Geologic Carbon Sequestration Research in Kansas: Subsurface Storage Capacities and Pilot Tests for Safe and Effective Disposal

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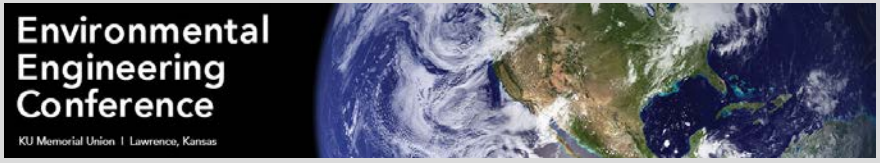
KU THE UNIVERSITY OF KANSAS
Department of Geology

DEPARTMENT OF ENERGY
NETL

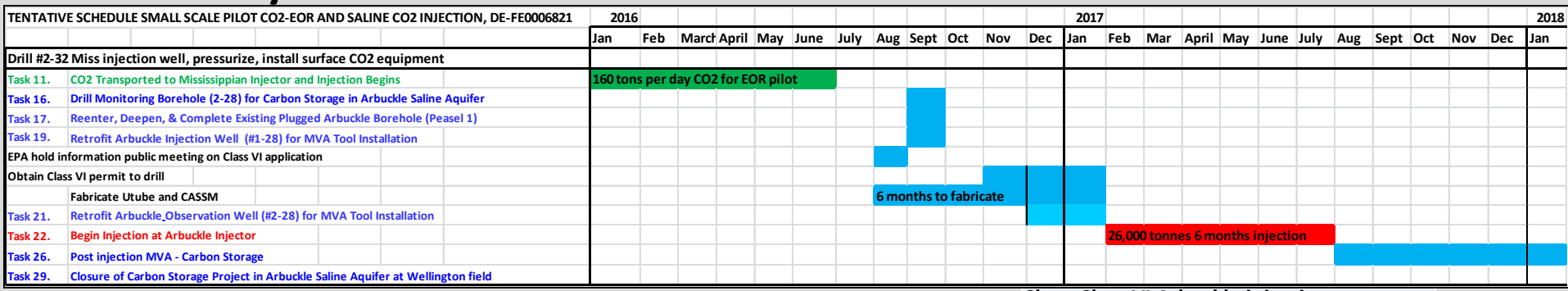
KSCO2



KANSAS

Overview

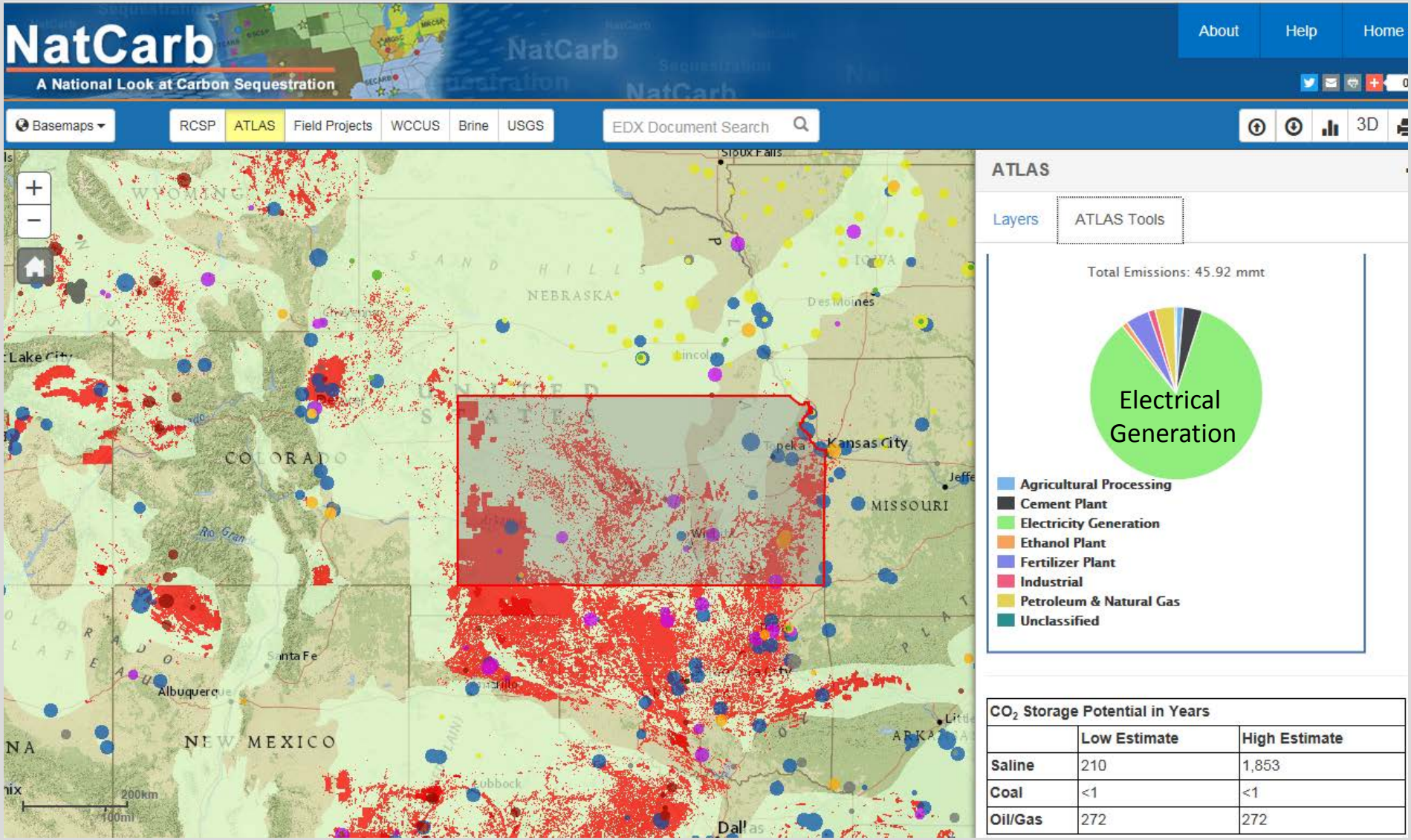
- **Evaluation of CO_2 storage and utilization in 25,000 mi^2, 33-county area in southern Kansas, DOE-NETL contract *DE-FE0002056* and partner cost share**
  - Southwest Kansas CO_2-EOR Initiative
  - CO_2 utilization in oil fields and storage in Arbuckle saline aquifer in southern Kansas
  - Cutter Field site characterization, Stevens Co.
  - Wellington Field site characterization, Sumner Co.
- **Pilot CO_2-EOR injection began January 9, 2016 in Mississippian dolomite reservoir in Wellington Field, Sumner County, Kansas (*DE-FE0006821*)**
- **Pilot CO_2 injection into Arbuckle at Wellington, pending EPA Class VI permit**
- **Steps toward implementing CO_2 Utilization and Storage (CCUS) in Kansas**
- **Summary**



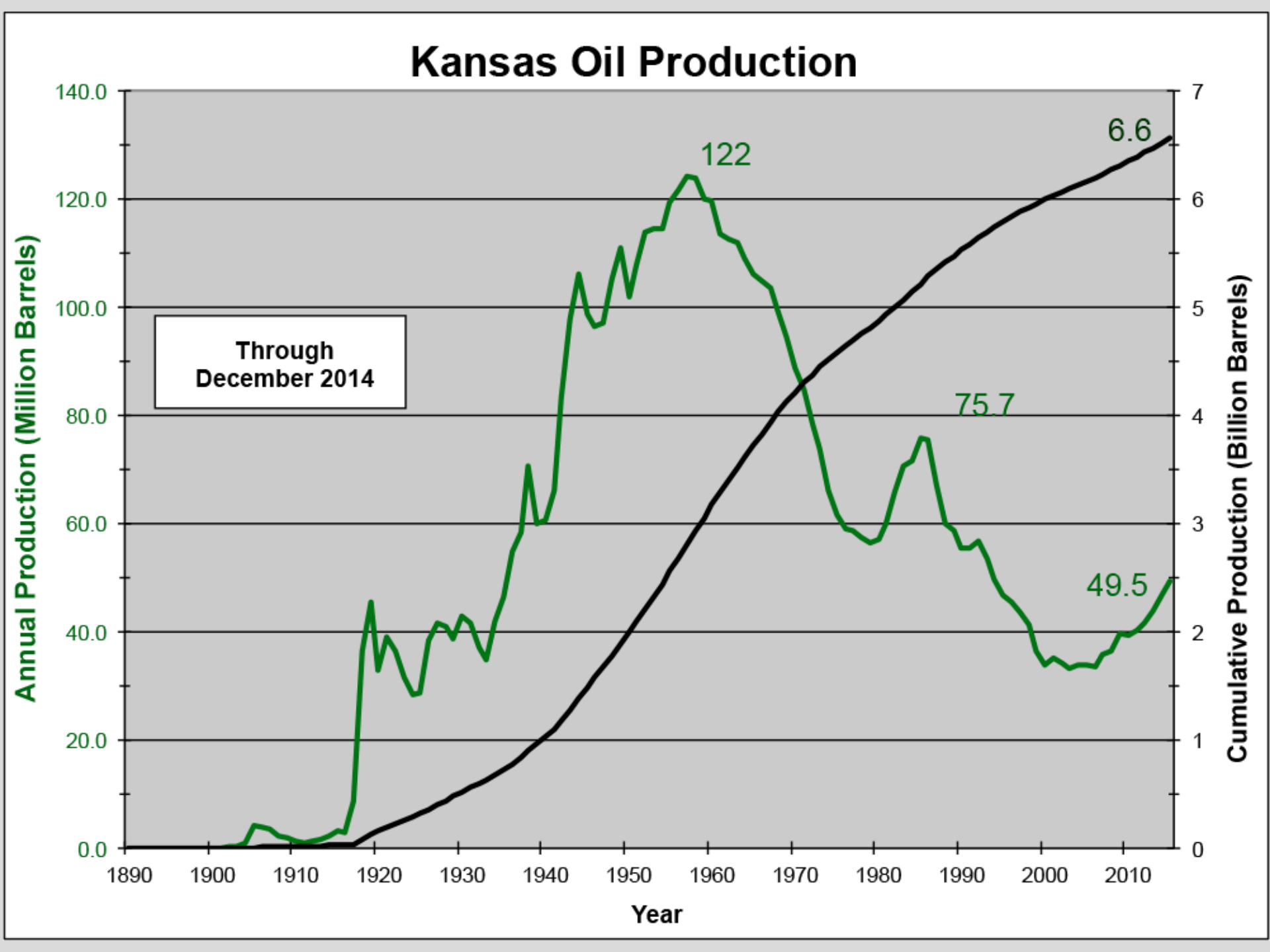
Total annual CO_2 emissions in Kansas in 2015
45.92 million tonnes

Potential Saline storage capacity for 210 to 1,853 years of KS emissions

Oil and gas reservoir storage capacity for 271 years (volumetric based estimates)



CO_2 Storage Potential in Years		
	Low Estimate	High Estimate
Saline	210	1,853
Coal	<1	<1
Oil/Gas	272	272

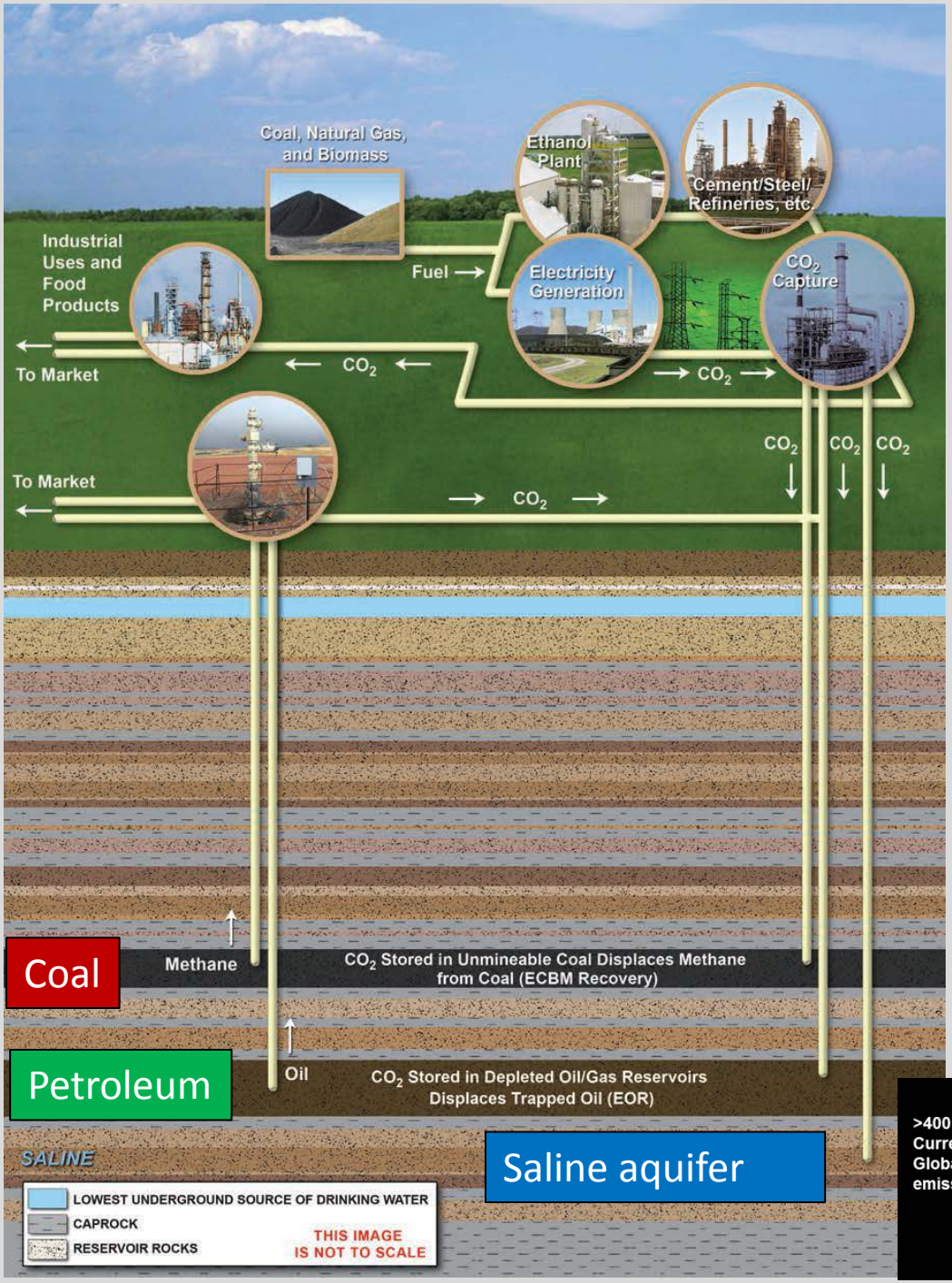

Kansas Oil Production
Annual Production (Million Barrels)
Cumulative Production (Billion Barrels)
Year
Through
December 2014
122
75.7
49.5
6.6
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
7
6
5
4
3
2
1
0
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

Geologic Carbon Utilization & Storage

The 2015 United States Carbon Utilization and Storage Atlas – Fourth Edition (Atlas IV)
DOE-NETL

Global annual CO_2 emissions ≈ $8 * 10^9$ tons

Earth Policy Institute



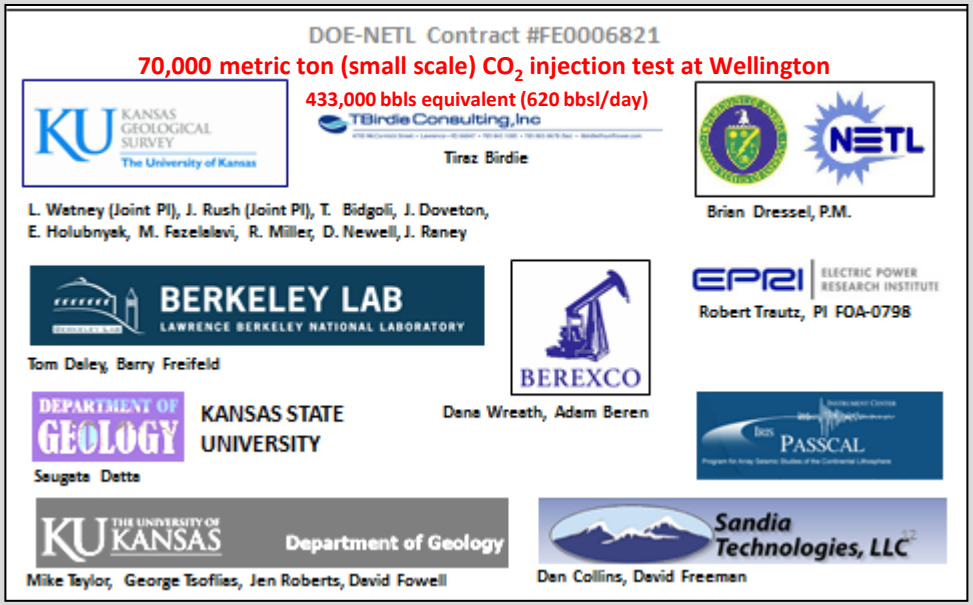
>400 yrs Current Global emissions

Formation Type	10^9 Metric Tons	%
Saline Aquifers	3,297 – 12,618	91.8 – 97.5
Unmineable Coal Seams	157 – 178	4.4 – 1.4
Mature Oil & Gas Reservoirs	138	3.8 – 1.1
Total Capacity	3,592 – 12,934	100.0

CO_2-EOR Technology & Carbon Management Research in Kansas

SW Kansas CO_2-EOR Initiative

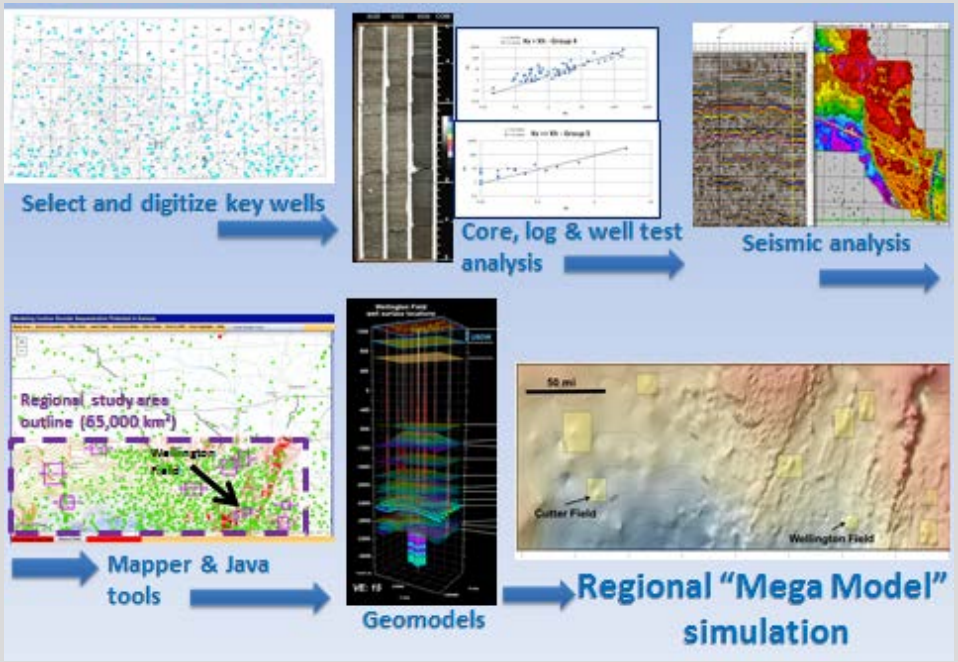
- Utilize oil and gas field Infrastructure
- Utilize comparable approaches to characterization and simulation of oil and reservoirs
- Evaluate regional CO2storage capacity of deep saline aquifer
- Conduct small scale CO2-EOR injection at Wellington Field, Sumner County Kansas
- KU & partners have performed extensive research on:
  - -monitoring
  - -verification
  - -accounting of CO_2 over the long term



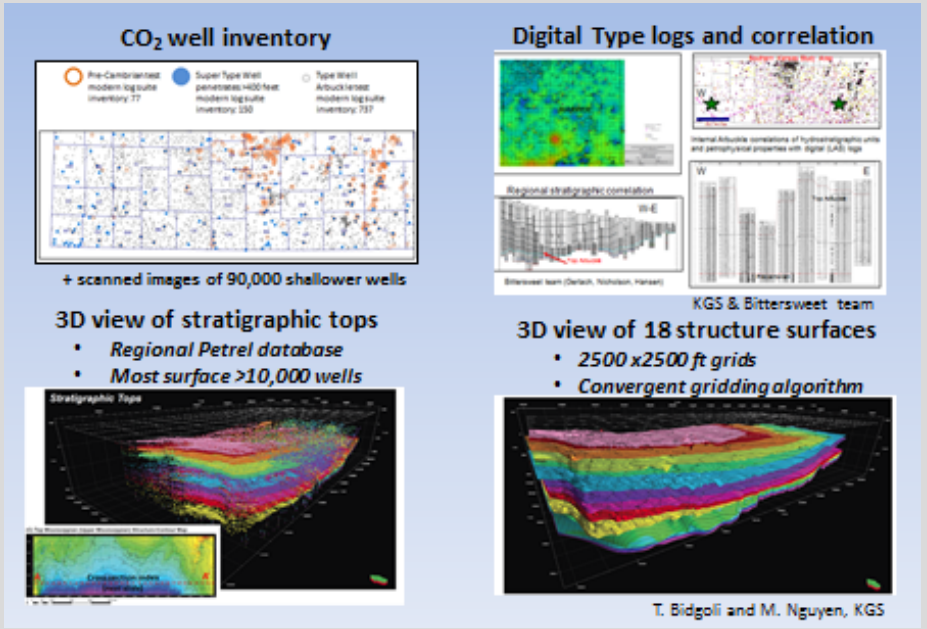
Completed evaluation of CO_2 storage capacity of a 25,000 mi^2, 33-county area in southern Kansas

- Southwest Kansas CO_2-EOR Initiative
- CO_2 utilization in oil fields and storage in Arbuckle saline aquifer in southern Kansas (**8-70** billion metric tonnes CO_2, P10/P90; volumetrically; **<u>4 billion</u>** by simulation based on **<u>injectivity and storage</u>**)
- Site characterization → Cutter Field site, Steven Co., Wellington Field, Sumner Co.

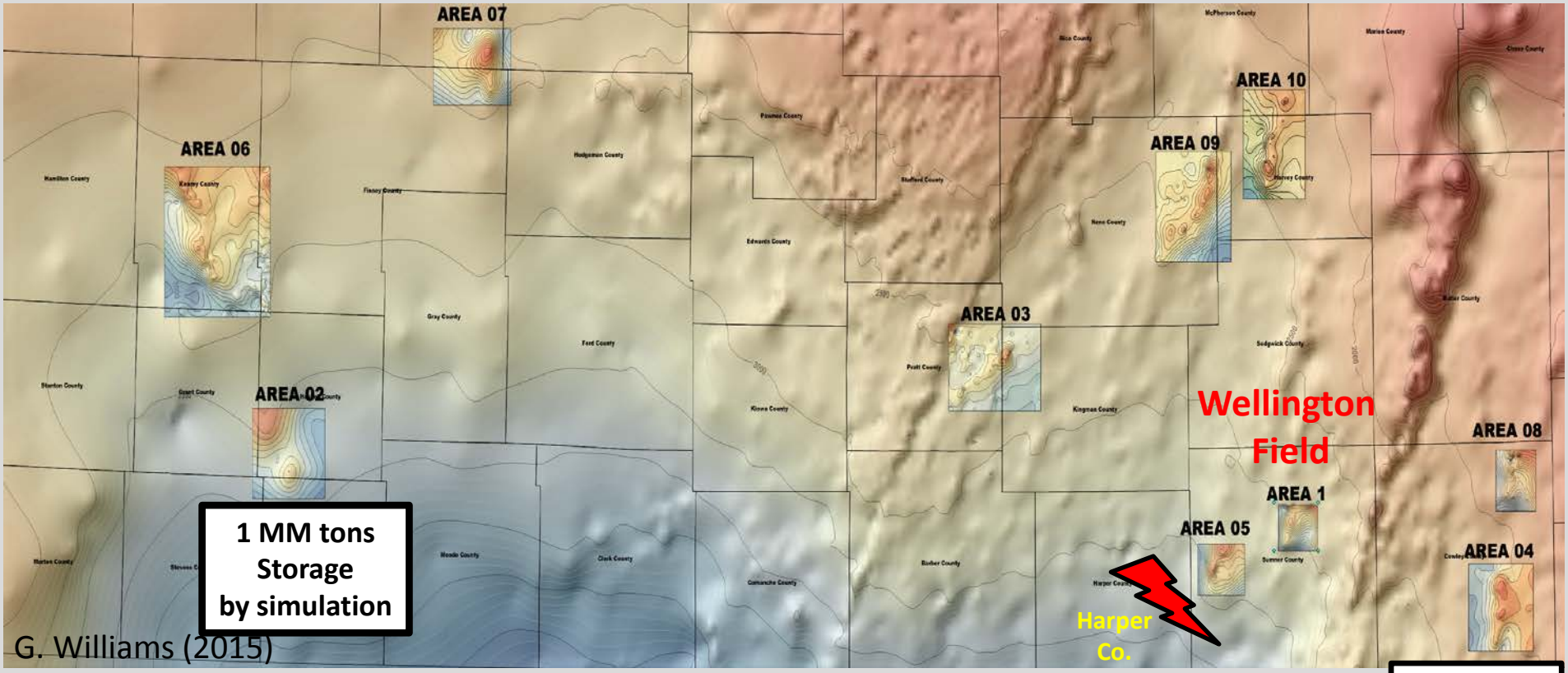
Project workflow



Maximize new information gained to quantify key variables in CO_2 injection and storage in Kansas



<u>Interactive mapper</u>: http://maps.kgs.ku.edu/co2/

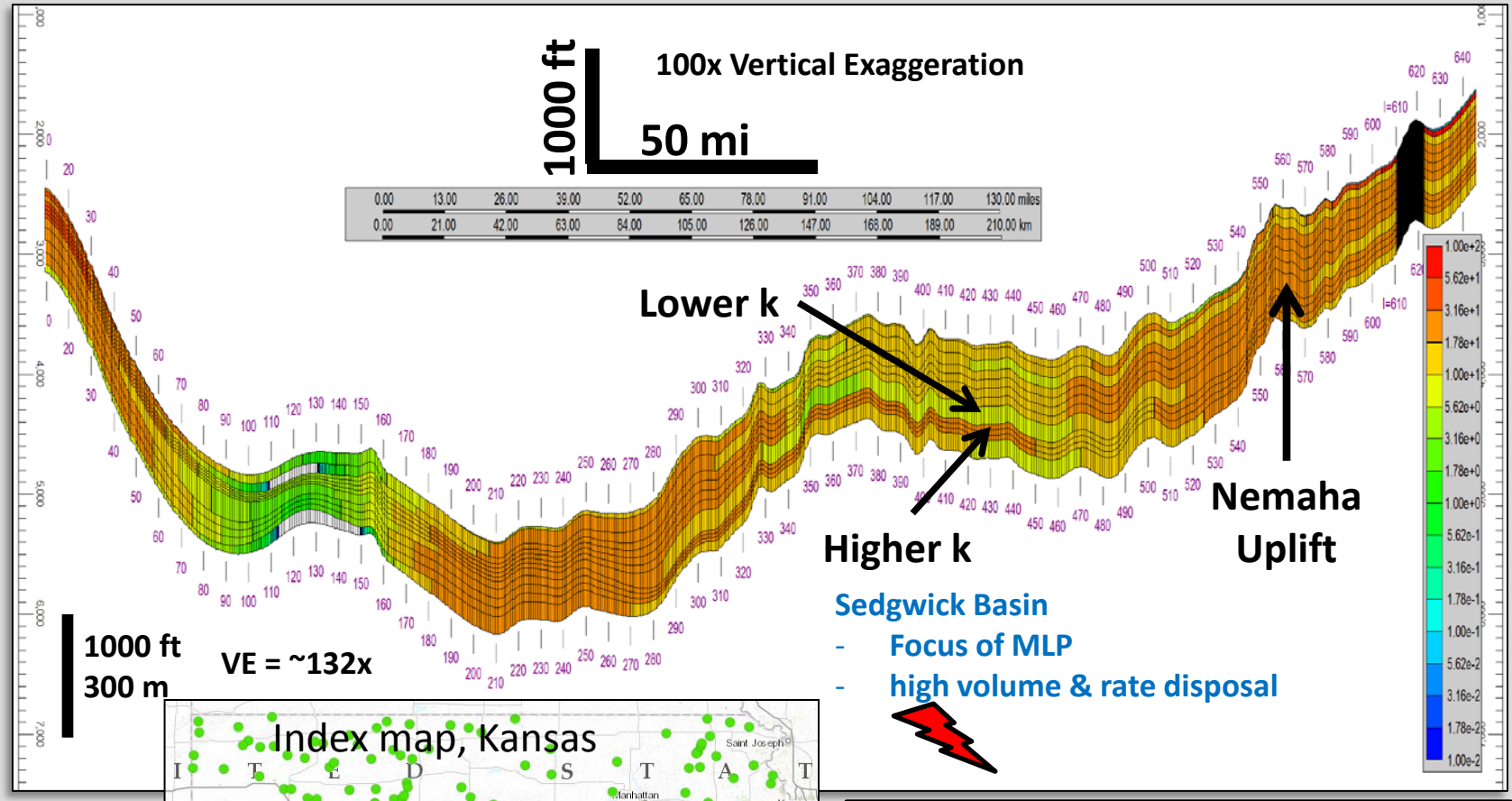


~180 MM tons By simulation

Regional Scale CO_2 Storage Capacity Simulation in the Lower Ordovician Arbuckle Group

- South Western and South Central Kansas
- 10 areas – benchmark sites
- One “mega” model
- Utilized database for simulating large scale brine disposal to understand induced seismicity in south-central Kansas

West-East structural cross section showing permeability distribution in 16 Arbuckle flow units, southern Kansas

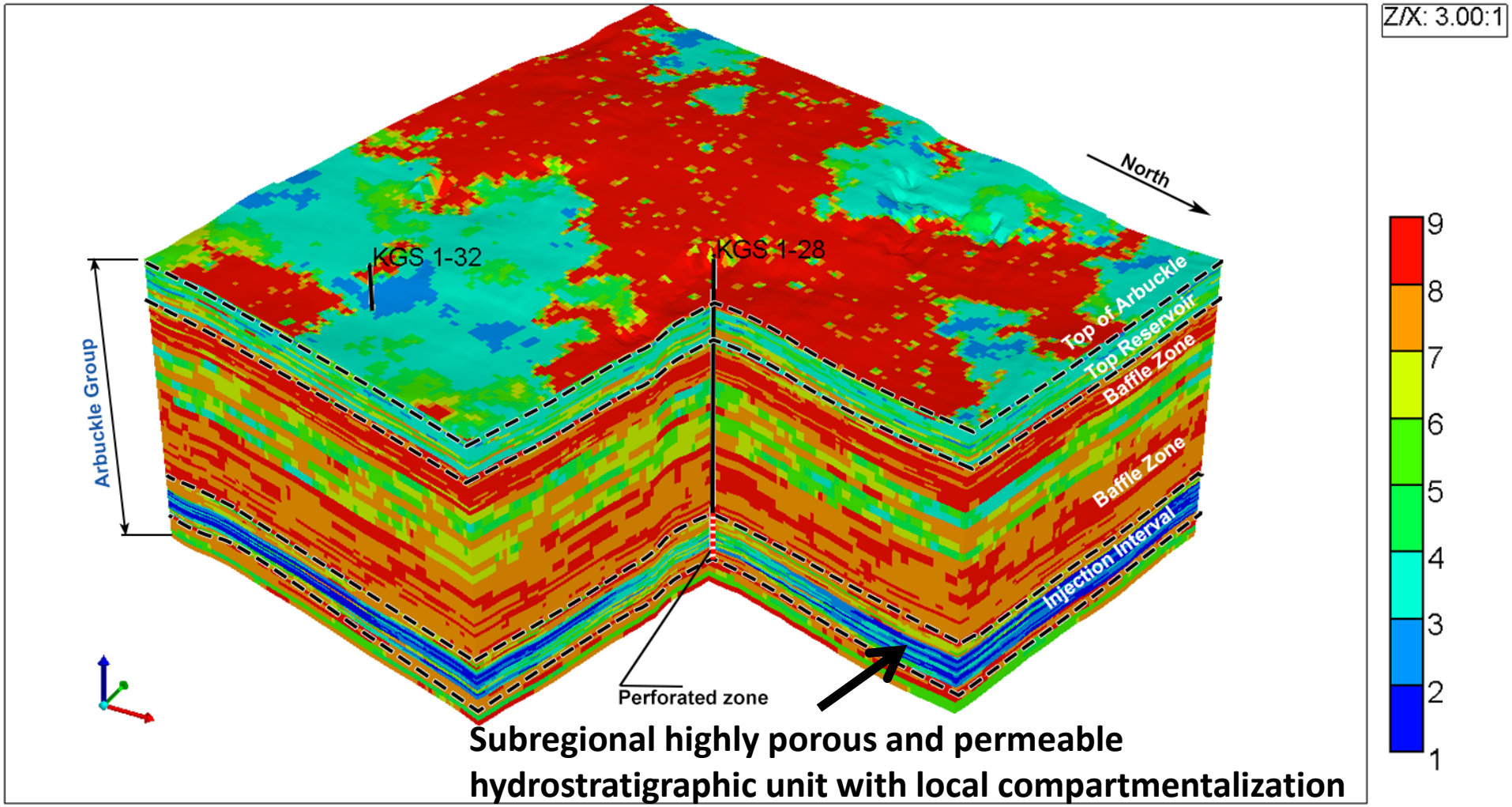


- Based on realizations of horizontal permeability, md
- Calibrated with core, logs, test data at Wellington and Cutter Fields

Williams, Gerlach, Fazelalavi, Doveton, KGS team, KS CO_2

Rock types mapped in Arbuckle at Wellington Field Based on RQI

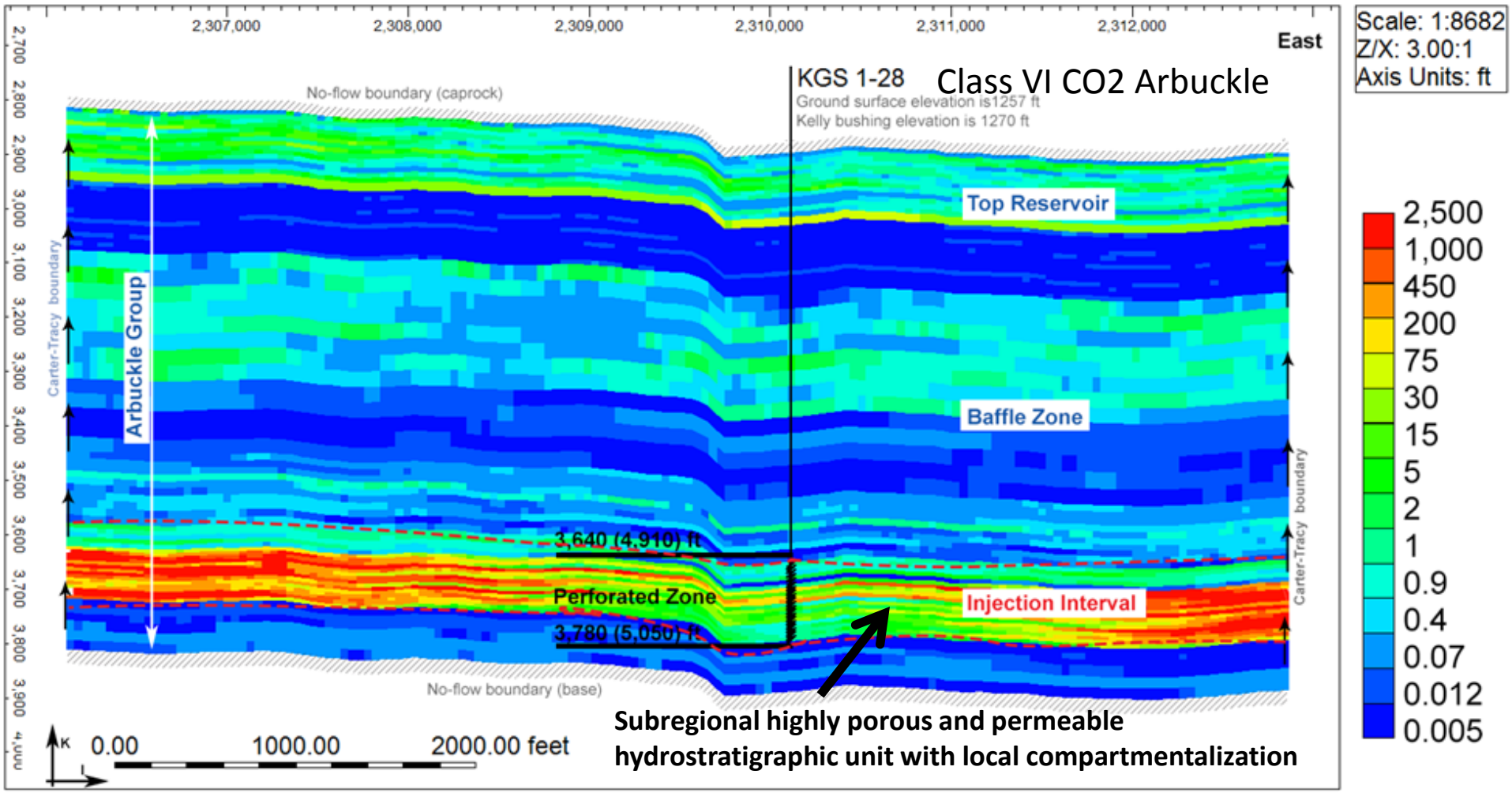
$$RQI(reservoir\ quality\ index) = 0.0314\sqrt{Perm/Porosity}$$



Subregional highly porous and permeable hydrostratigraphic unit with local compartmentalization

Vertical permeability (mD) distribution in the Arbuckle saline aquifer beneath Wellington oil field

-- east-west cross section through the injection well (KGS 1-28)



WELLINGTON FIELD PILOT DEMONSTRATION

DOE-NETL Contract #FE0006821

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L. Watney (Joint PI), J. Rush (Joint PI), T. Bidgoli, J. Doveton, E. Holubnyak, M. Fazelalavi, R. Miller, D. Newell, J. Hollenbach
(static & dynamic modeling, well test analysis, high-resolution seismic, passive seismic, accelerometers, geomechanical analysis, project management)

Brian Dressel, DOE Project Manager

BEREXCO

Dana Wreath & Adam Beren
(field operator and operations, repeat 3D multicomponent seismic)

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY

Tom Daley, Barry Freifeld *(CASSM, U-Tube, cross well seismic)*

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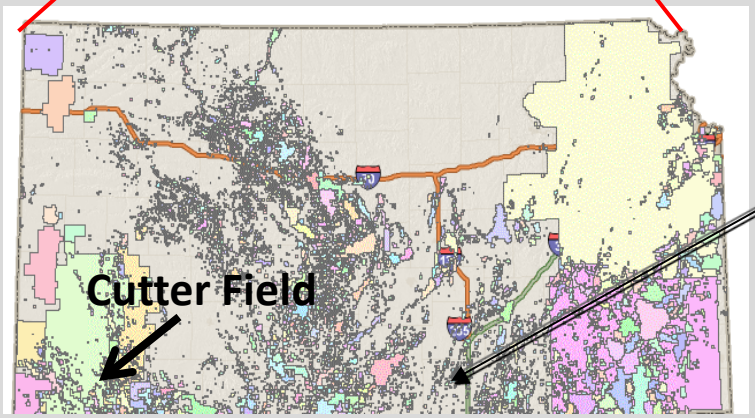
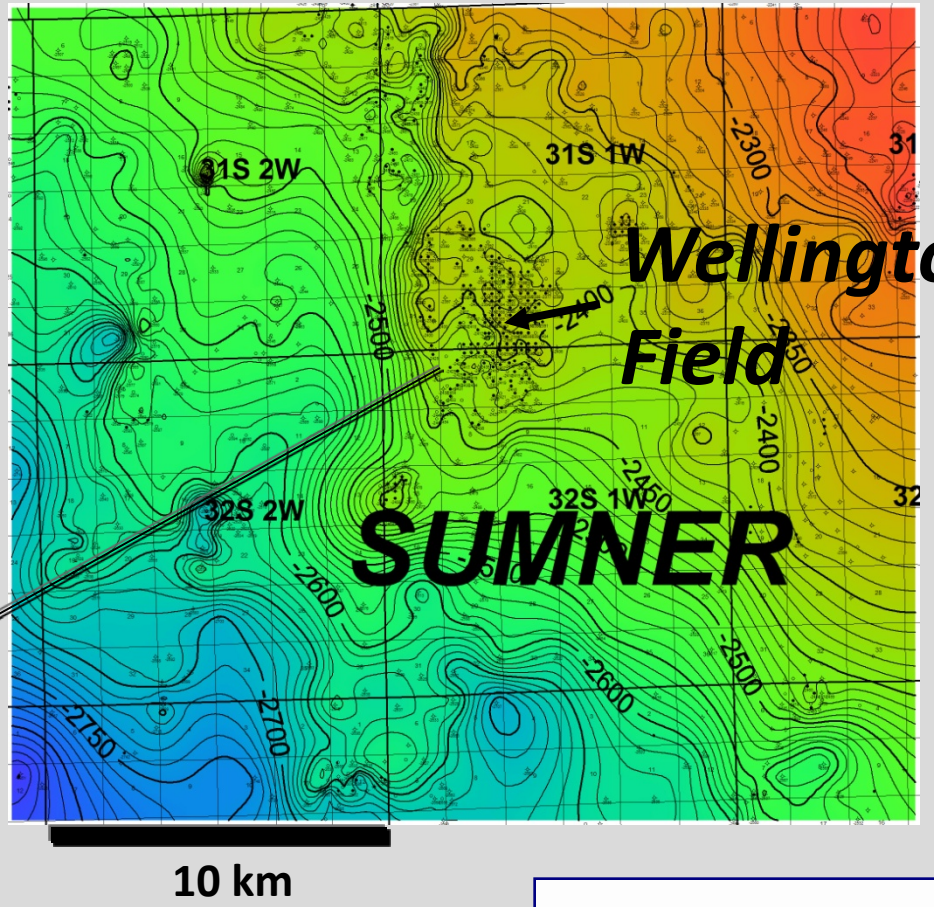
Jennifer Roberts, Leigh Stearns (cGPS), Mike Taylor *(InSAR)*, George Tsoflias *(passive and active seismic)*

Wellington Field
Site of Small Scale Field Test



Top Mississippian Structure, 10 ft C.I.



20 Million Barrel Oil Field above Arbuckle Group

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Wellington Field has experienced an excellent waterflood

File Product Plot Curves ON/OFF

1st Plot Title: Field Production

2nd Plot Title: Wellington

3rd Plot Title: OIL

X-Axis Year		Y-Axis Production/Cumulative	
Minimum:	1938	Minimum:	1.0
Maximum:	2015	Maximum:	1000.0
Increment:	4	Cycles:	3

Production Decline Curve Calculator

Decline Curve Analysis Methods: ○ Exponential ◉ Harmonic ○ Hyperbolic

Enter Production Rate for Computations: ○ Daily ○ Monthly ◉ Yearly

Initial (Qi): Rate:	Year:	Final (Qt): Rate:	Year:
191439	1974	52784	1998

Decline Curve Equation: Qt = Qi / (1+Kt), t=time — Constant (K): 0.109459 — Exponent (n): 0.0

Cumulative Production: Production (Actual): 12990396 BBL — Present (Computed): 11731445 BBL

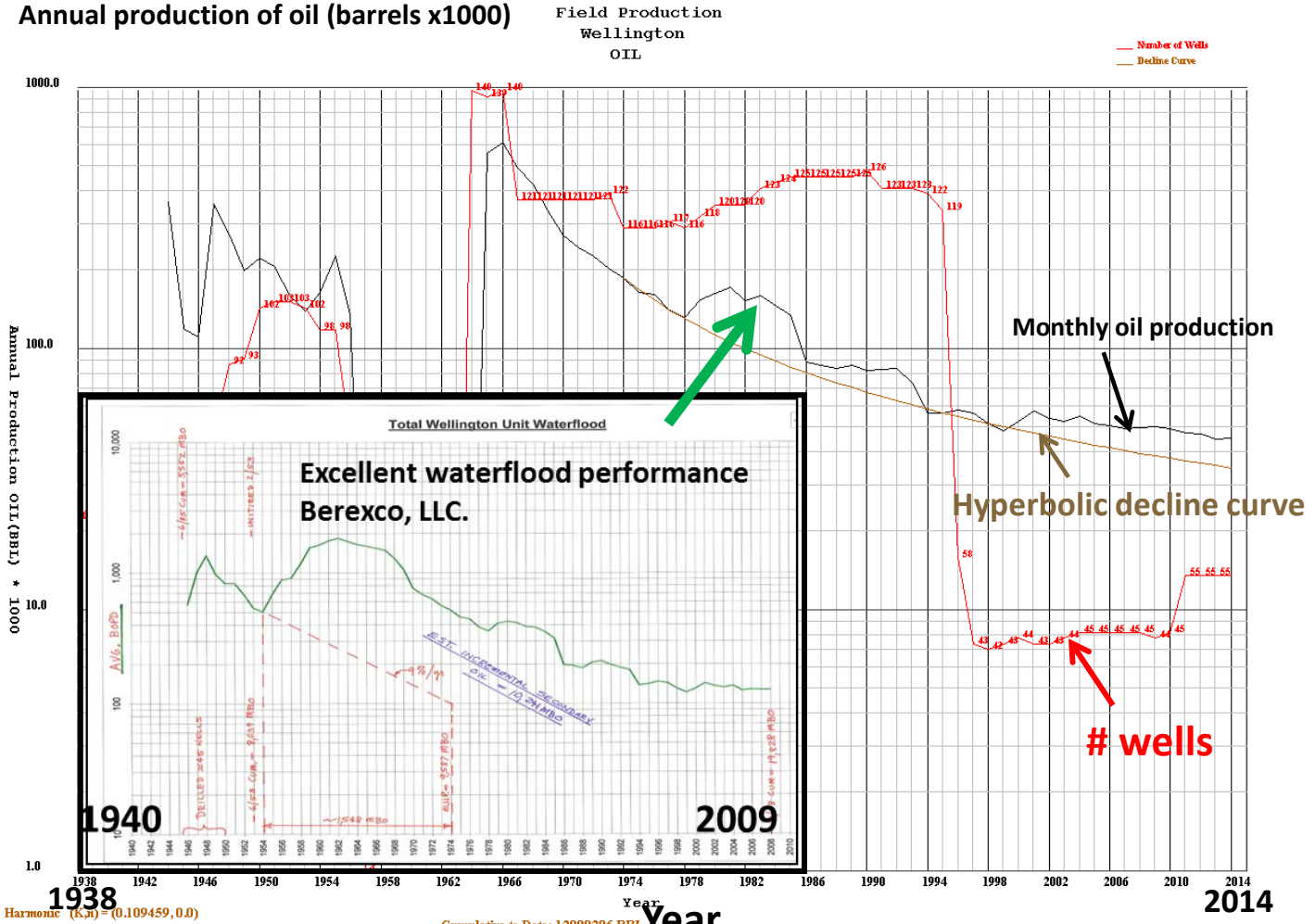
Production at Economic Limit: Economic Limit Rate (Qf): Rate: 15 BBL Per ◉ Day ○ Month ○ Year — Date: 2284

Economic Limit (EUR): 15694578 BBL — Reserves (RR): 2704182 BBL

Extend to Limit

Production

Annual production of oil (barrels x1000)



Harmonic (K,n) = (0.109459, 0.0)
Initial Production Year Rate (Qi): 191439 BBL at 1974
Present Production Year Rate (Qt): 52784 BBL at 1998
Decline Rate (De): 3.018 % Per Year
Economic Limit Year Rate (Qf): 5475.0 BBL at 2284

Cumulative to Data: 12990396 BBL
Computed: 11731445 BBL
Cumulative at Limit: 15694578 BBL
Remaining Reserves: 2704182 BBL

J. Victorine, KGS

Production Plot & Decline Curve Analysis Applet

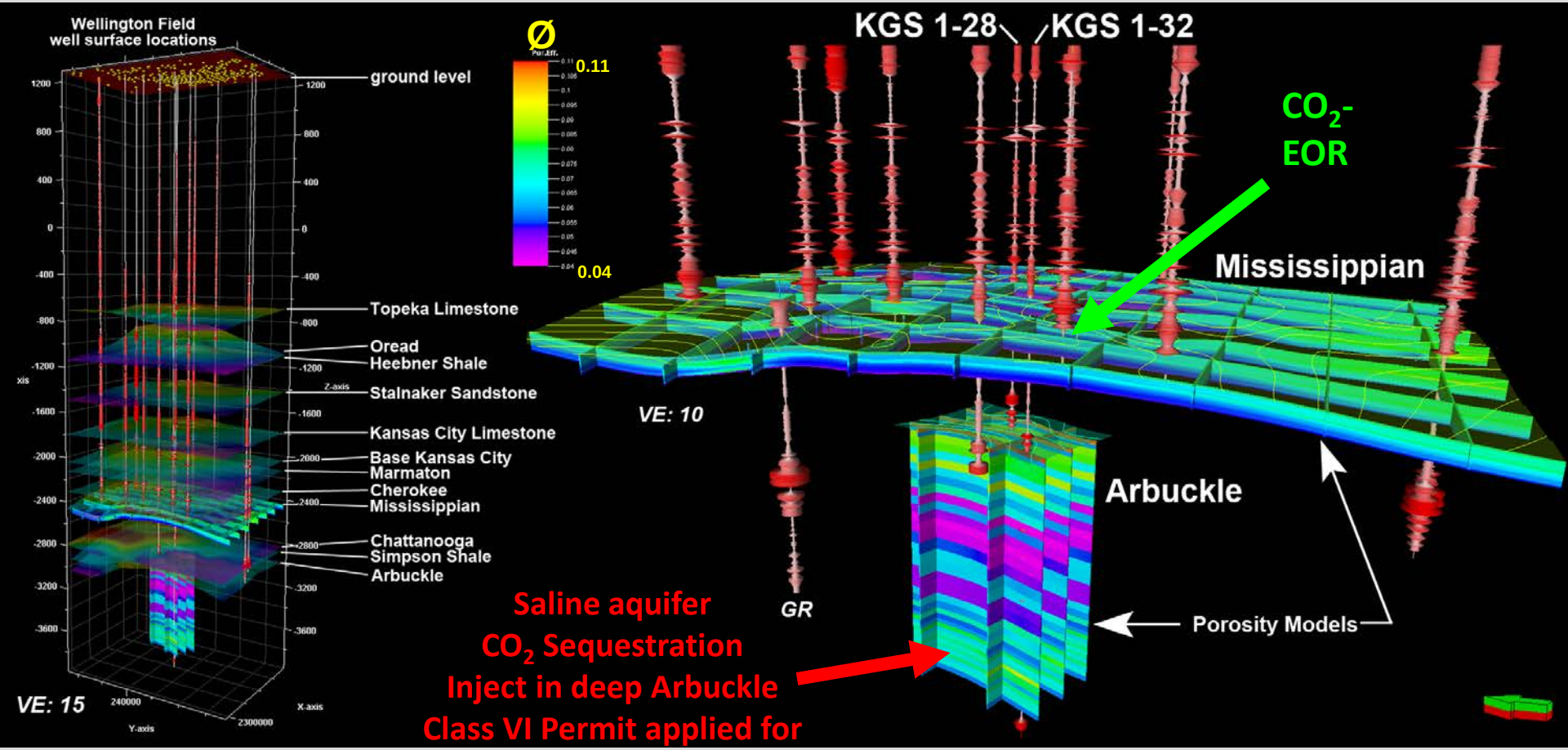
http://www.kgs.ku.edu/software/production/applet.html

Main Page | Description | Applet | Help | Copyright & Disclaimer |

Production

Wellington Field – eastern calibration site

Mississippian siliceous dolomite reservoir & Arbuckle aquifer saline aquifer



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Pilot CO_2-EOR well drilled in 2015 and injection began in January 2016

Mississippian dolomite reservoir in Wellington Field
Sumner County, Kansas

Berexco LLC
Wellington KGS #2-32
2680'FSL & 709'FEL, Sec 32, T 31S, R 1W
Sumner County, Kansas

Drilled in March 2015

BEREXCO

Fossil Drilling

MUDCO

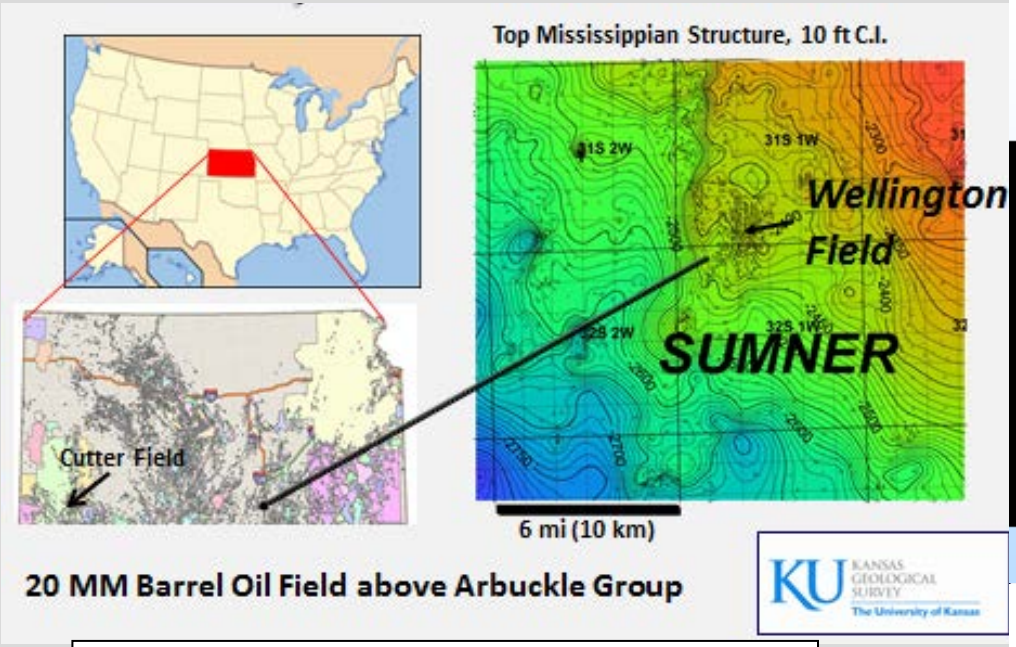
DEVILBISS CORING SERVICE, INC.
"QUALITY SERVICE SINCE 1992"

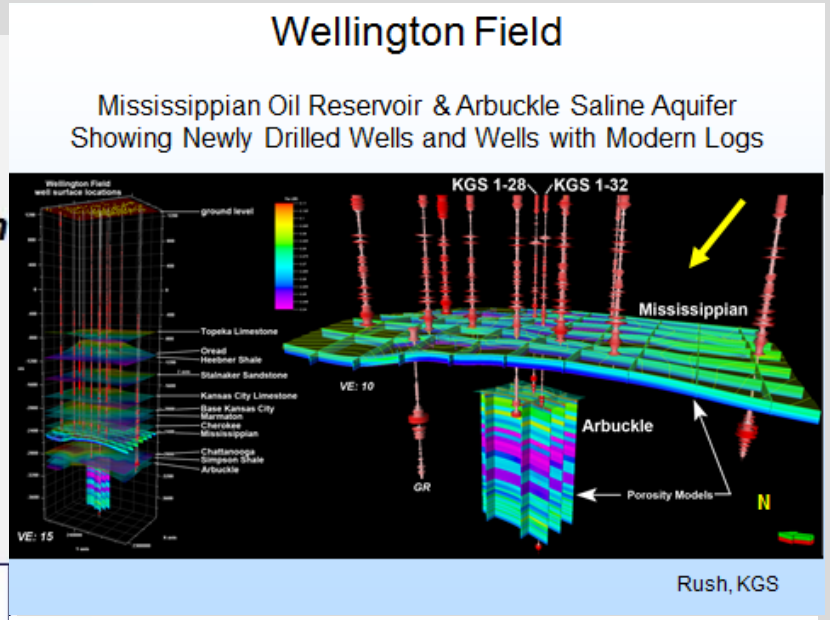
HALLIBURTON

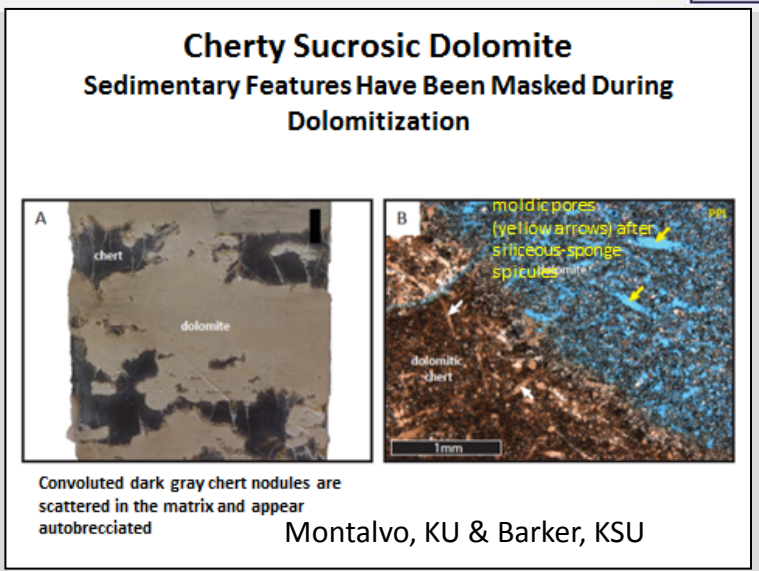
Core Lab
RESERVOIR OPTIMIZATION

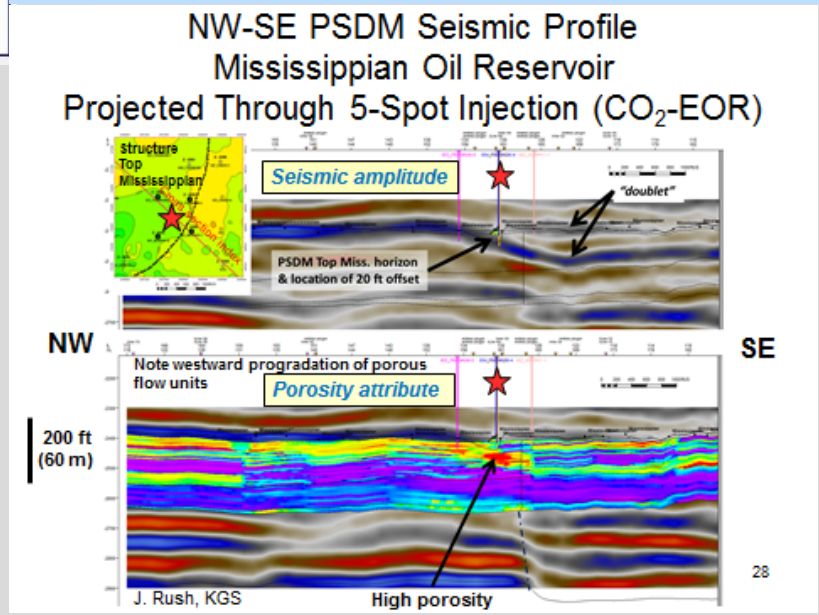
TRILOBITE TESTING, INC.

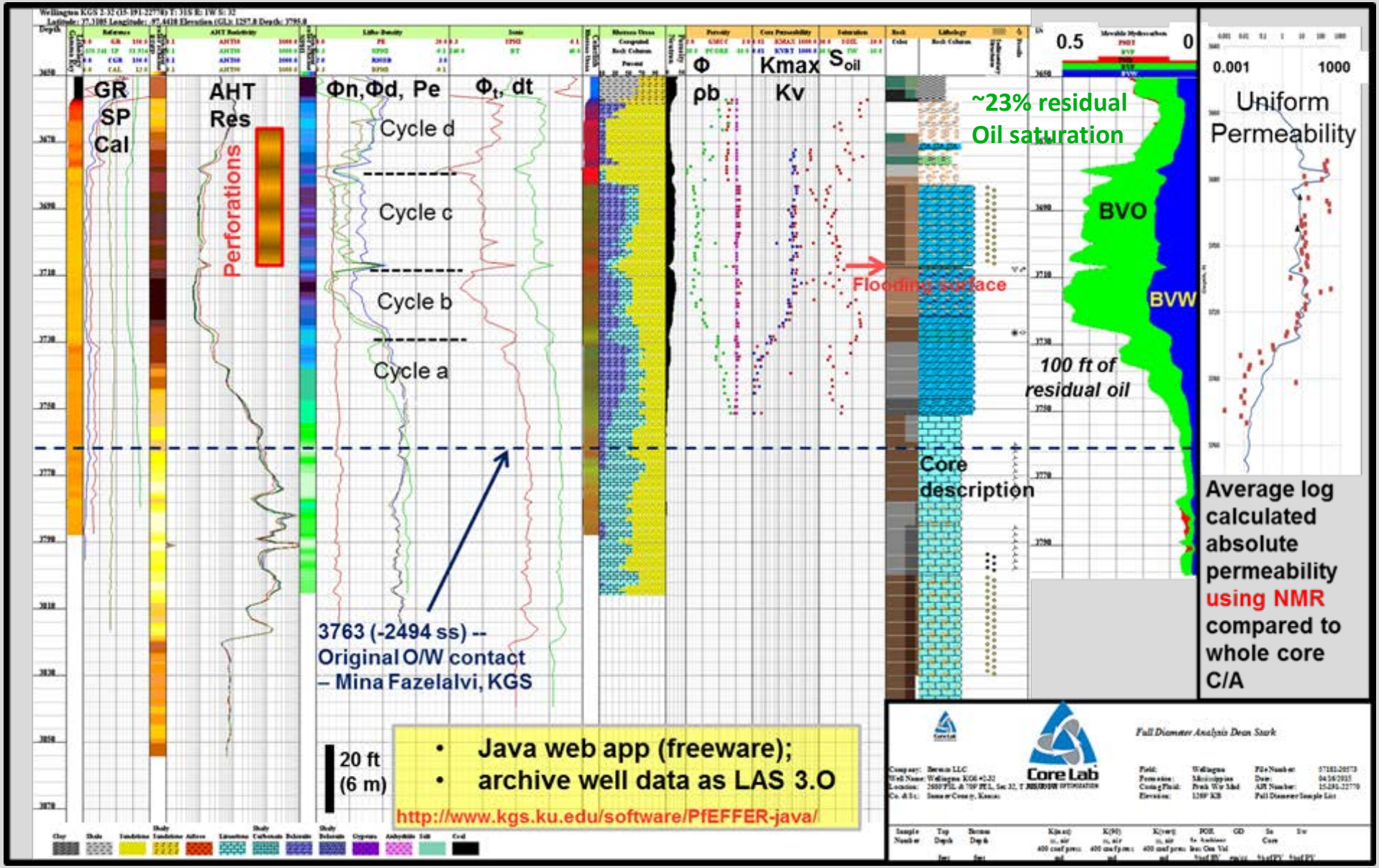
Wellington Field site characterization
Sumner County, Kansas under DE-FE0002056





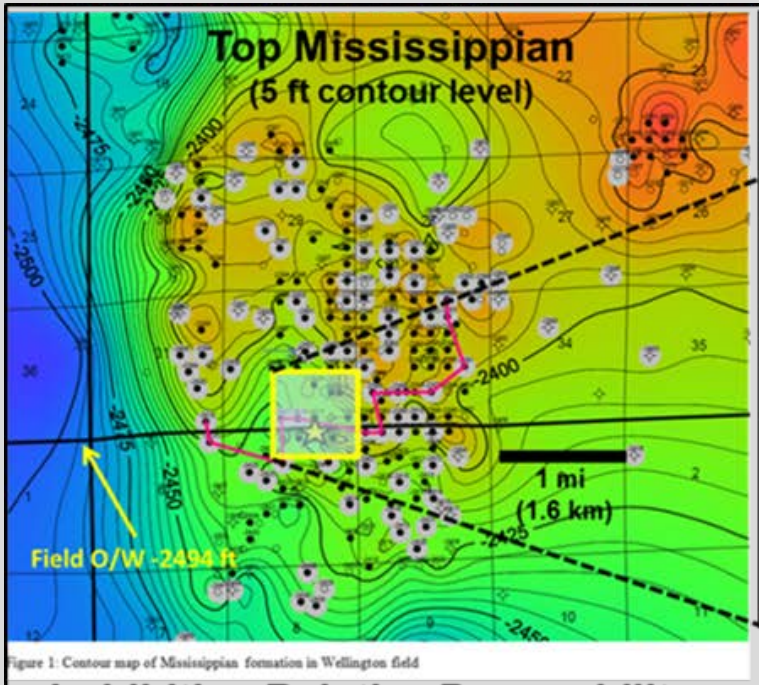


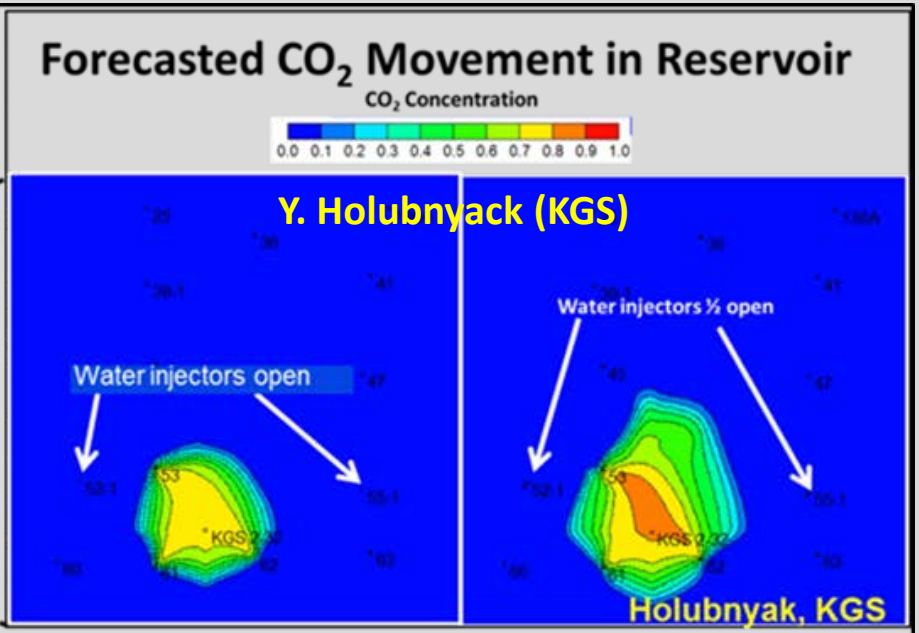


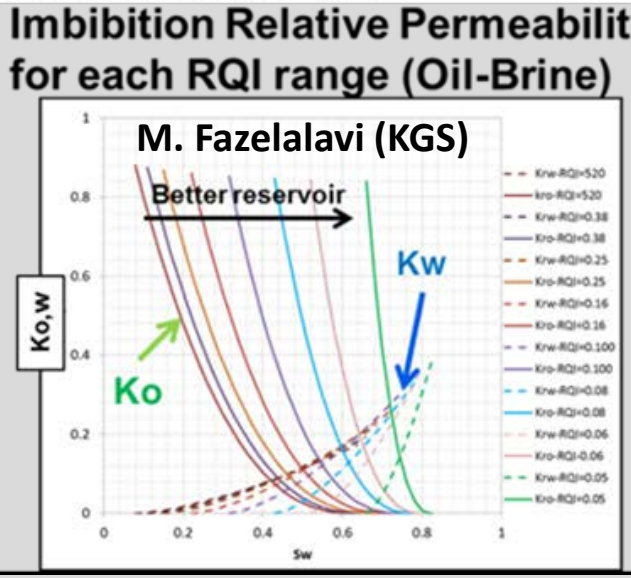


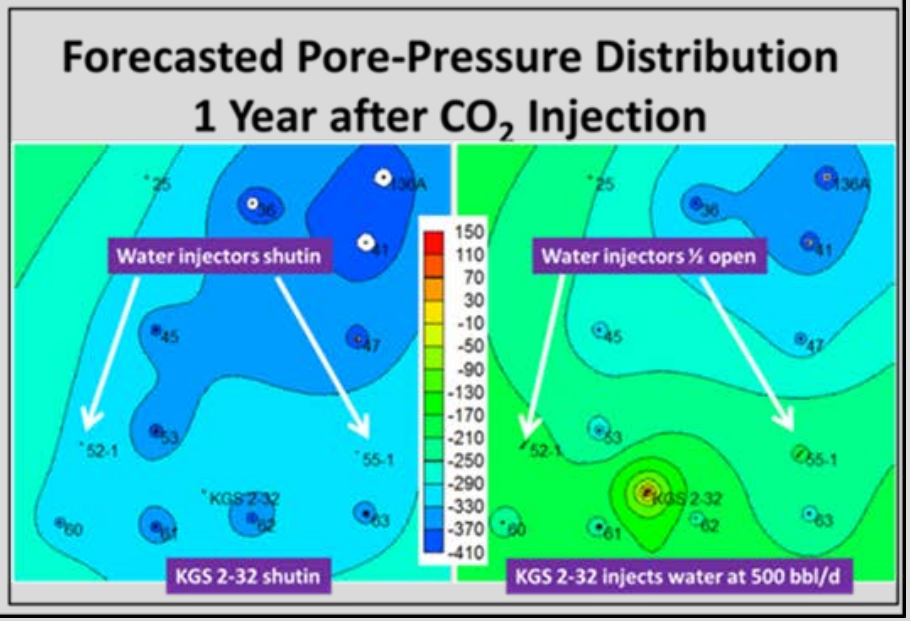
Berexco Wellington KGS #2-32 showing well logs, lithologic interpretation from logs, core analysis, lithology from core description, and moveable oil (green, residual oil saturation).

J. Victorine (KGS)





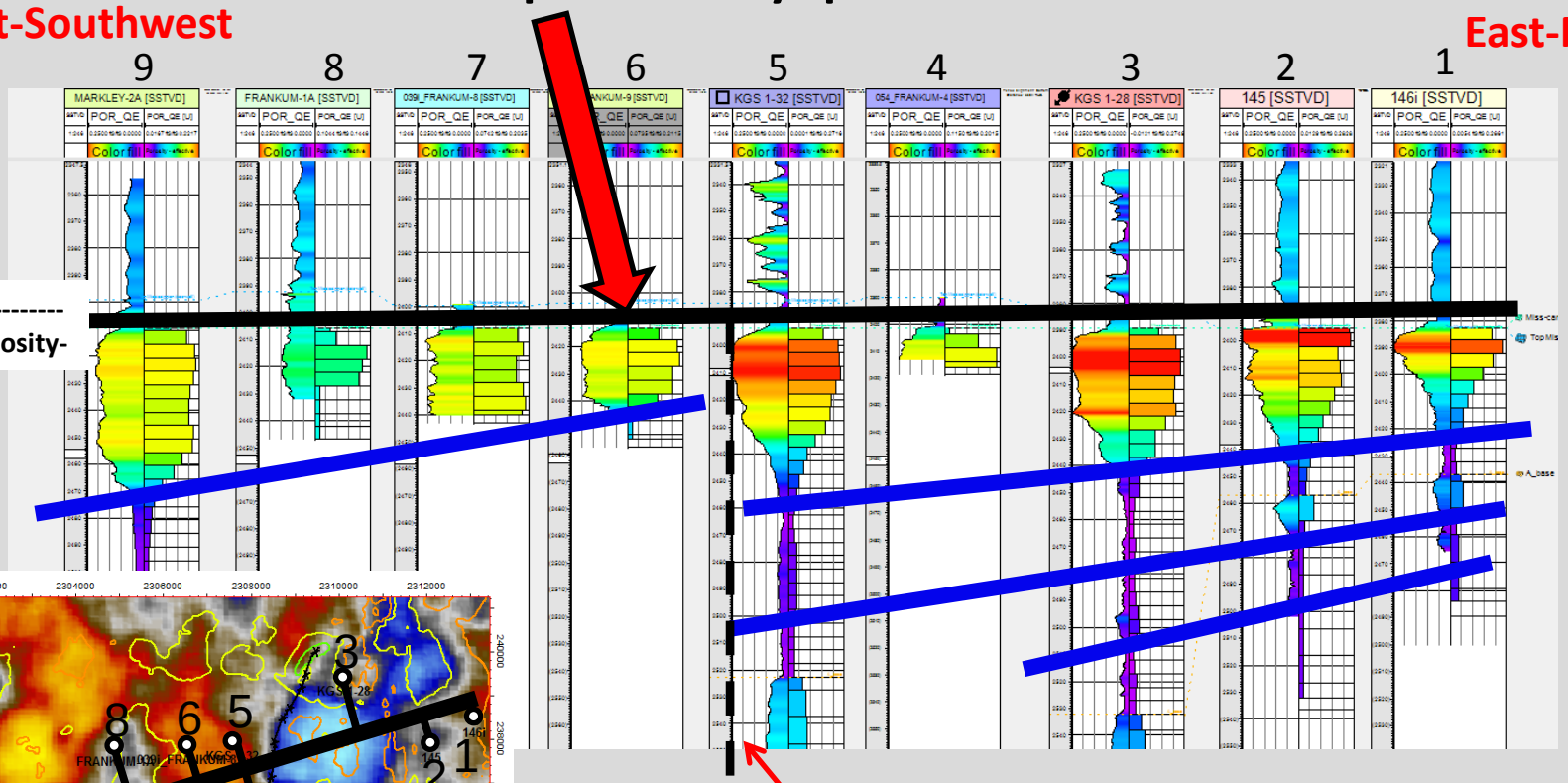


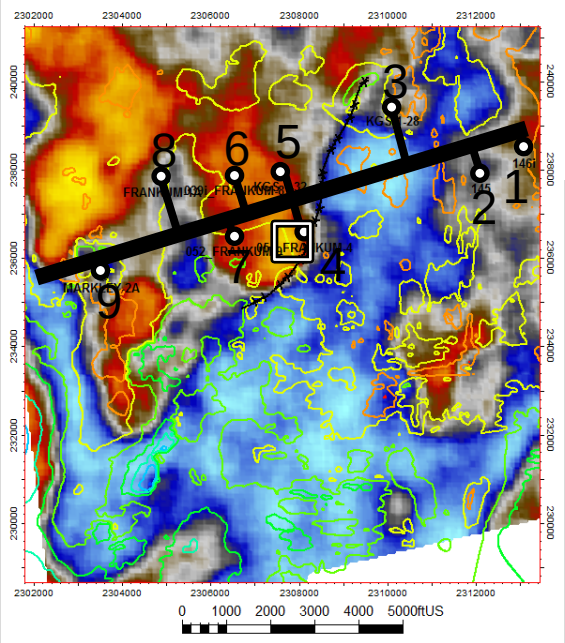


Top Mississippian structural elevation (25 ft contour interval), (upper right) forecasted CO2 movement after 26,000 tonnes, (lower right) pore pressure distribution used to control the sweep of the CO2, and (lower left) relative permeability curves determined for each reservoir rock type (reservoir quality index).

CO_2-EOR injection in area of reservoir with uniform porosity profile of reservoir

West-Southwest **East-Northeast**

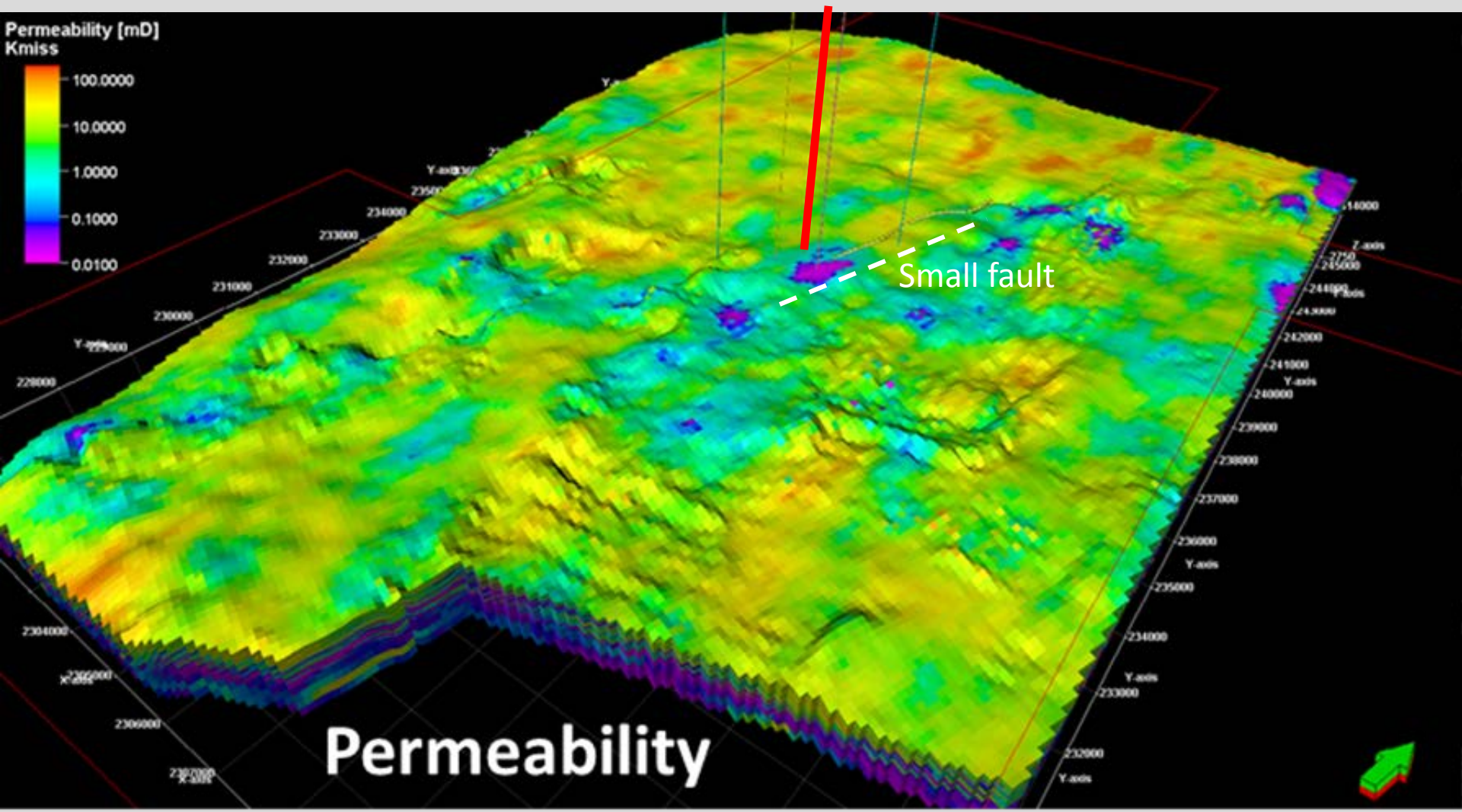




Small fault acting as barrier to flow on east side of pilot site (250 ft from the fault)

- **Porosity thickening indicative of low-angle, westward progradational wedges**
- **Confirmed by 3D seismic**

J. Rush (KGS)



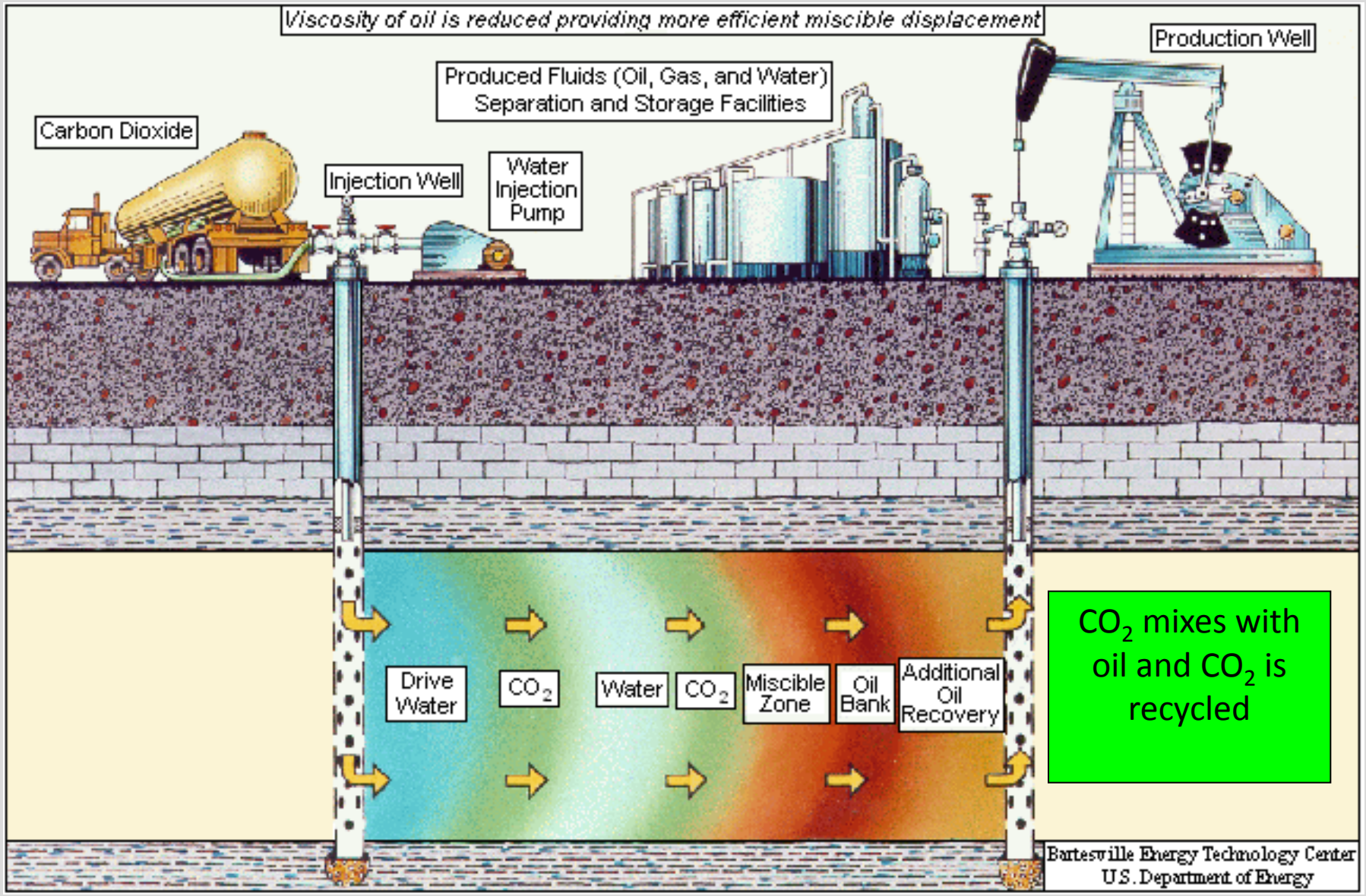
- Petrel-based map of permeability for the Mississippian oil reservoir.
- CO2 injection well is red colored vertical line.
- Lower permeability noted east and south of the injection well, KGS #2-32.
- Thin north-northwest trending yellow line is the trace of the medial fault.

J. Rush (KGS)

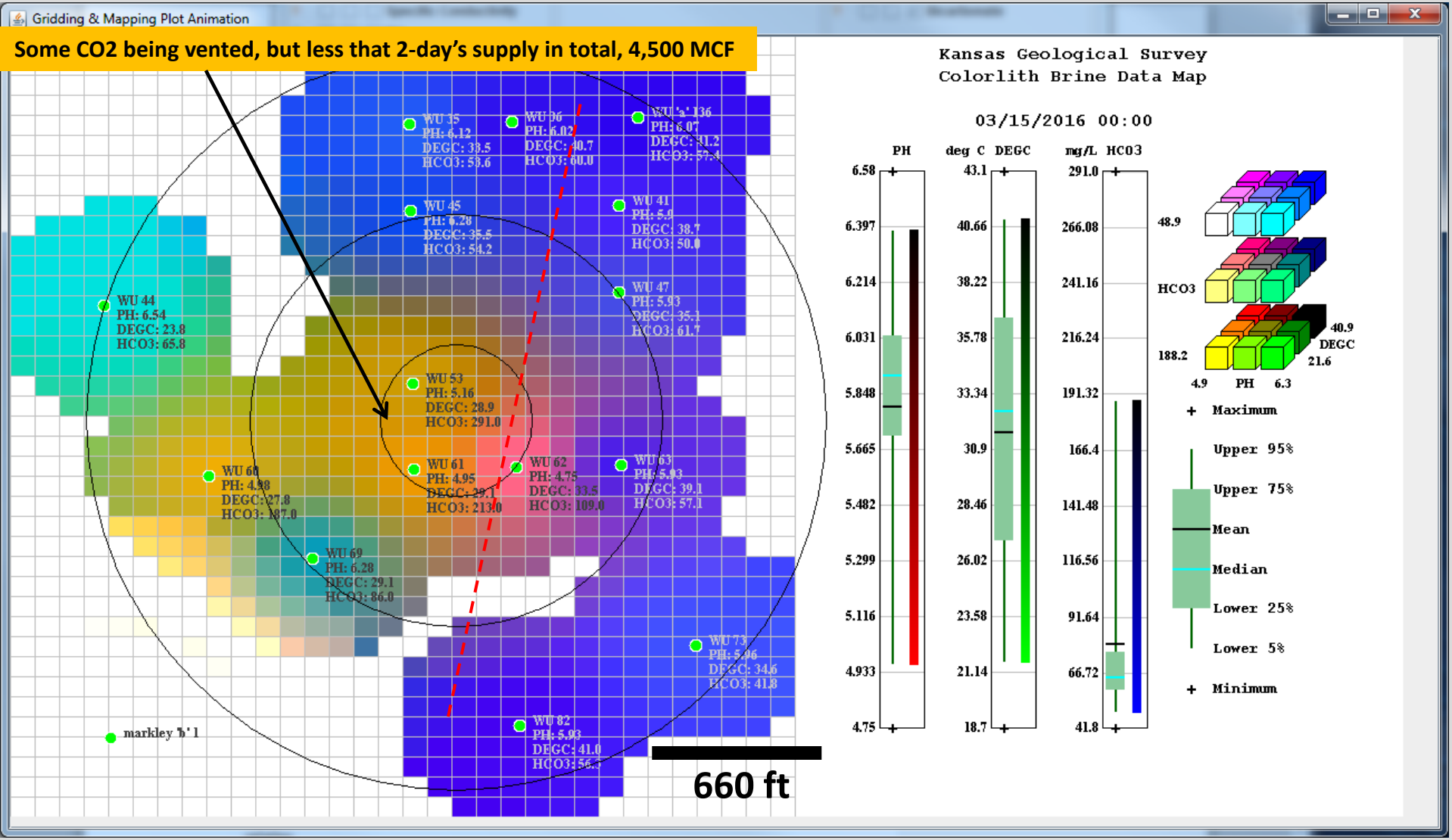
Wellington Mississippian CO2-EOR Small Scale Injection began January 9, 2016 → operated by Berexco, LLC

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

CO_2 utilization in enhanced oil recovery (EOR)

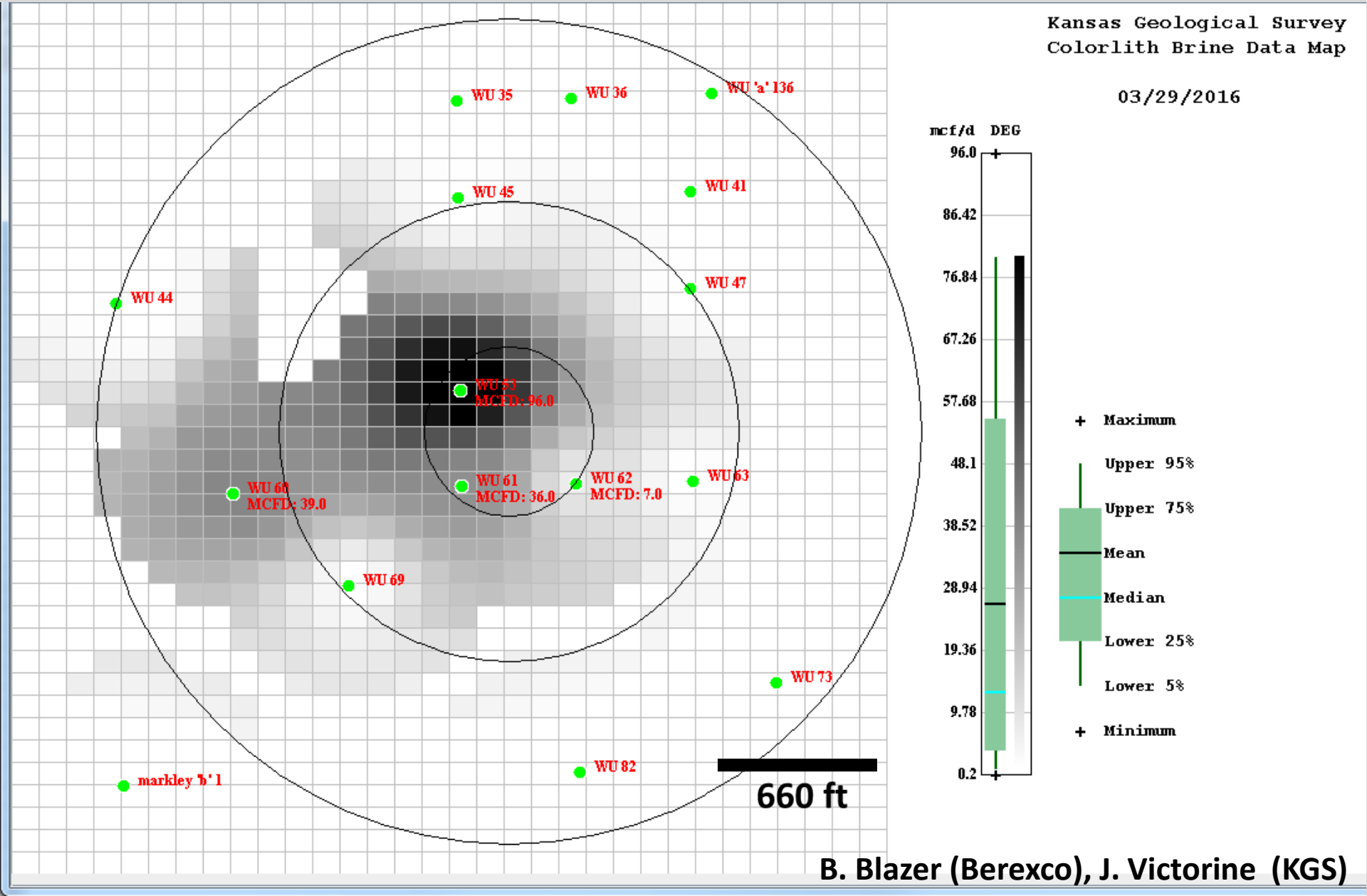


Combined pH, temp brine, and alkalinity



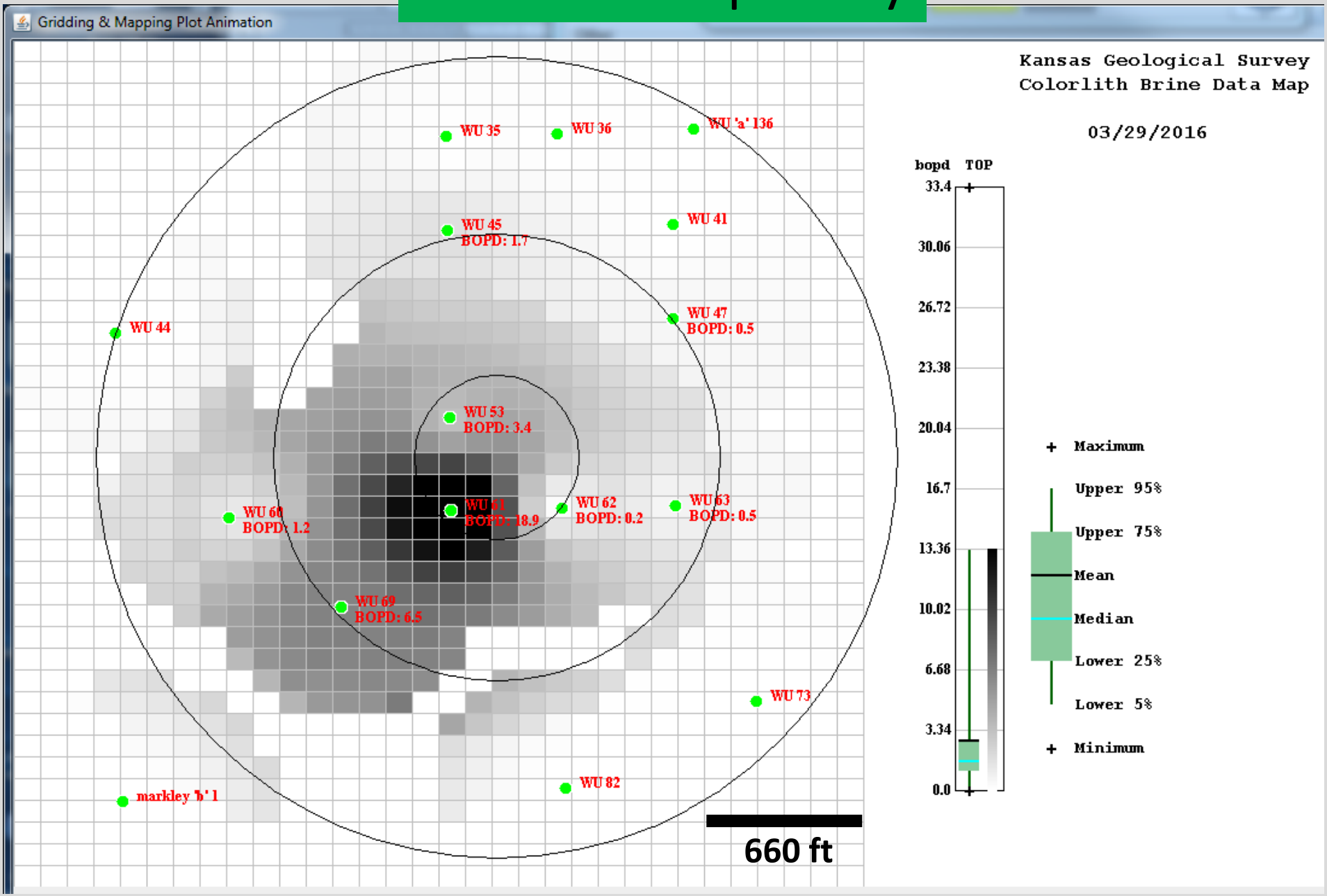
B. Campbell (Berexco), C. Jackson, K. Graham, J. Hollenback, J. Victorine (KGS)

CO2 vented at well



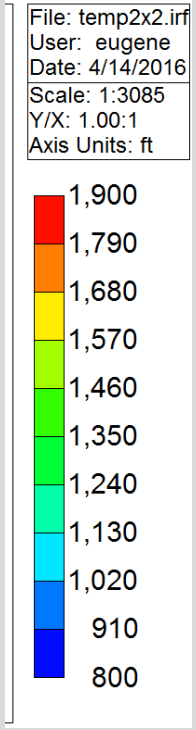
B. Blazer (Berexco), J. Victorine (KGS)

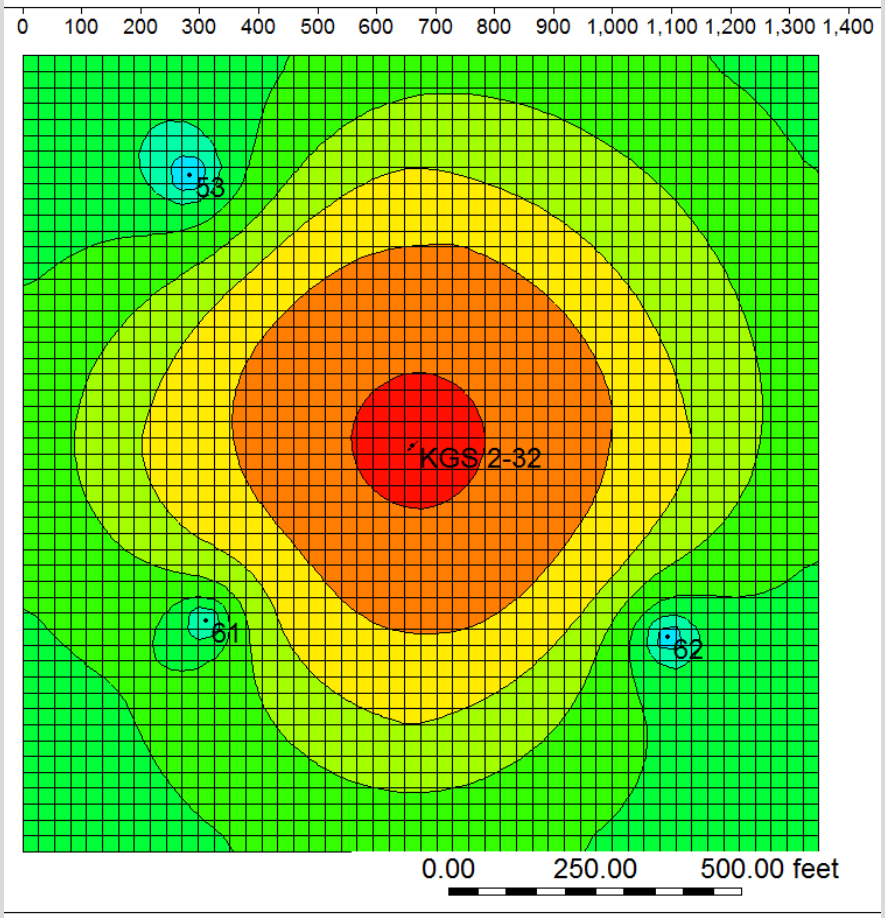
Barrels of oil per day



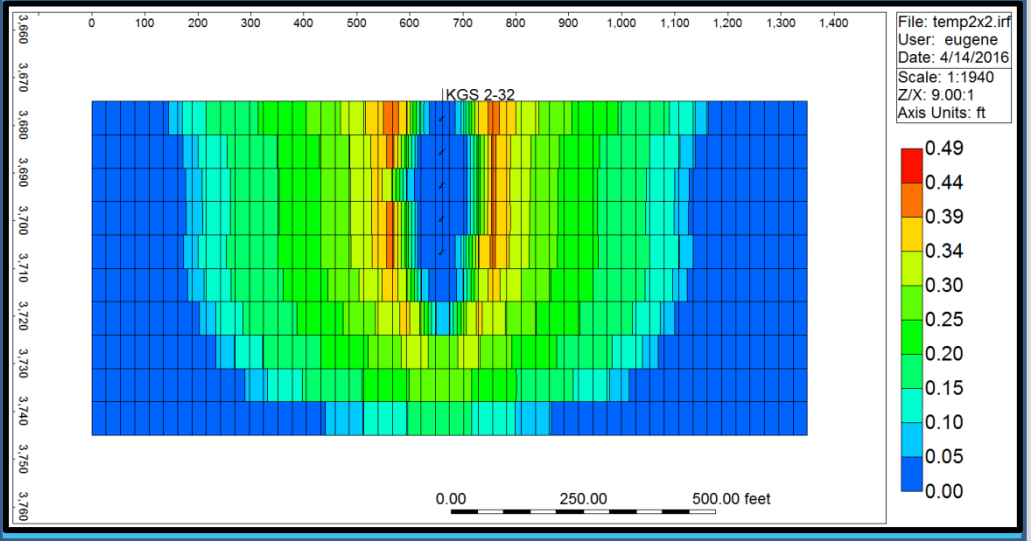
B. Blazer (Berexco), J. Victorine (KGS)

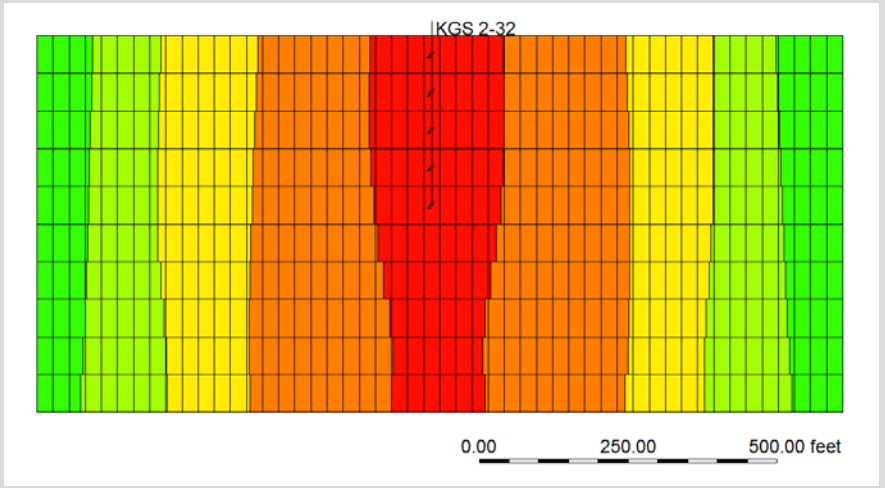
Modeled pressure (psi) map and profile CO_2 injection at KGS 2-32 vertical cross-section view

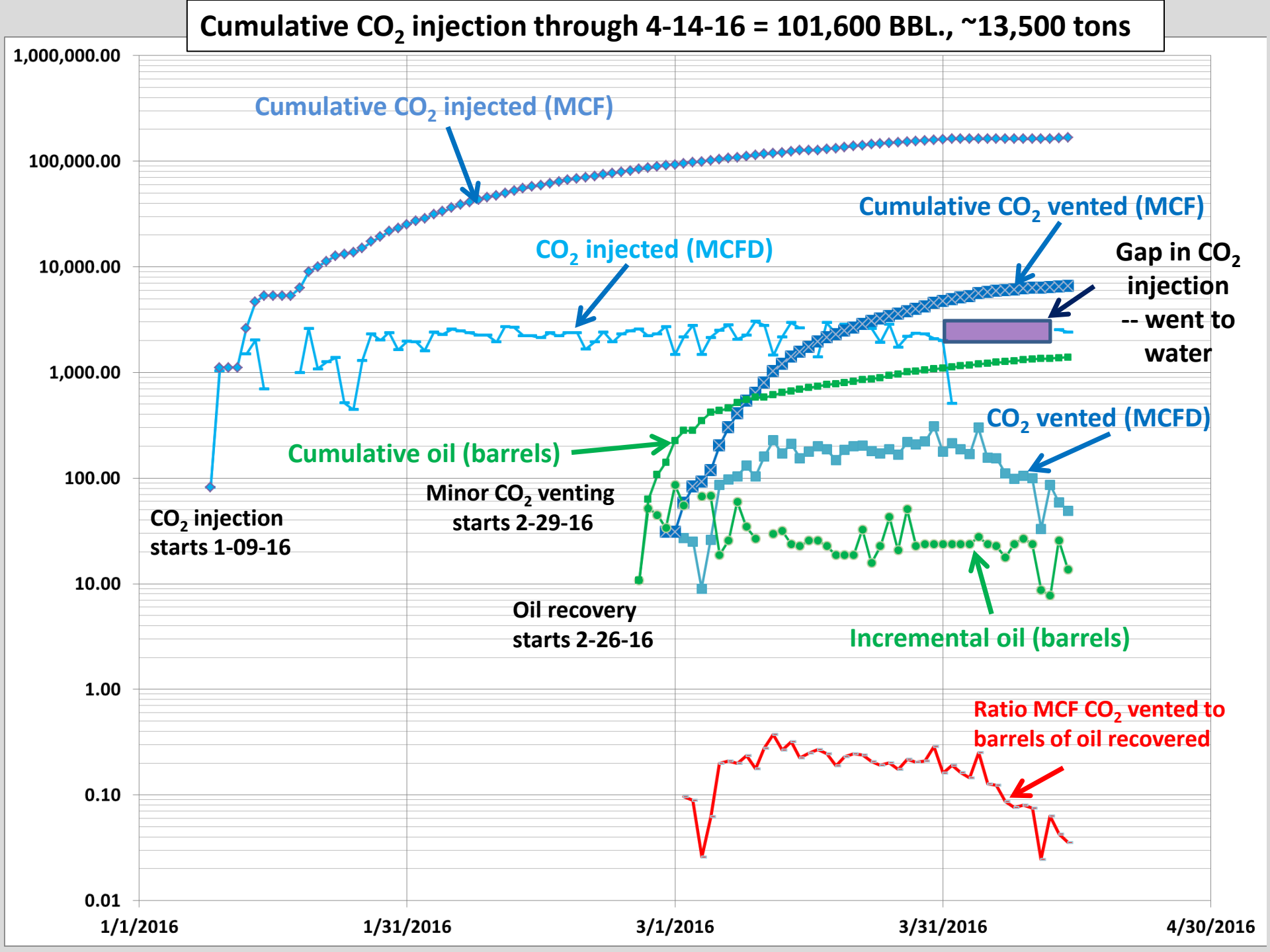




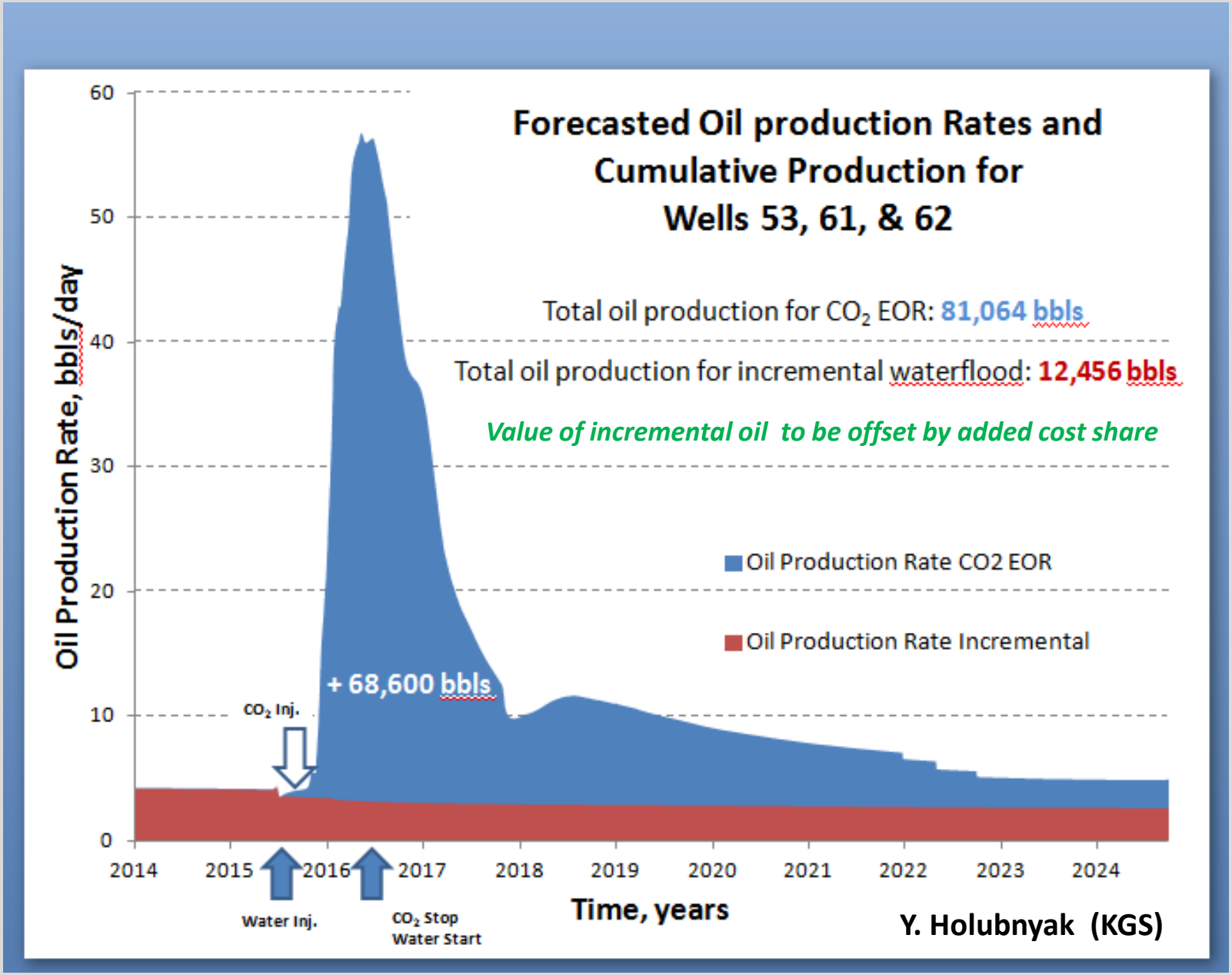
Modeled supercritical CO_2 at KGS 2-32 vertical cross-section

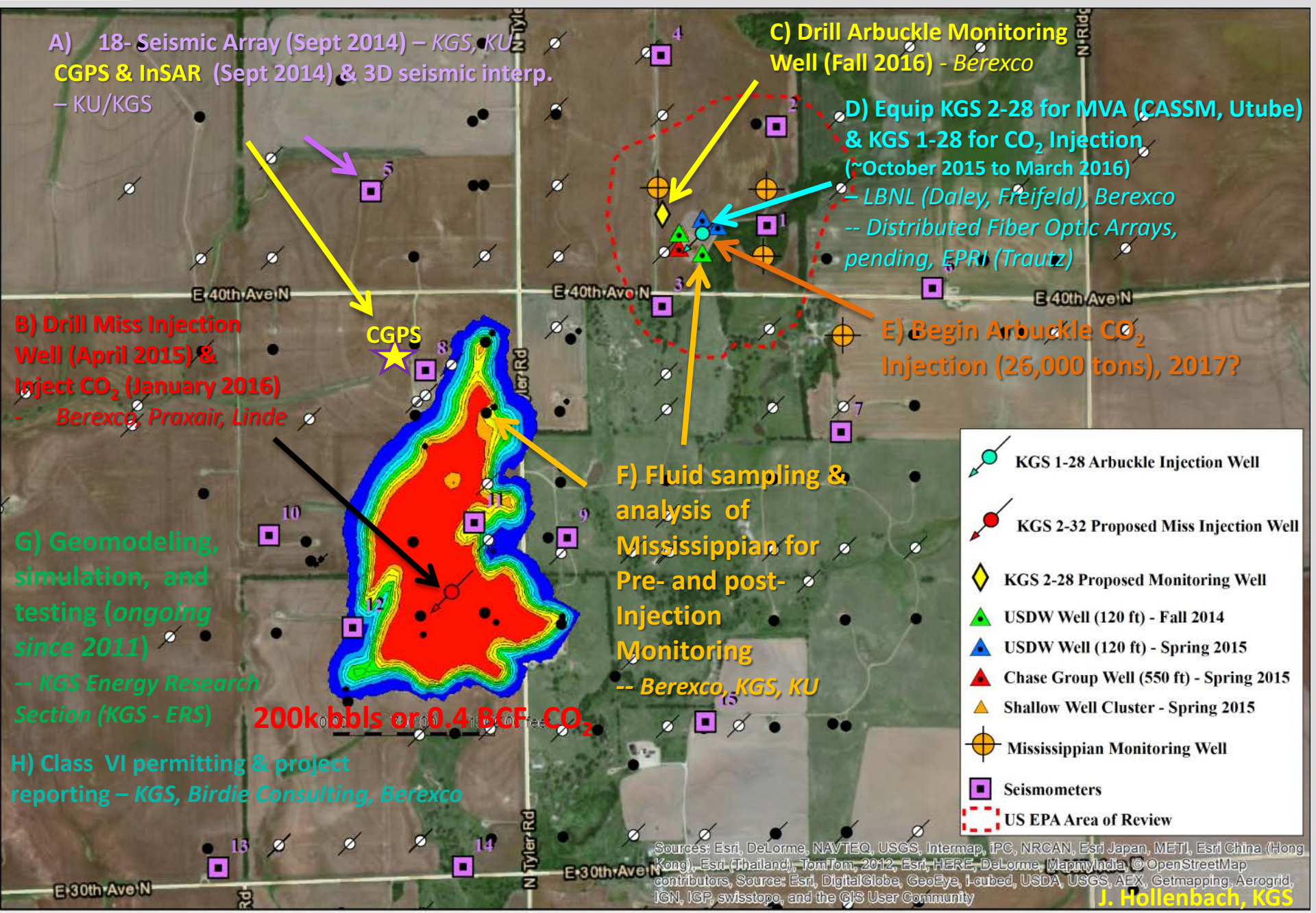





Cumulative CO_2 injection through 4-14-16 = 101,600 BBL., ~13,500 tons
1,000,000.00
100,000.00
10,000.00
1,000.00
100.00
10.00
1.00
0.10
0.01
1/1/2016
1/31/2016
3/1/2016
3/31/2016
4/30/2016
Cumulative CO_2 injected (MCF)
CO_2 injected (MCFD)
Cumulative CO_2 vented (MCF)
Gap in CO_2 injection -- went to water
CO_2 vented (MCFD)
Cumulative oil (barrels)
Minor CO_2 venting starts 2-29-16
CO_2 injection starts 1-09-16
Oil recovery starts 2-26-16
Incremental oil (barrels)
Ratio MCF CO_2 vented to barrels of oil recovered

Ideal oil recovery with 26,000 tonnes of CO_2 injected





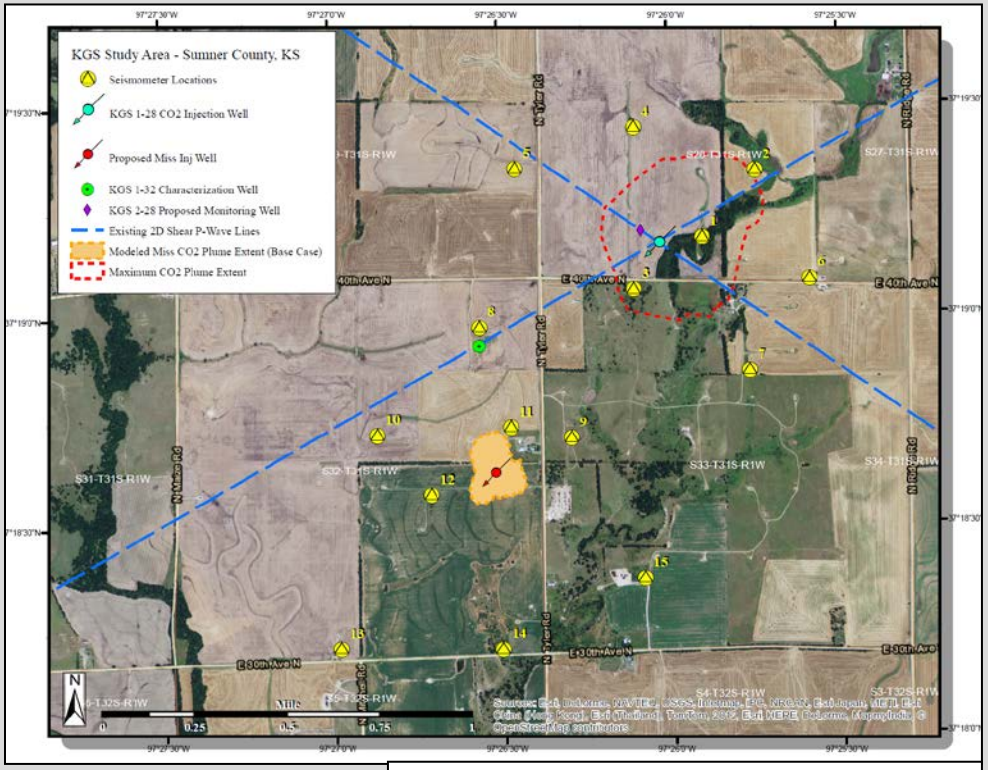
MVA Activity at Wellington CO2 injection site
Sumner County, Kansas
Twn 31S - R 1W

N

Feet
0 750 1500 3000

Sources: USGS, Kansas Geological Survey, Kansas Corporation Commission, DASC.
Map Created October 14, 2014

18 seismic seismometer array operating at Wellington Field to monitor CO_2 pilot tests



G. Tsoflias
Alex Nolte
KU Geology
J. Hollenbach &
J. Victorine, KGS

IRIS Seismometer Installation

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

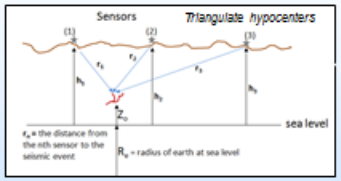
Shelby Peterie, KGS Exploration Services, checking installation in July 2014

21

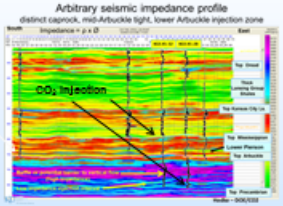
R. Miller and S. Peterie, KGS

Resolution of Hypocenters from IRIS Seismometer Array at Wellington

Refining location of operational seismicity -- Initially for the CO2-EOR injection to evaluate feasibility of methodology

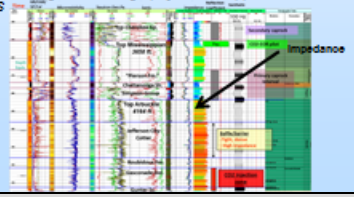


Mississippian and Arbuckle injection zones have good impedance

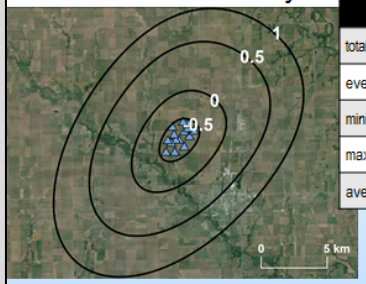


Adapting Java toolset to manage, interpret, and display solutions on project maps (Victorine, KGS)
→ *Time, location (x,y,z) of event from seismometers*

KGS #1-32 --Synthetic seismogram integrated with well logs and stratigraphy – Java app. (Victorine, KGS)



Network Sensitivity



- Minimum magnitude versus distance from the network
- Operational seismicity from active waterflood being recorded in Wellington Field
- Research underway to improve location of hypocenters of events

Local Activity

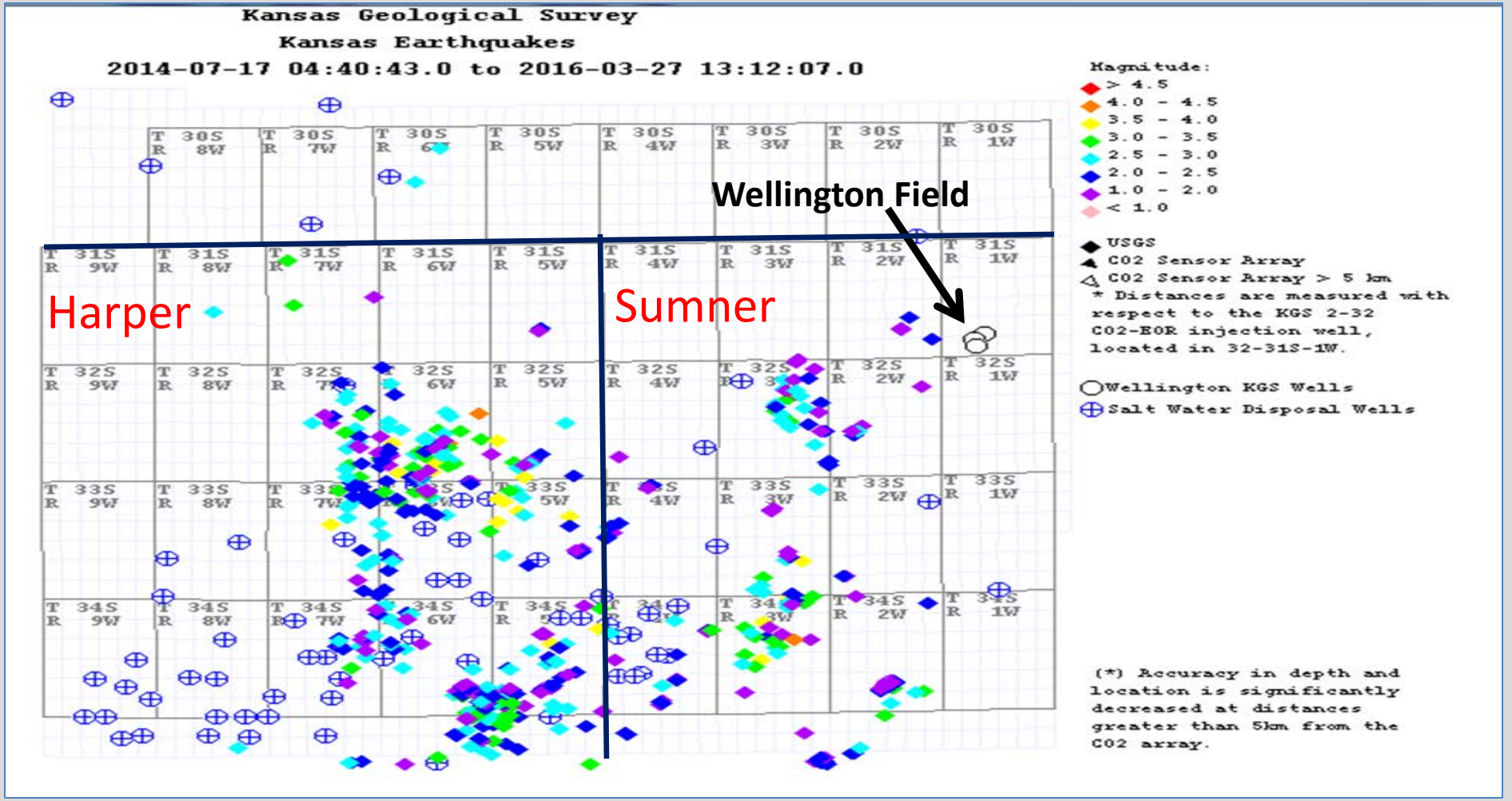
Events detected at ≥ 7 stations†	
total events	53
events/day	4
minimum magnitude	-0.3
maximum magnitude	1.4
average magnitude	0.6

- Earthworm software for automated detection of earthquakes.
- Reporting 2.5+ magnitude per USGS convention.

†Initial recording over one weeks time

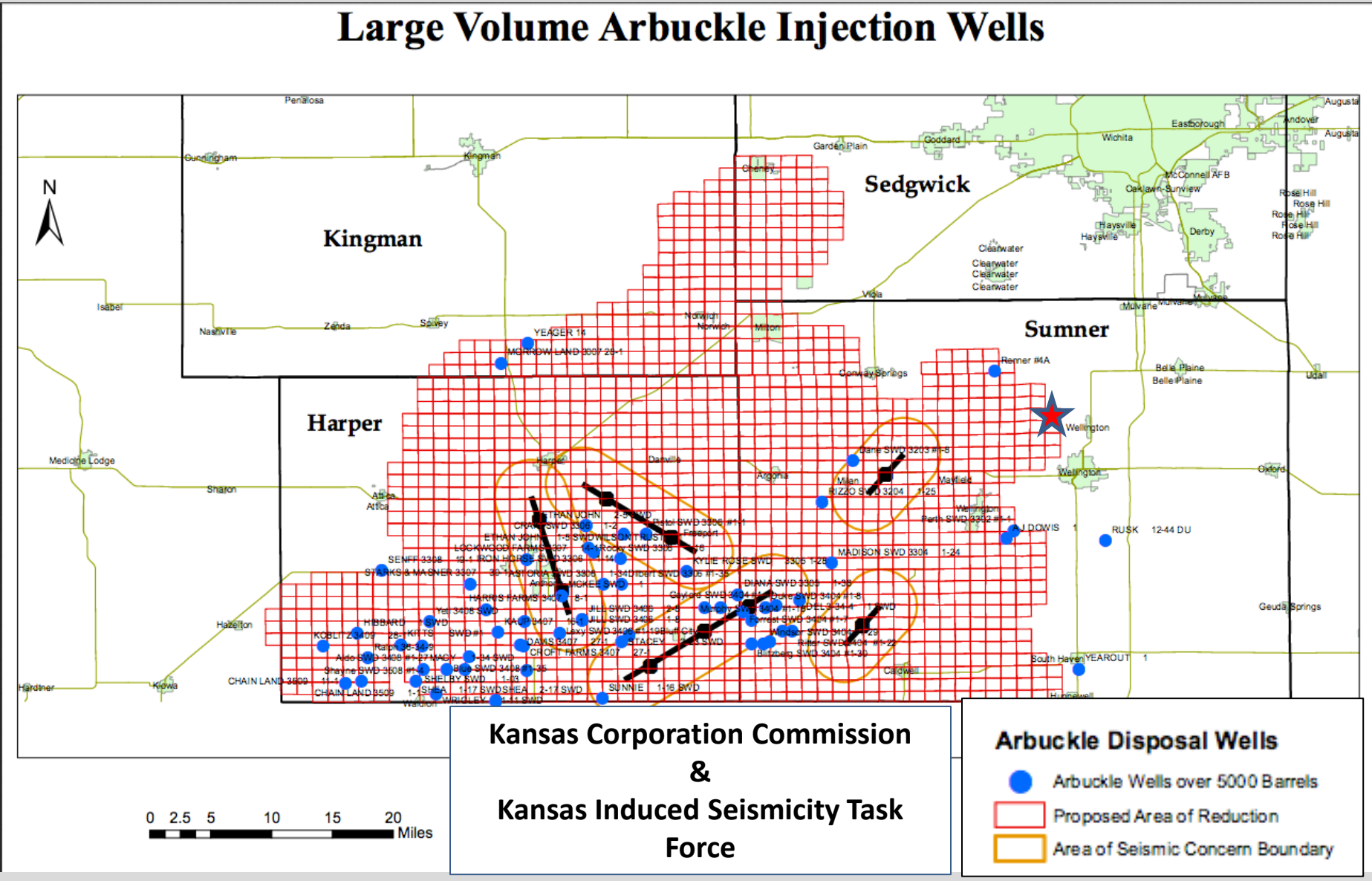
R. Miller and S. Peterie, KGS

Map showing magnitudes of earthquakes recorded by USGS in NEIC catalog during the period 7-17-15 and 3-27-16 in Harper and western Sumner Co.

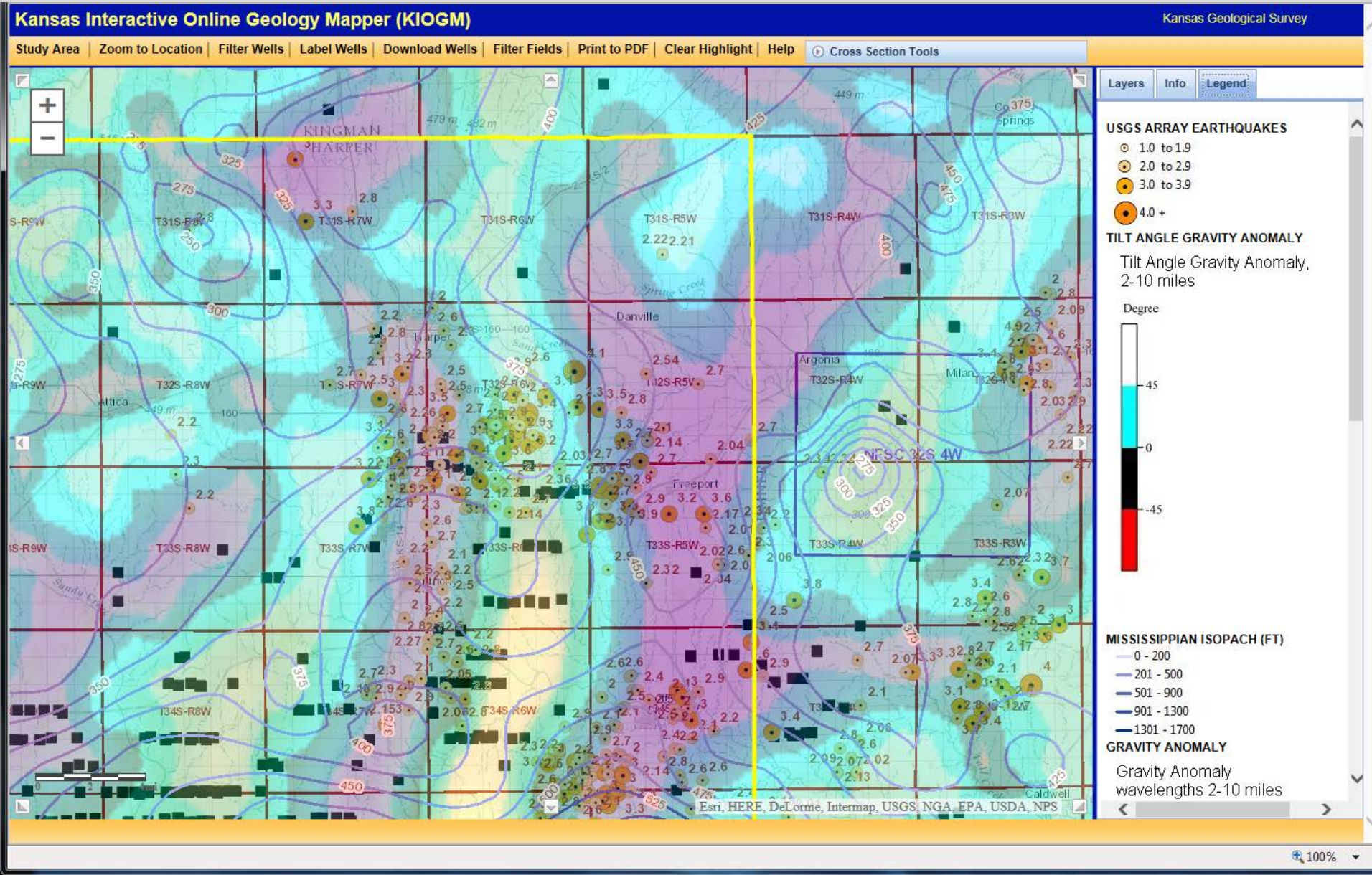


J. Victorine (KGS)

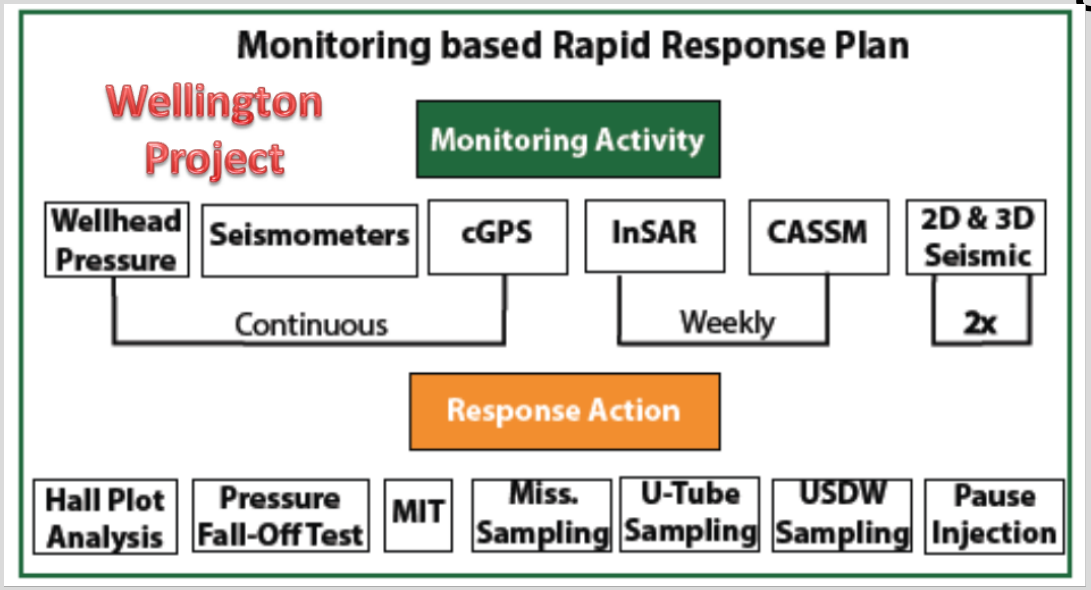
Proposed area of reduction of disposal for management of induced seismicity



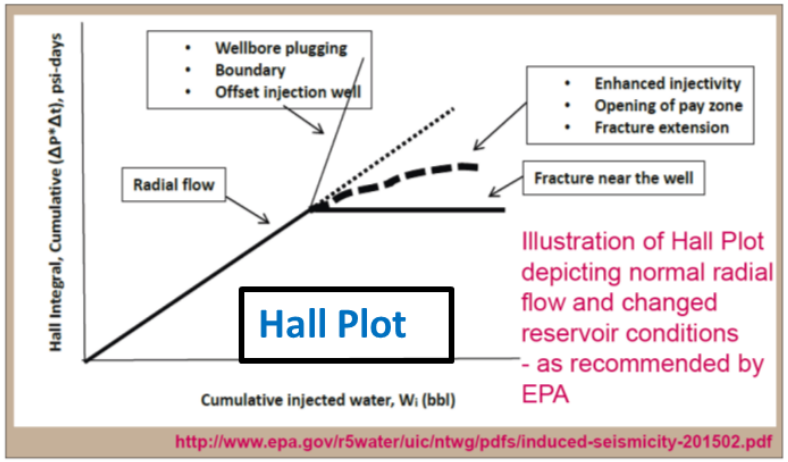
Possible basement controls on clusters of seismicity in south-central Kansas



Operational plan for safe and effective injection in the Arbuckle at Wellington Field



- Injection Control Plan
- Wellington Seismic Action Plan
- Monitoring-based Rapid Response Plan
- Emergency Remedial Response Plan



Under review by EPA

Operational plan for safe and efficient CO2 injection as part of Draft emergency and remedial response plan for Class VI permit

The success of the Monitoring and Rapid Response Plan developed for the Wellington Project is based on prioritizing the monitoring technologies:

1) Reliability of the data and approaches used to analyze the data,
2) Frequency that the data is acquired during injection
3) Sensitivity and precision of the monitoring method and its ability to detect small changes in CO_2 plume behavior;
4) Location and therefore resolution from which the data is collected,
5) Spatial resolution and coverage of the CO_2 plume; and
6) Ability to detect movement out of the injection zone both above and below the injection zone.

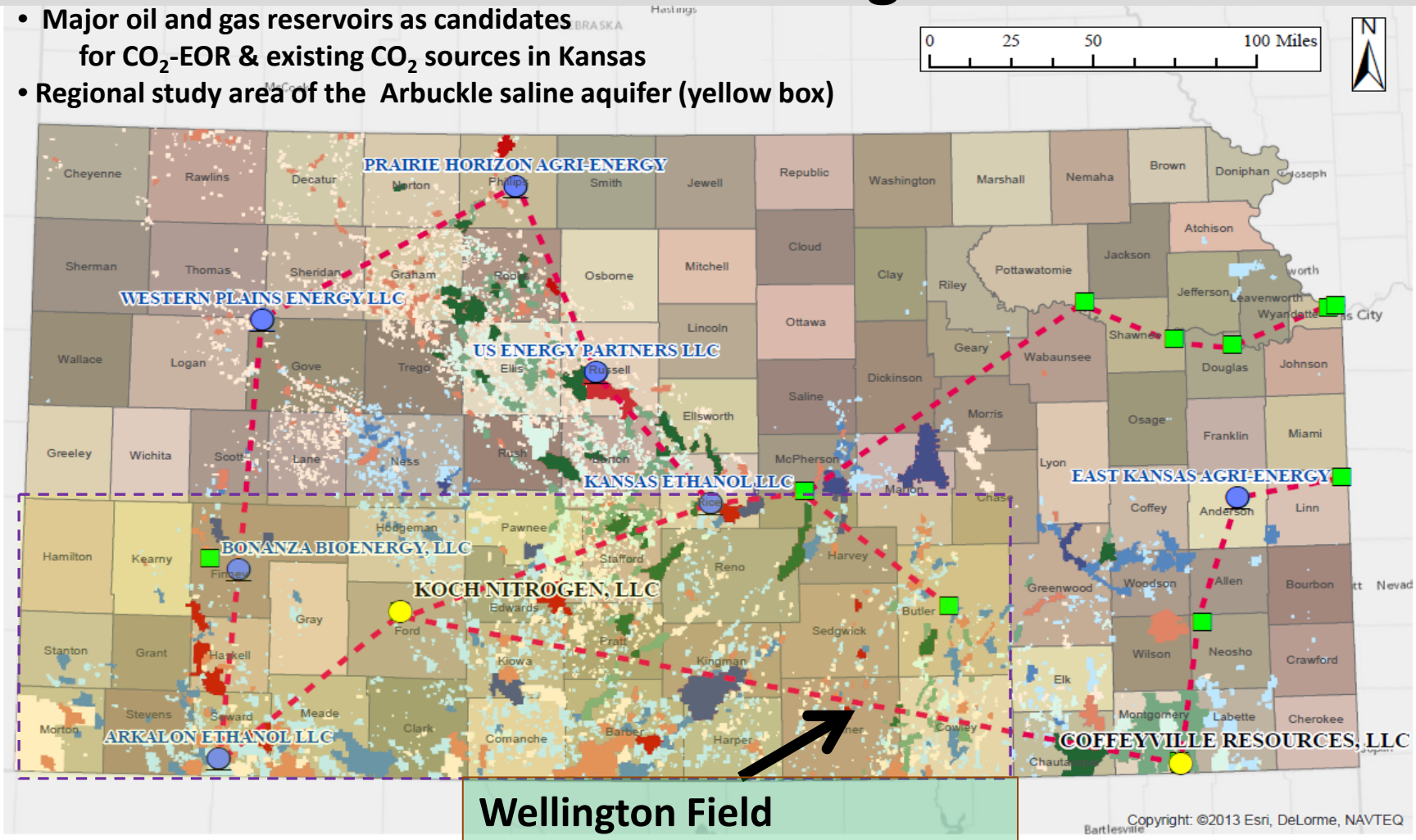
Implementing CO_2 utilization and storage (CCUS) in Kansas

- **Carbon storage and utilization offers significant potential to revitalize Kansas' oil fields.**
  - A 2010 report for the Midwest Governor's Association with input from Tertiary Oil Recovery Program and KGS indicated more than 750 million barrels of oil are potentially recoverable in Kansas with enhanced recovery methods using carbon dioxide
  - Over 50 million metric tons of geologic sourced CO_2 are injected annually into oil reservoirs in the US, mainly in West Texas, with roughly 400,000 bbls of incremental oil recovered per day using the available supplies of naturally occurring CO_2.
- **Why now?**
  - Improved reservoir characterization with the widespread use and availability of cost-effective 3D seismic
  - Improved geoengineering models and monitoring technologies
  - All combined will likely overcome the decades of inertia that have faced the implementation of CO_2-EOR in Kansas

Are you ready?

Kansas concept of large-scale commercial carbon storage via CCUS

- Major oil and gas reservoirs as candidates for CO_2-EOR & existing CO_2 sources in Kansas
- Regional study area of the Arbuckle saline aquifer (yellow box)



Source: USGS, Kansas Geological Survey, DASC

J. Hollenback, KGS

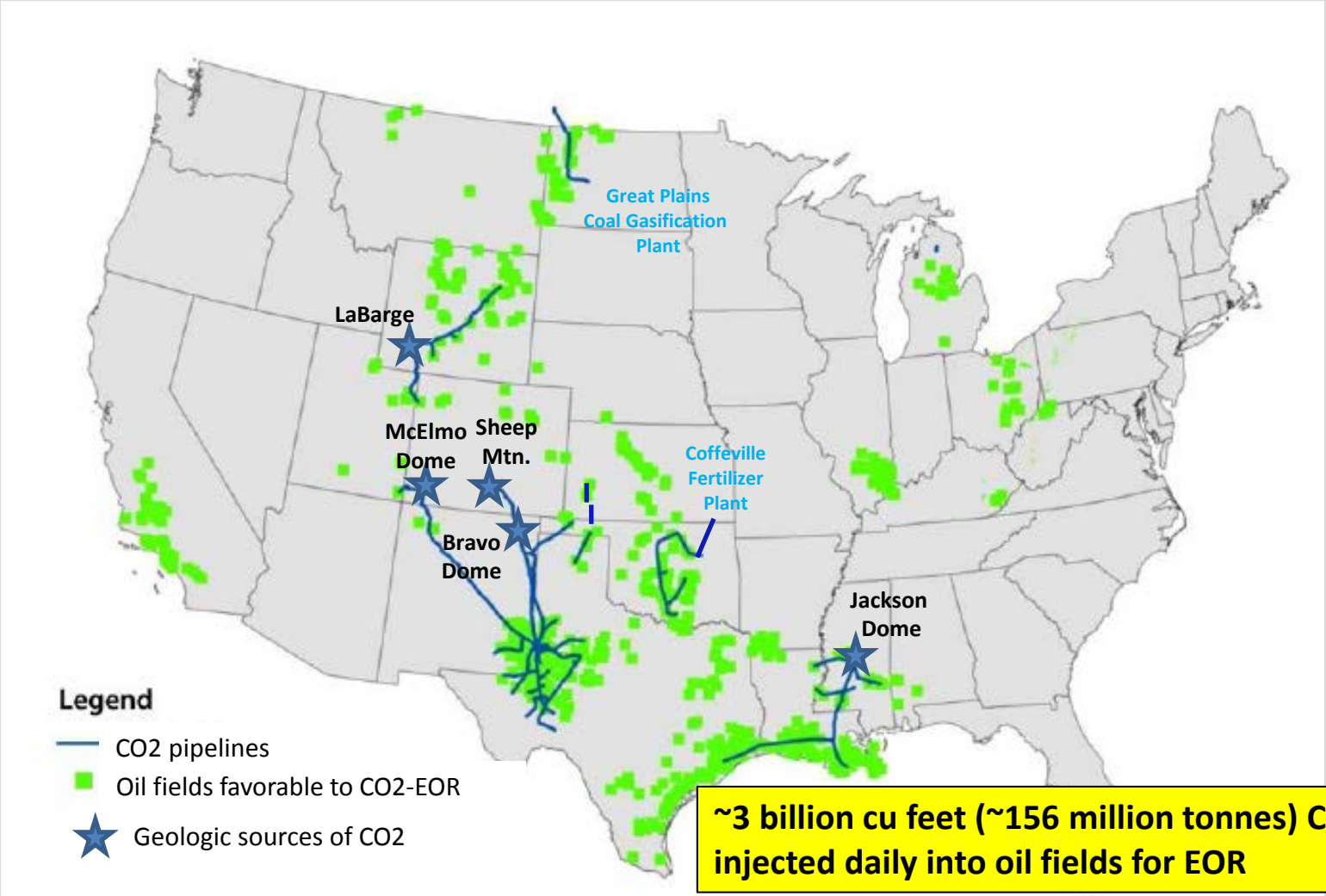
Arbuckle Fields
- 0 - 1,000,000 bbls
- 1,000,000 - 10,000,000
- 10,000,000 - 100,000,000

Lansing-KC Fields
- 0 - 1,000,000 bbls
- 1,000,000 - 10,000,000
- 10,000,000 - 100,000,000

Mississippian Fields
- 0 - 1,000,000 bbls
- 1,000,000 - 10,000,000
- 10,000,000 - 100,000,000

- Ammonia Plant
- Ethanol Plant
- 500,000+ tonnes CO2 emmitted in 2011
- Potential CO2 Pipeline Network

Kansas oil and gas fields are currently isolated from the major regional CO_2 pipeline systems



~3 billion cu feet (~156 million tonnes) CO_2 injected daily into oil fields for EOR

Oil-bearing formations favorable for CO_2-EOR, onshore lower 48 states.
(Source: ARI disaggregated database, Ventex Velocity Suite Database)

Summary

- **Accomplishments**
  - Regional geology & estimate of CO_2 storage capacity in the Arbuckle saline formation in southern Kansas
  - Source-sink network for CO_2 utilization and storage
  - Calibration sites for CO_2-EOR and Arbuckle saline formation
    - Wellington Field, Sumner County (3 wells, multicomponent 3D seismic)
    - Cutter Field, Stevens County (1 well, multicomponent 3D seismic)
    - Pleasant Prairie South, Eubank North, and Shuck fields (120 mi^2 of donated seismic data and
- **Small scale field test at Wellington Field**
  - Assessment of CO_2 injection zone, caprocks, and isolation from USDW
  - CO_2 plume management through simulation, monitoring, verification, and accounting
  - 52,000 metric tons CO_2 pilot injections from Praxair and Linde sources
- Spin-off research on the Mississippian Lime Play, lower Paleozoic hydrocarbon system, induced seismicity
- **Are you ready for CCUS in Kansas?**

KU KANSAS GEOLOGICAL SURVEY
The University of Kansas

NETL

BEREXCO

KSCO2

Acknowledgements & Disclaimer

Acknowledgements

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