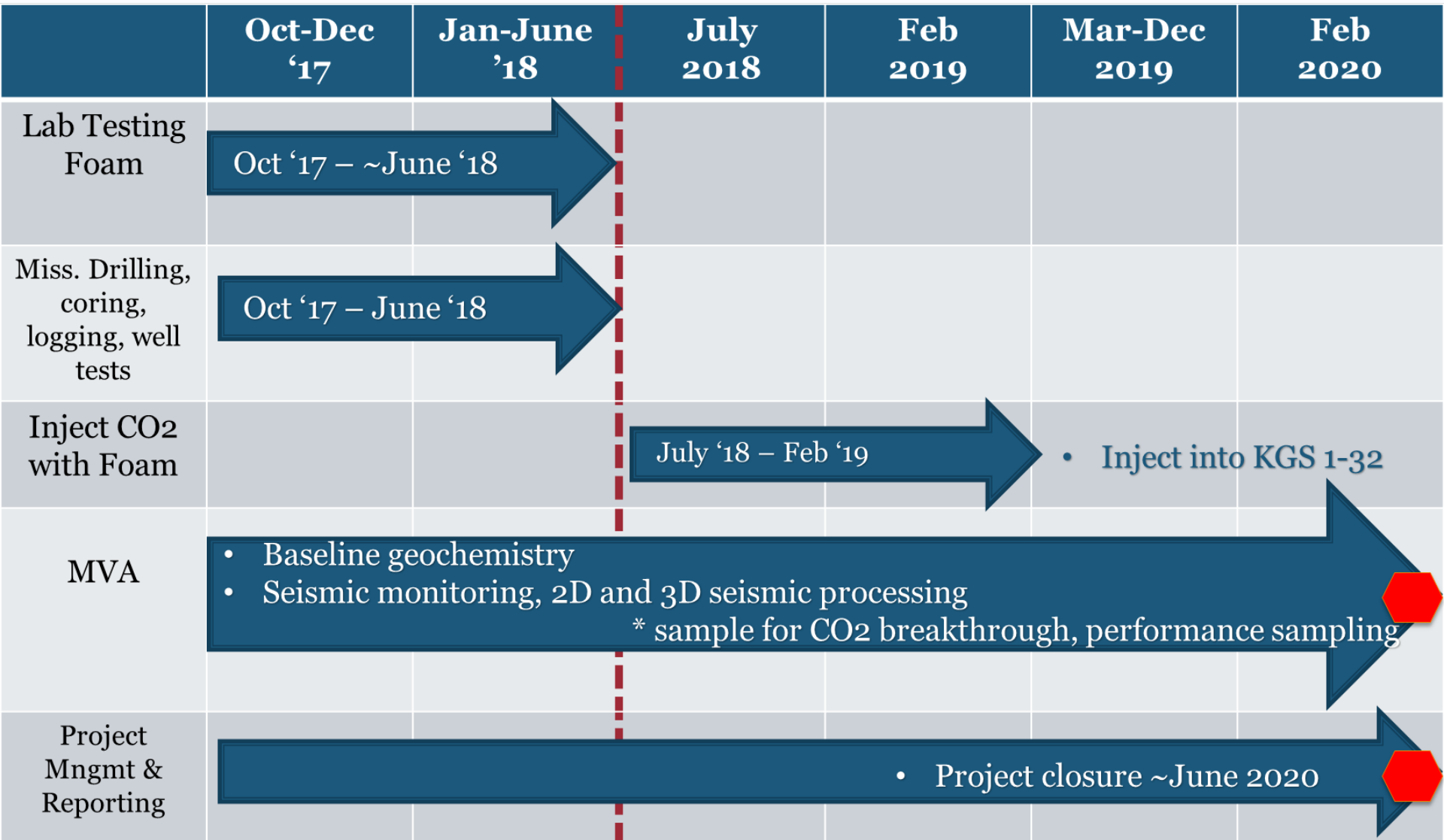


Proposed Alternative Plan Forward

To stay as close to original scope of work as possible:

- Inject CO₂ into Mississippian reservoir
 - Class II well (KCC - 1 month application process)
 - Repurpose KGS 1-32
 - Drill and equip monitoring well with U-Tube and CASSM
 - Suggested addition: surfactant or other mobility control agent
- Inject and produce brine through KGS 1-28 at Arbuckle Group saline aquifer
 - Storage capacity estimations
 - Basement connectivity
 - Possibility of collaboration with KDHE and KCC on far-field hydrological testing
- Use the project as a lab for testing NRAP tools

Alternative Plan Timeline



Acknowledgements & Disclaimer

Acknowledgements

- *The work supported by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) under Grant DE-FE0006821, W.L. Watney and Jason Rush, Joint PIs. Project is managed and administered by the Kansas Geological Survey/KUCR at the University of Kansas and funded by DOE/NETL and cost-sharing partners.*

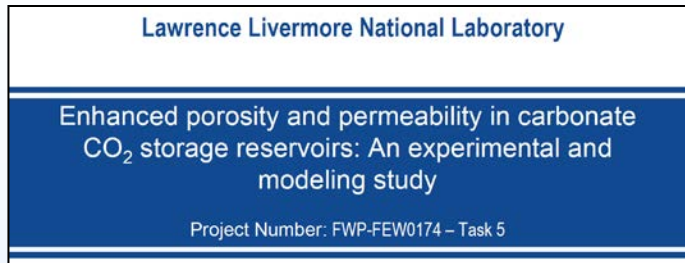
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Synergistic Activities

- Collaboration with Susan Carroll, PI, LLNL



- Task addition → *Experimental calibration of NMR well logs to determine pore connectivity in the injection zone at the Wellington CO₂ storage demonstration site, Kansas*
- Data rich site with considerable data sharing with all data publically available
 - Carbonate and caprock cores, modern wireline logs, tests -> KU, KSU et students and faculty; industry consortium
 - Water and oil samples
 - Multicomponent 3D → new processing techniques → KU, KSU, BEG
 - Earthquake catalog being built from operating IRIS/KGS 18-seismometer array
 - Monitoring and risk analysis from operational plan for safe and effective injection and adaptation by EPA for this project
 - Test NRAP tools
- Extensive Web (Java) application tools and development, petrophysical application focus, data archiving
 - Need more users and explore incorporation into NATCARB

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