Business Implications of A Class VI Permit – The Long View? A Kansas Perspective

W. Lynn Watney
Kansas Geological Survey
Lawrence, KS 66046
lwatney@kgs.ku.edu

April 4-5, 2012 - Golden, Colorado

PUTTING THE BUSINESS ELEMENTS TOGETHER
FOR CO_2 EOR USING CAPTURED CARBON

Colorado School of Mines
Ben Parker Student Center, Ballrooms A & B

NETL

CO2 EOR CCUS PTTC APTA AAPG
PERMIAN CCUS CENTER

KU KANSAS GEOLOGICAL SURVEY
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Outline/Topics

- Update to CCUS in Kansas
  - Current activities sponsored by DOE-NETL
- Resources
  - Oil fields
  - CO_2 supply
  - Arbuckle saline aquifer beneath significant oil fields in southern Kansas
- Addressing and Reducing Uncertainties Associated With a Class VI geosequestration permit
  - Evaluate potential to significant reduce uncertainty and risk in the utilization of deep saline aquifer CO_2 storage beneath existing oil fields
  - Kansas small-scale field test at Wellington Field, Sumner County characterizing and developing refined static and dynamic whole earth models to evaluate flow, storage, and seals to quantify risk and uncertainty, and develop compliance
  - Employ and test monitoring, verification, and accounting (MVA) methodologies that are cost effective and practical, and standard practices of the local petroleum industry
  - Give regulators, state and federal govt. officials assurances that best practices in geology and engineering can be effectively employed to protect freshwater aquifers and manage in context of other resources

Key Points

- ***CCUS* – Carbon Capture, Utilization, and Storage**
  - **Kansas has major CO_2-EOR potential with saline Aquifer sequestration as additional asset beneath oil fields in southern Kansas**
  - **Manage CO_2 by building on existing infrastructure of viable, local petroleum industry**
- **Managing CO_2 plume in deep saline aquifer**
  - **CO_2 plume initially a supercritical free phase liquid that is eventually trapped in the aquifer**
    - **solution, small pores, and reaction with rock**
  - **Tailored computer simulations of CO_2 storage based on rock and fluid data for review and permitting**
  - **Monitor CO_2 plume with latest technology**
    - **Evaluate progress and compare to simulations**
    - **Demonstrate containment with off-the-shelf technology**

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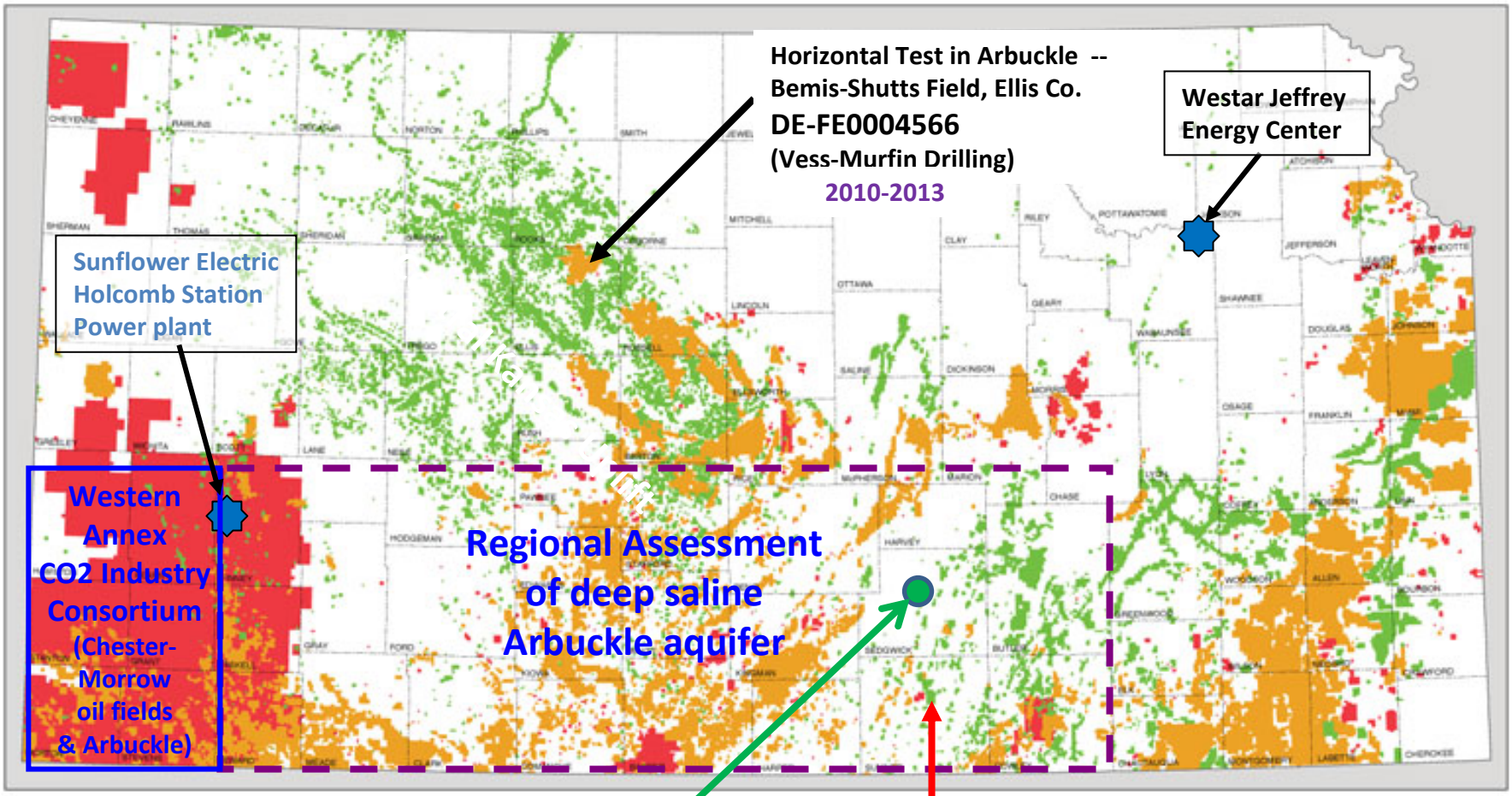
OIL AND GAS FIELDS OF KANSAS



Partners
FE0002056

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NETL

U.S. DEPARTMENT OF ENERGY

DEPARTMENT OF GEOLOGY
KANSAS STATE UNIVERSITY

KU THE UNIVERSITY OF KANSAS Department of Geology

Wellington Field Operator
BEREXCO

fairfieldnodal

ECHO GEOPHYSICAL CORPORATION
INTEGRITY-STABILITY-INNOVATION

PARAGON
GEOPHYSICAL SERVICES, INC

noble energy

Devilbiss Coring Service
Basic Energy Services

LOCKHART GEOPHYSICAL

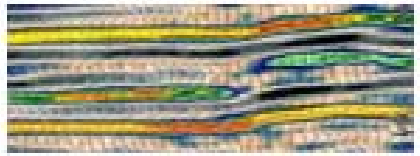
MUDCO

Weatherford LABORATORIES

TRILOBITE TESTING, INC.

HALLIBURTON

HEDKE-SAENGER GEOSCIENCE, LTD



Bittersweet Energy Inc.

Charter Consulting
Integrated Geology & Geophysics

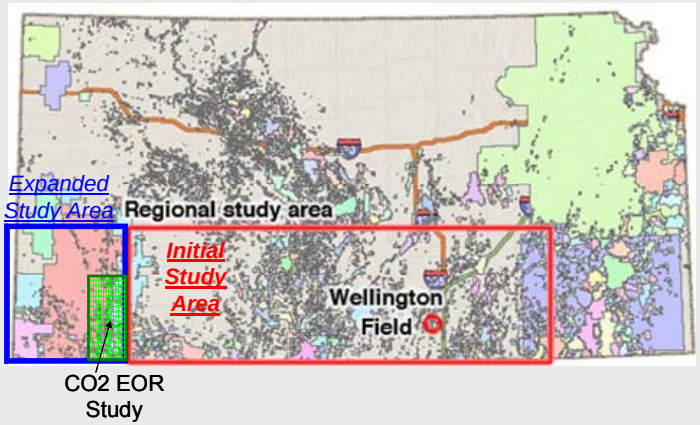
Petrotek

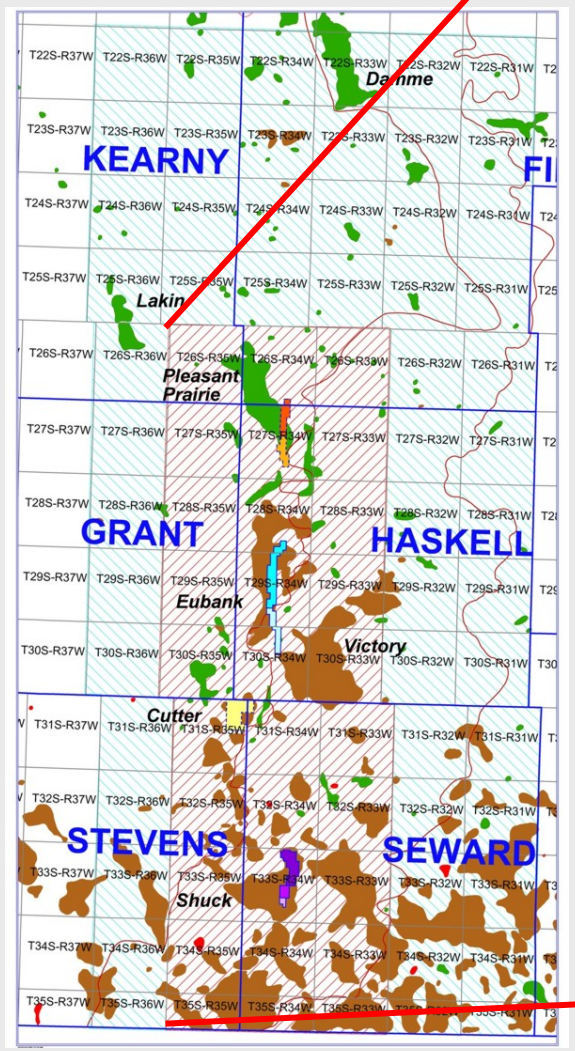
KOGER
REMOTE SENSING

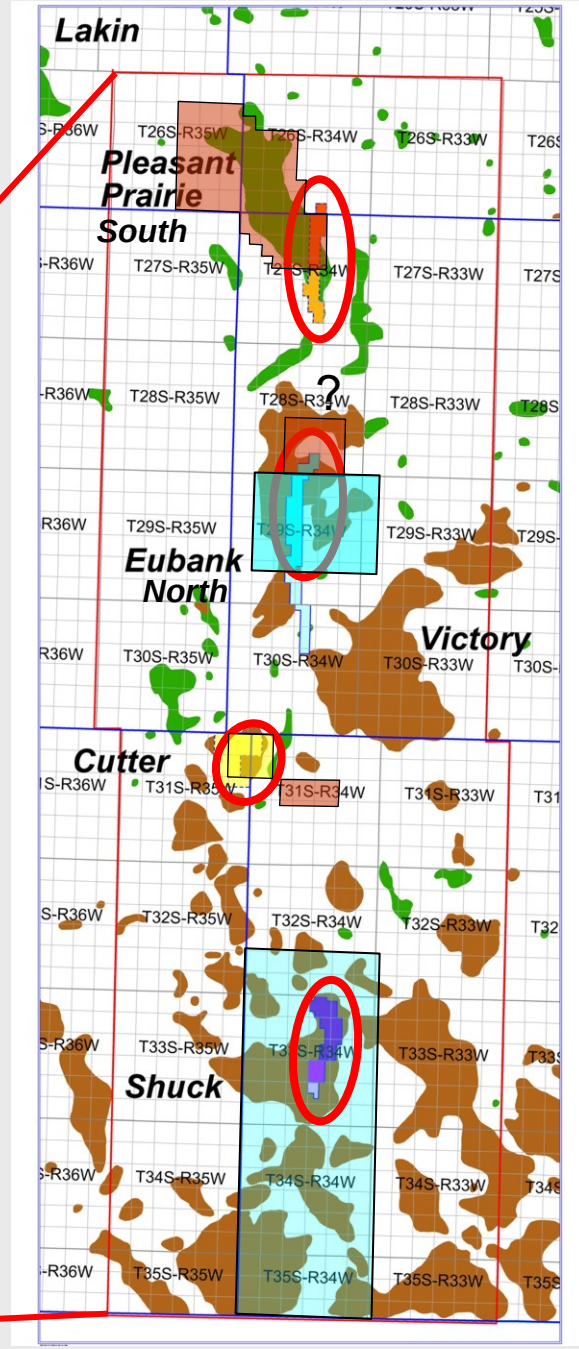
LOGDIGI
A LEADING CONSULTING COMPANY

Southwest Kansas CO_2 Consortium (*Western Annex*)

Seismic blocks are color coded by operator (~120 mi² of 3D seismic)







Chester/Morrow Sandstone (IVF) & Deep saline Arbuckle aquifer

Industry Partners (Enhancement to FE0002056)

SW Kansas CO_2 Consortium/Western Annex

IHR Improved Hydrocarbon Recovery LLC

HEDKE-SAENGER GEOSCIENCE, LTD

SUNFLOWER ENERGY LLC

+drilling and seismic contractors TBN

CIMAREX

GloriOil

BEREXCO

Anadarko Petroleum Corporation

Dawson-Markwell Exploration Co.

CELEBRATING 20 YEARS

MERIT ENERGY COMPANY

Industrial and Electrical Power Sources of CO_2

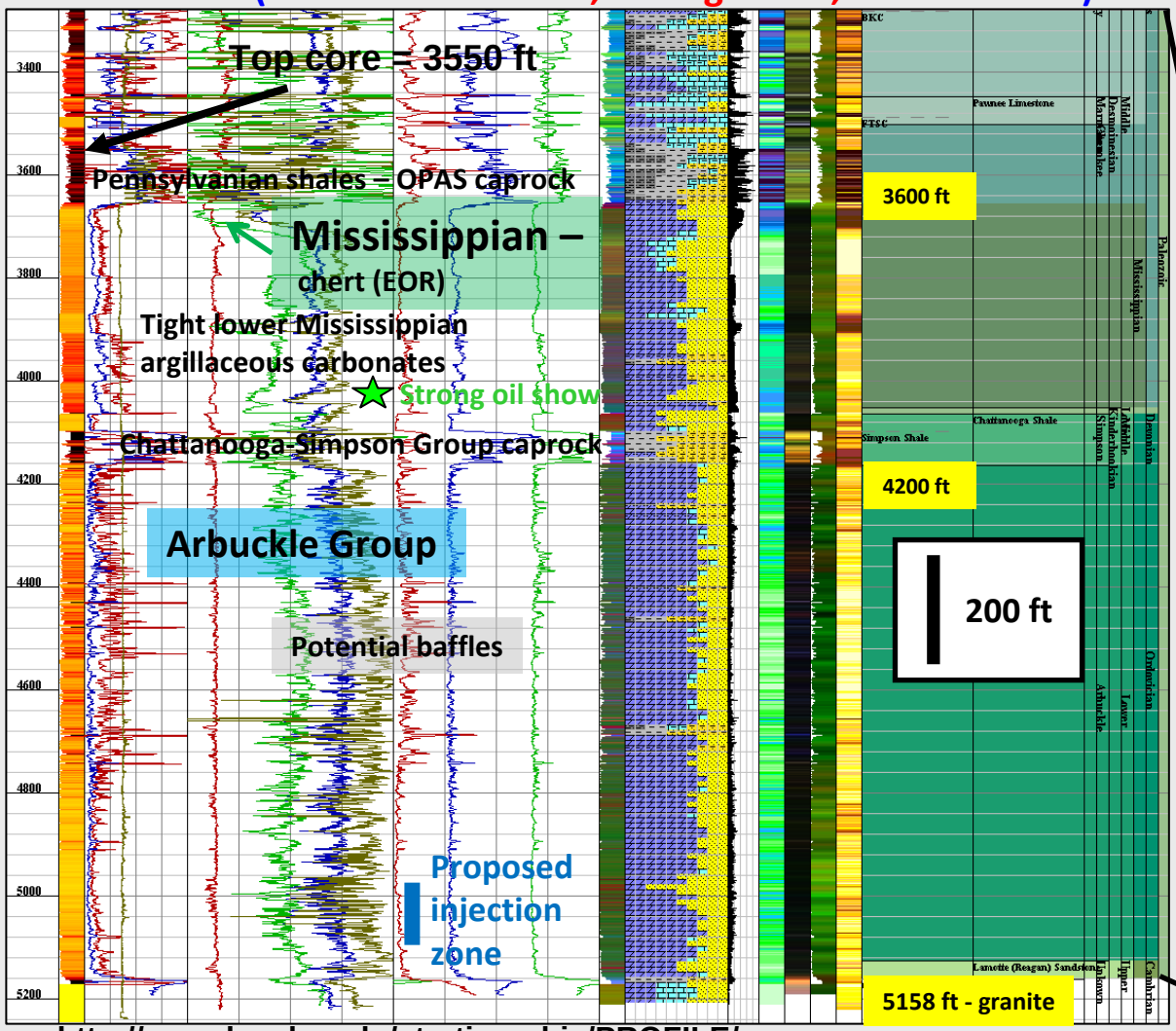
Conestoga Energy Partners, LLC
fueling the new frontier

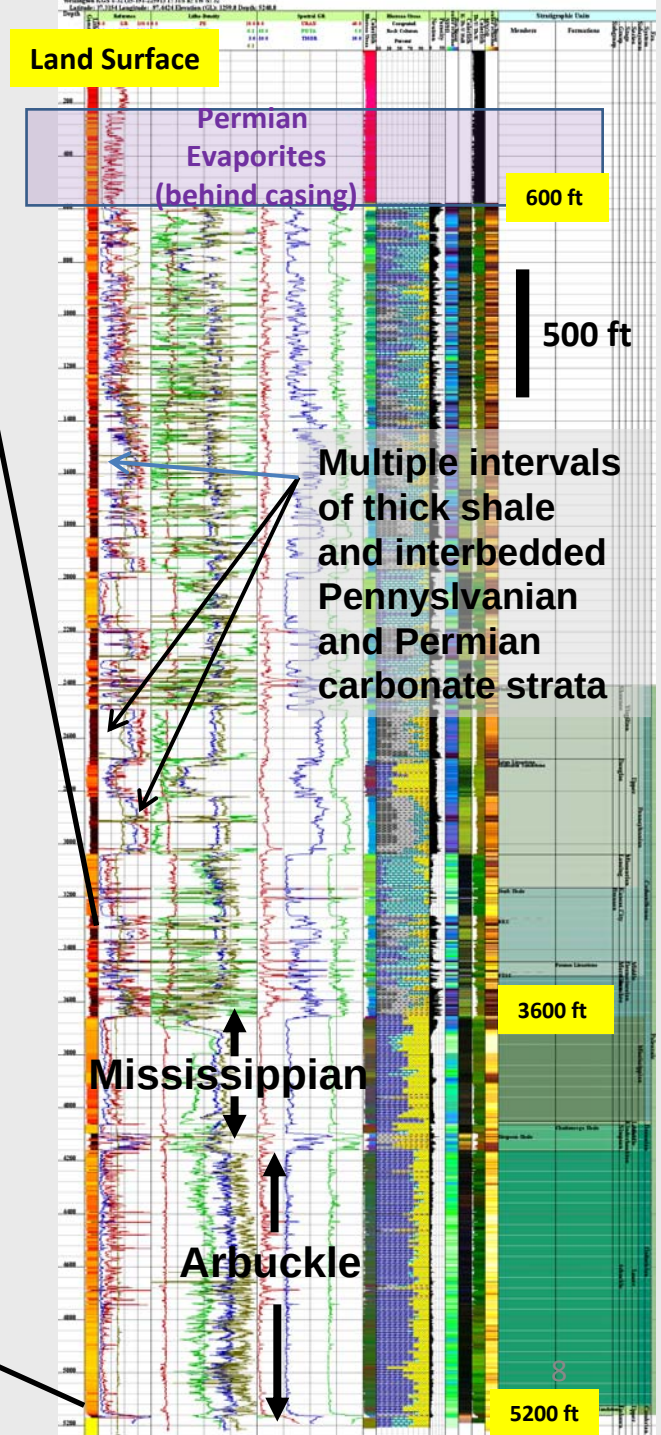
SUNFLOWER ELECTRIC POWER CORPORATION
A Touchstone Energy® Cooperative
. . . energy done right

Abengoa Bioenergy : The Global Ethanol Company

Stratigraphic Column New Basement Test
Berexco Wellington KGS #1-32

Completed at Wellington Field
February 2011
Conventional 4.5 inch core from base Pennsylvanian shales to basement (3550-5178 interval, 1628 gross ft, 1528 net feet)

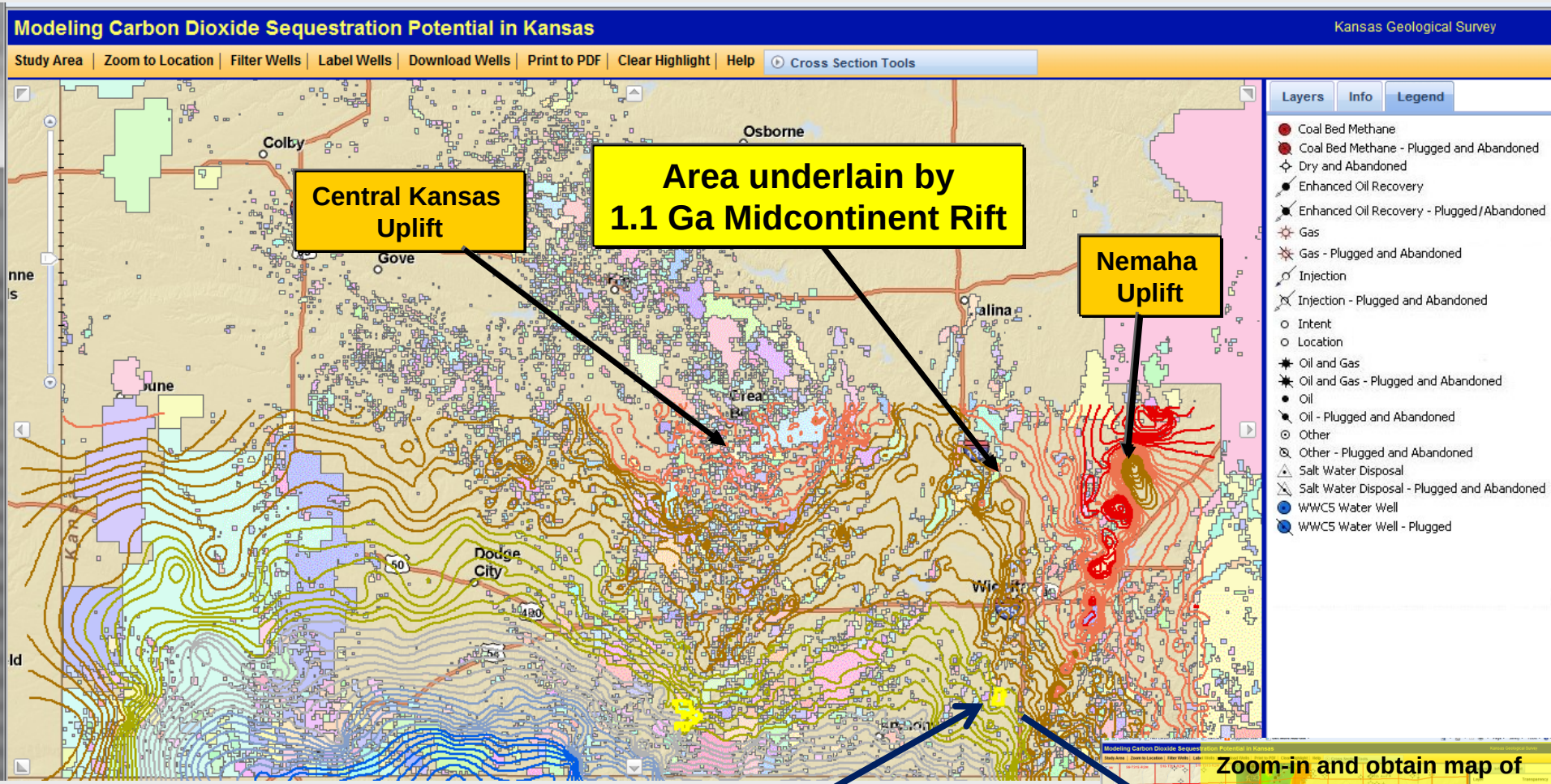




http://www.kgs.ku.edu/stratigraphic/PROFILE/

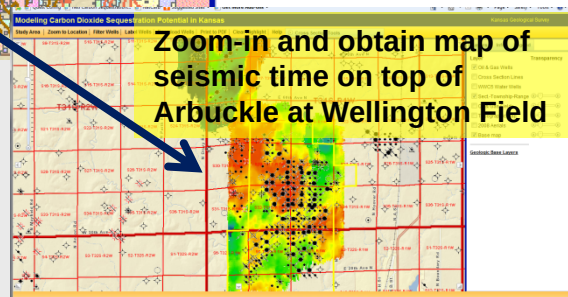
Web-based Interactive Project Mapper

Overlay of Oil and gas field outlines and Top Arbuckle Group in study area of southern Kansas



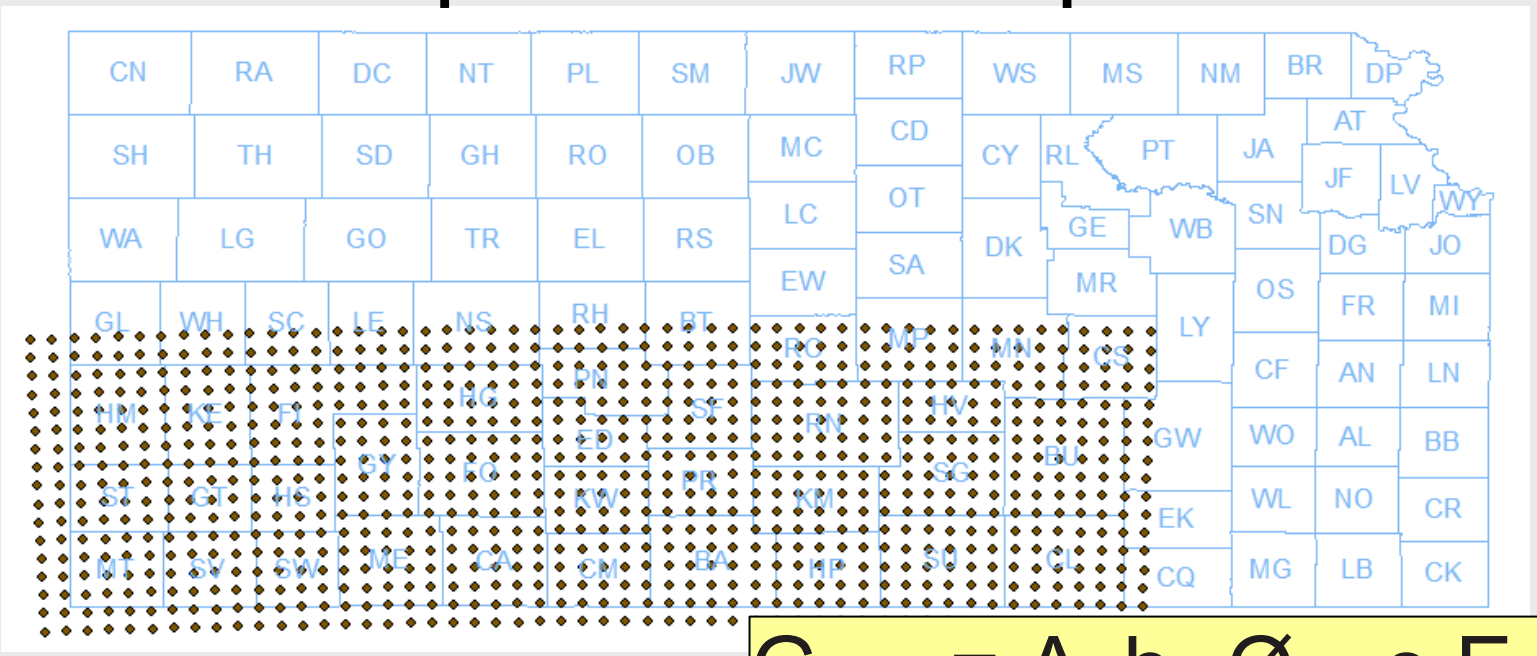
Contours = Elevation on Top of Arbuckle

Wellington Field



http://maps.kgs.ku.edu/co2/?pass=project

Initial Storage Capacity Estimate (April 2011)
Deep Arbuckle Saline Aquifer



$$G_{CO2} = A_t \, h_g \, \emptyset_{tot} \, \rho \, E_{saline}$$

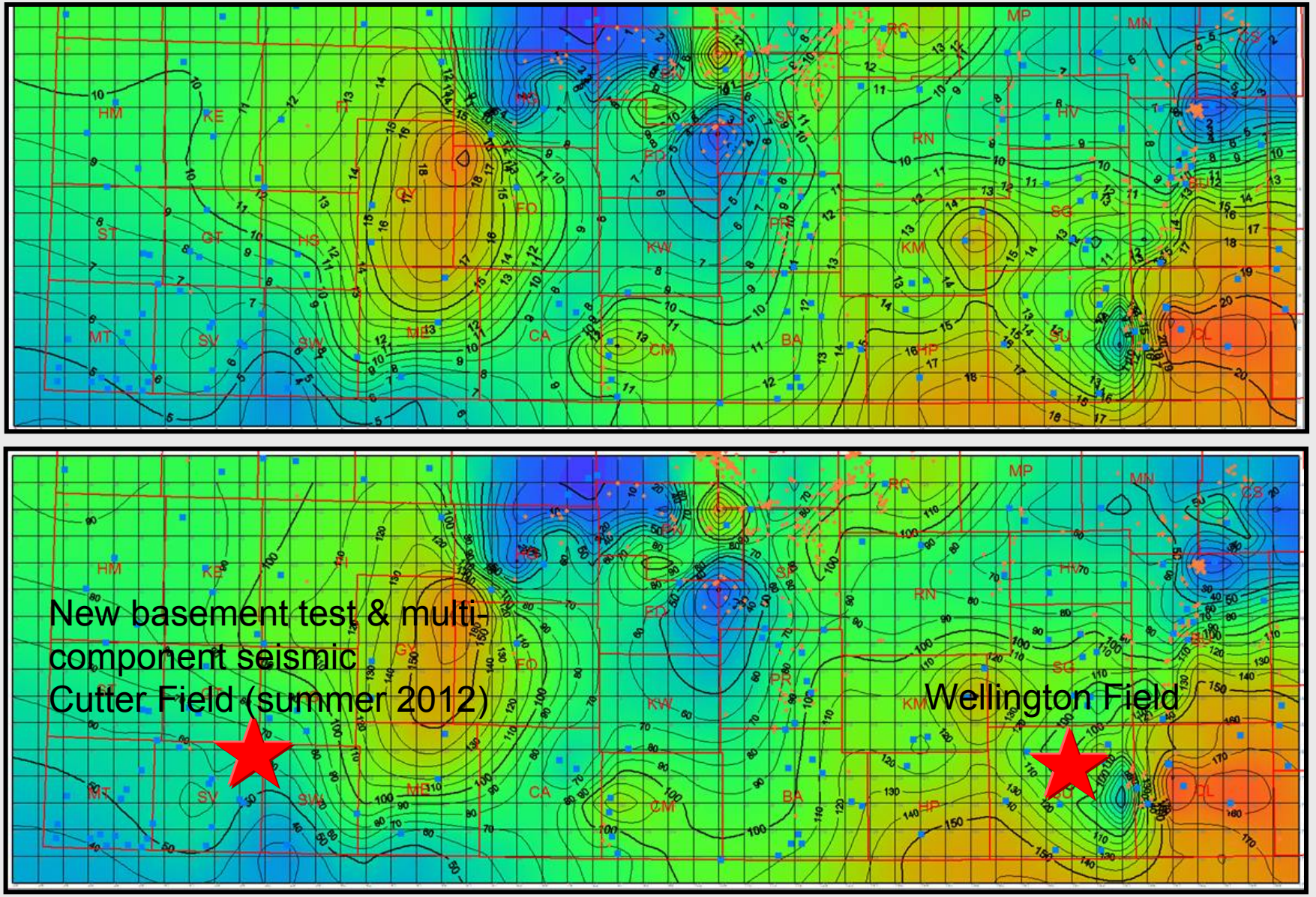
Tonnes CO_2 per Grid Cell 10 km^2 (3.8 $mi^{2)}$

Each grid cell is 10K (+/-)

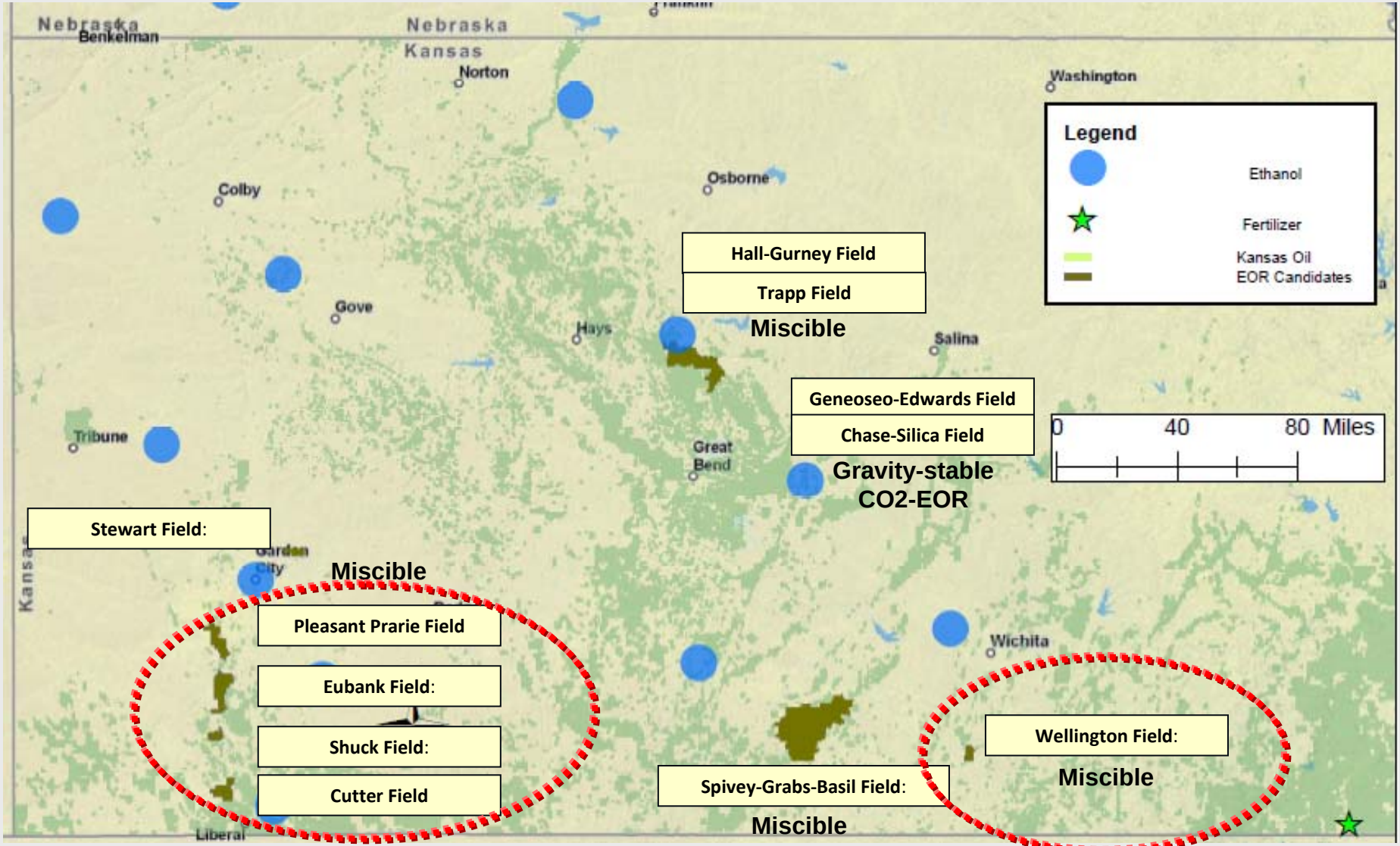
P10	
8,781,380,535	Total All Cells
22,214,247	High Cell
10,287,863	Median Cell
10,554,544	Mean Cell

P90	
75,464,988,970	Total All Cells
190,903,682	High Cell
88,411,323	Median Cell
90,703,112	Mean Cell

P10 (top) and P90 (bottom) storage volume CO_2 (million tonnes)

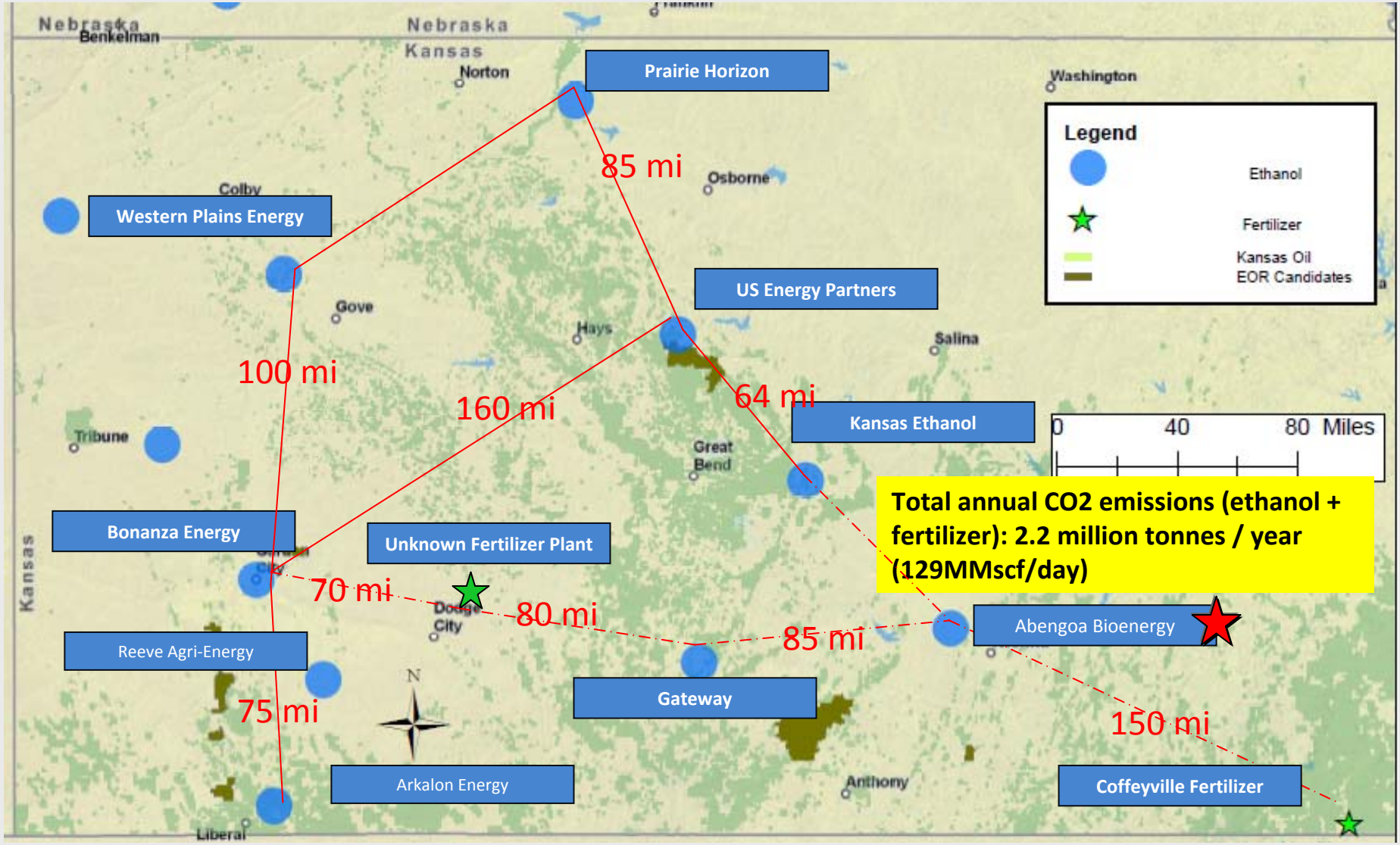


Ethanol Plants and Selected Oil Fields for CO2-EOR



SW industry CO2 EOR partnership
Chester/Morrow fields

CO_2 (Ethanol & Fertilizer Based) Pipeline

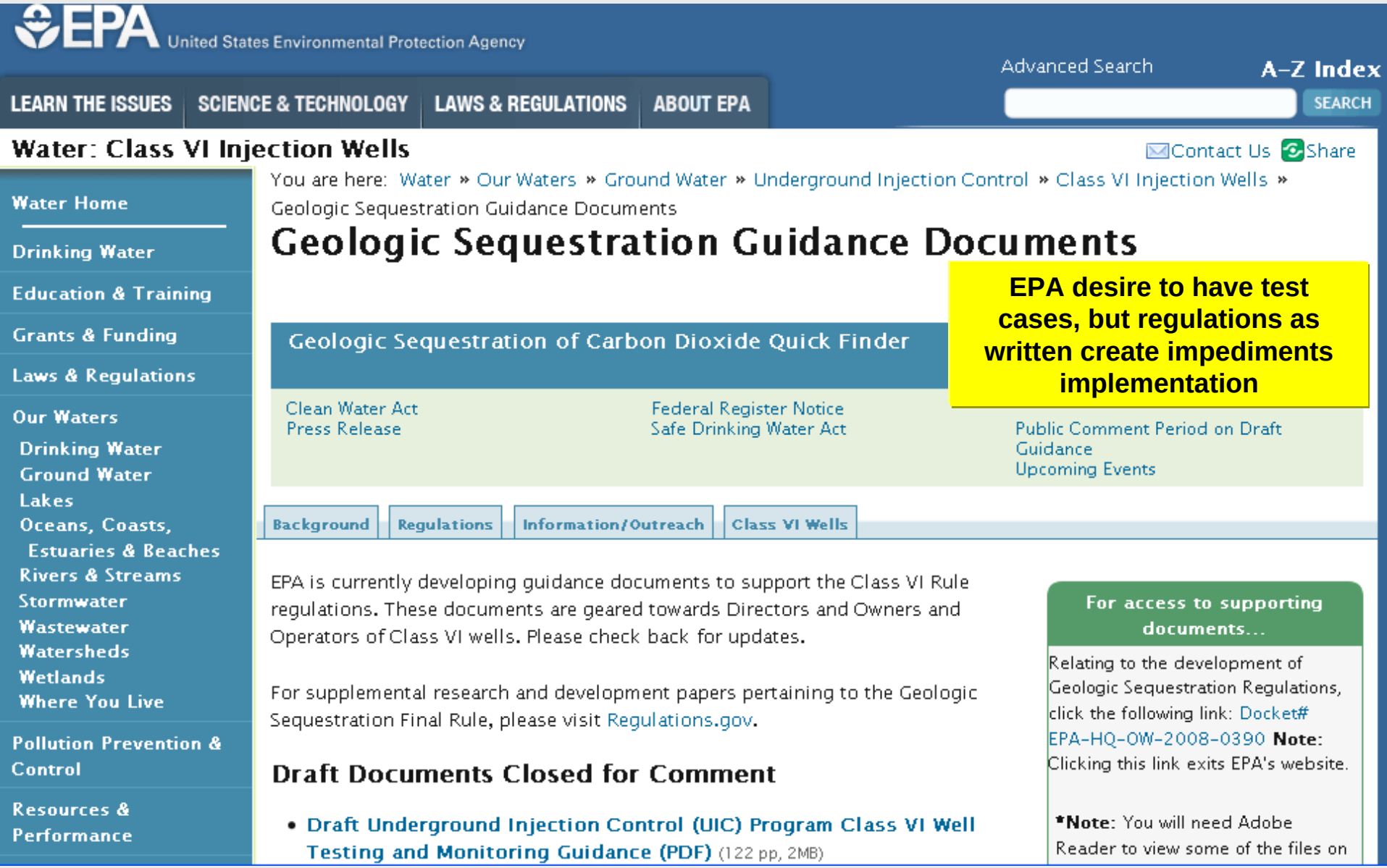


Reducing Uncertainties Associated with a Class VI Permit

- **Key questions needed to guide decision to inject:**
  - What exactly does EPA need to see in our modeling results to consider modifying default requirements?
  - What corresponding relief in the monitoring/bonding obligations can we expect?
  - What is the expected duration of the Class VI application process?
  - What are targets associated with modeling/monitoring/application parameters and processes?

- **Dialog with regulators:**
  - Provision in Class VI Final Rule to reduce the monitoring period by demonstrating through modeling/monitoring that there is no danger to the freshwater aquifers
  - 50-yr period monitoring is by default
  - Show by modeling and monitoring that the pressures and plume have "stabilized"
  - Up to applicant to demonstrate by modeling that there will be minimal impacts
  - If the pressures and the CO_2 plume have stabilized and that no alarming trends have been observed in the monitoring network, then the monitoring can also be shortened.
  - Bonding is a function of risk, duration, and type of monitoring needed to time of closure
  - Recognition that saline aquifer beneath oil field inherently reduces uncertainty of containment

EPA (Region 7) and State Regulators in Kansas working together with the petroleum industry and other stakeholders to implement Class VI Injection



GS Rule Related Guidance
Document Development

- **Guidance Documents Currently Under Development:**
  - Financial Responsibility (***Open for Comment Now***)
  - Public Participation Fact Sheet
  - Site Characterization
  - Area of Review and Corrective Action
  - Well Construction
  - Testing and Monitoring
  - Revised UICPG #83 for Class V Experimental Wells
  - Project Plan Development
  - Injection Depth Waiver
  - Primacy Application and Implementation Manual

Geologic Carbon Sequestration -- Characterizing Pore Space & Managing CO_2 Plume

W. Lynn Watney
Kansas Geological Survey
Lawrence, KS
lwatney@kgs.ku.edu

Joint Committee on Energy and Environmental Policy
Room 152-S
October 18, 2011

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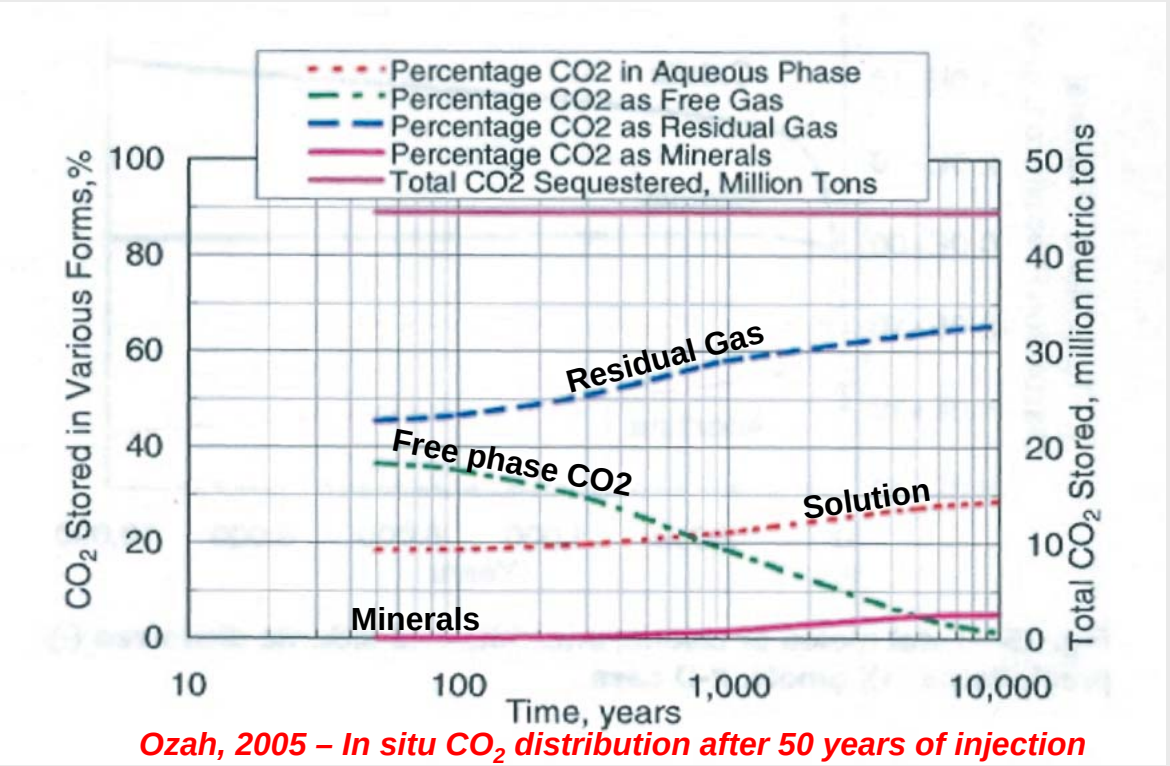
KANSAS LEGISLATURE

Fate and Entrapment of CO_2 in Saline Aquifers

Injected CO_2 entrapped in 4 different ways

- some dissolves in brine
- some gets locked as residual gas (saturation)
- some trapped as minerals
- Remaining CO_2 – resides as free phase
  - Sub- or super-critical as per *in situ* conditions (depth/pressure and temperature)



Ozah, 2005 – In situ CO_2 distribution after 50 years of injection

CO_2 Entrapment Audit:

1. ***Residual gas***
   - ***Start 45% to End 65%***
2. ***Solution***
   - ***Start 18% to End 28%***
3. ***Minerals***
   - ***Start negligible to End 5%***
4. ***Free Phase***
   - ***Start 37% to End 2%***

Small Scale Field Test Demonstrating CO_2 sequestration in Arbuckle Saline Aquifer and by CO_2-EOR at Wellington field, Sumner County, Kansas --

W. Lynn Watney and Jason Rush
Kansas Geological Survey
Lawrence, KS 66047

Regional Carbon Sequestration Partnerships
Annual Review Meeting
October 15-17, 2011
Pittsburgh, PA

Funding Opportunity Number: DE-FOA-0000441
Contract #FE0006821
$11,484,499 DOE
$3.236 million cost share

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BEREXCO

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY

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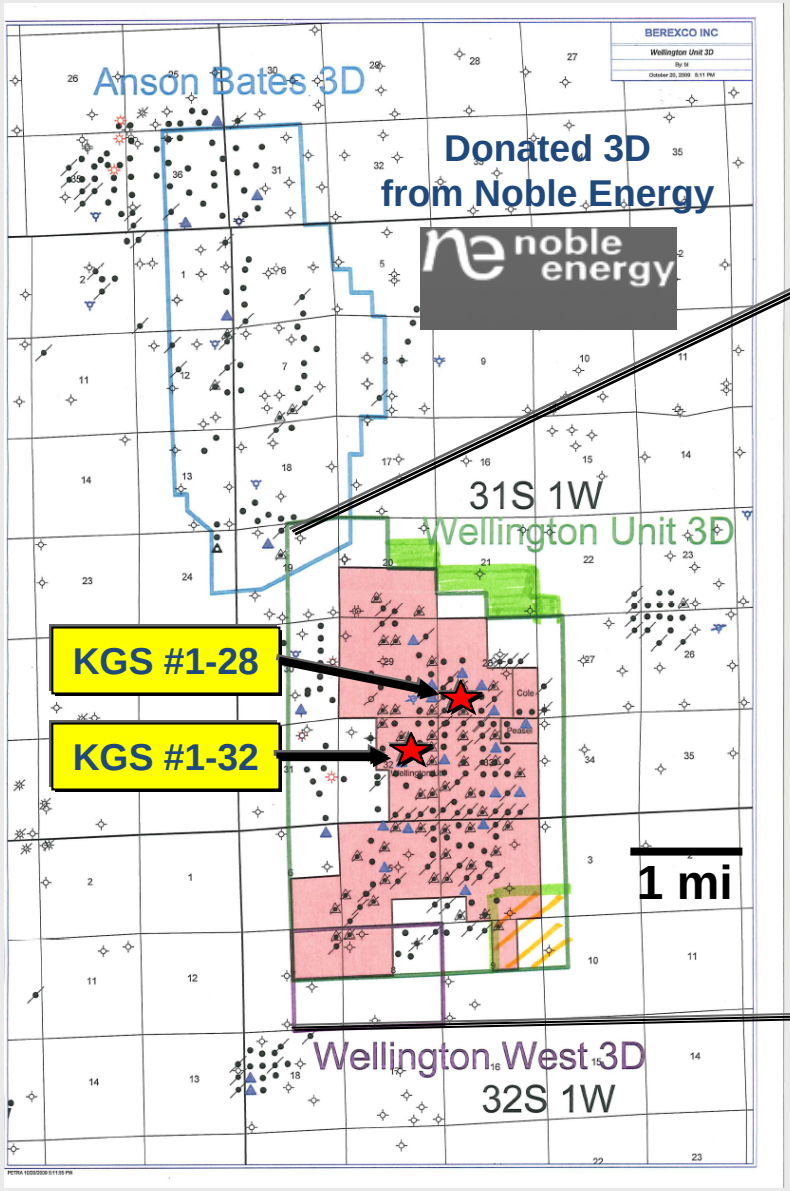
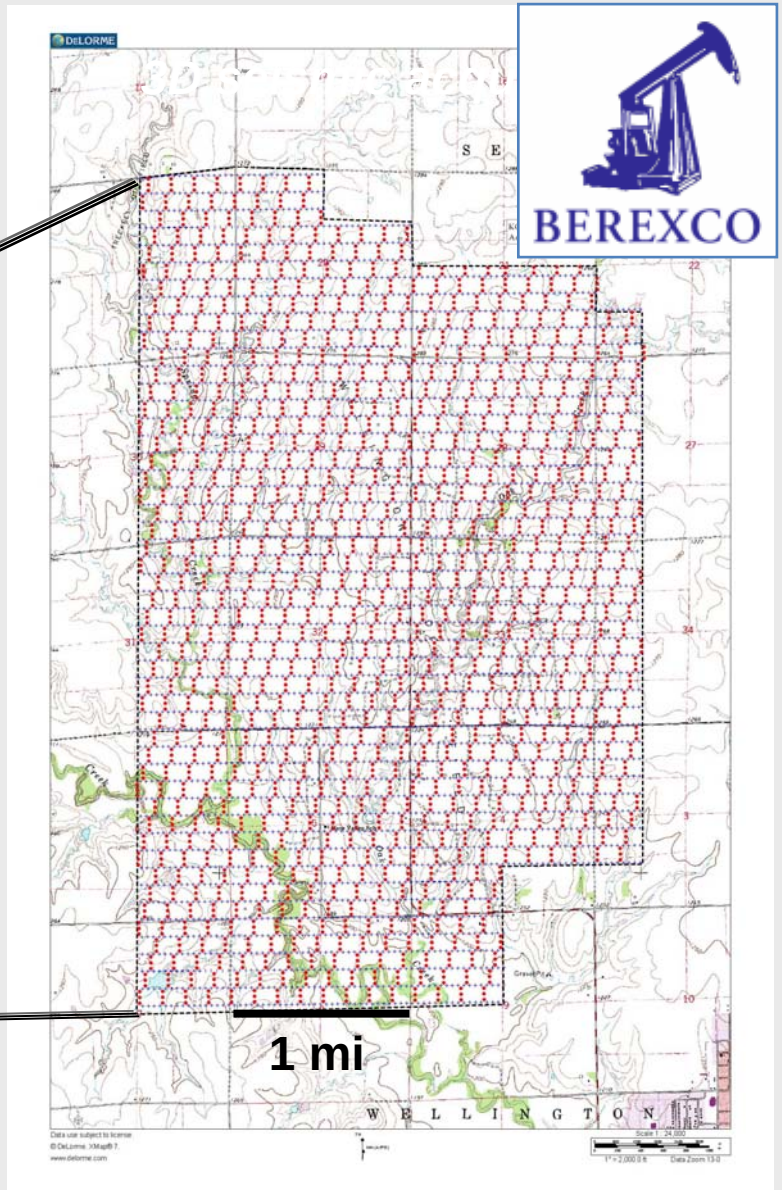
KU THE UNIVERSITY OF KANSAS
Department of Geology

Sandia Technologies, LLC

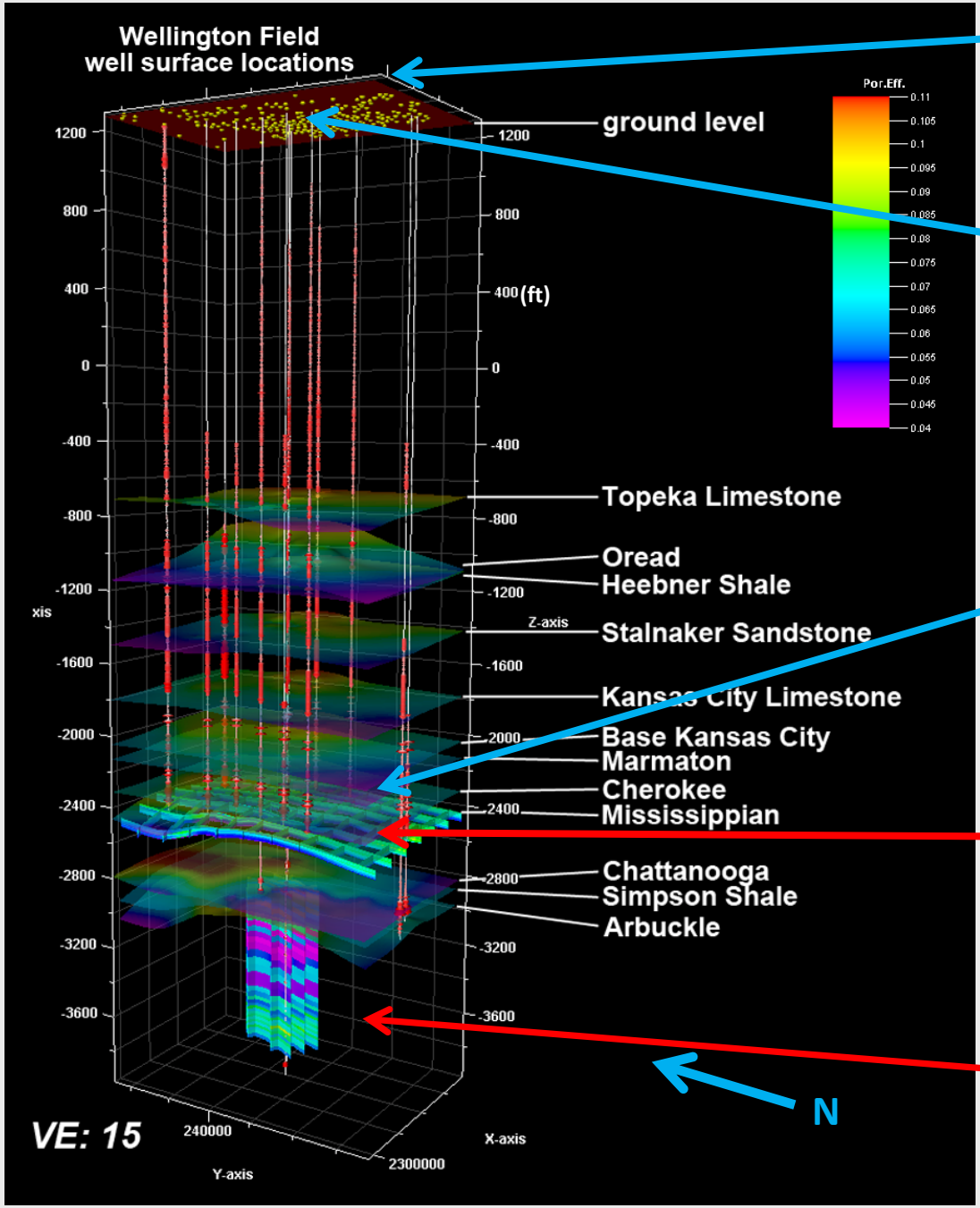
Wellington Field

3D Multicomponent 3D Seismic survey & 2 basement tests





Optimal Injection and Best Practice Monitoring



- InSAR/LIDAR surface deformation/IRIS seismometers
- Measure soil gas flux and chemistry through series of shallow probes.

- Monitor for tracers, CO_2, inorganics and organics in 12 shallow freshwater wells (in two nests of 6 wells)
- Monitor two deeper wells ~600 ft deep below shallow evaporite cap rock

- Measure for tracers and CO_2 casing head gas and fluid samples from Mississippian wells (if positive, run 2D seismic)

(*Underpressured oil reservoir [900 psi] should trap any vertically migrating CO2*)

Inject 30,000 tonnes of CO_2 into Mississippian chert oil reservoir to demonstrate CO2-EOR (offset injector from Arbuckle)

Inject 40,000 tonnes of CO_2 with SF6 and krypton tracers into lower Arbuckle saline aquifer and seismically image and sample in situ CO_2 plume development to verify geomodel and simulations

Source of CO_2

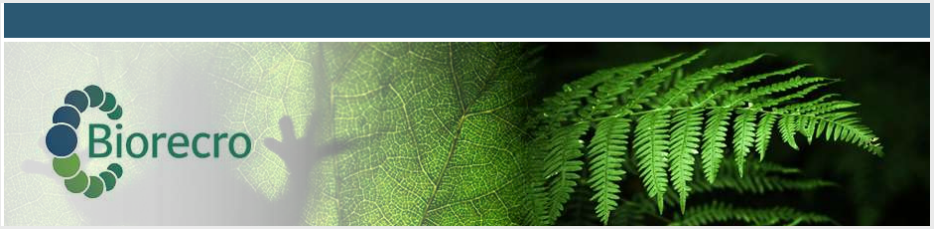
Abengoa Colwich plant and CO_2 site

- Feedstock – dryland crops
- Nearly half of energy requirement from landfill-derived methane

Future CO_2 Plant Site

- Constructed in 1982, has been upgraded and expanded many times over the years, and is a modern well equipped plant.
- Production capacity of approximately 25 M gallons of ethanol per year and produces over 200 tons per day of raw CO_2.
- CO_2 was captured, processed and sold for approximately 10 years from this facility.

Carbon credits will provide income for CO_2 that is injected into the saline formation at Wellington Field



Karlavägen 18
Stockholm

Biorecro develops and enables of climate mitigation measure that combines biomass with carbon storage

Kansas, USA

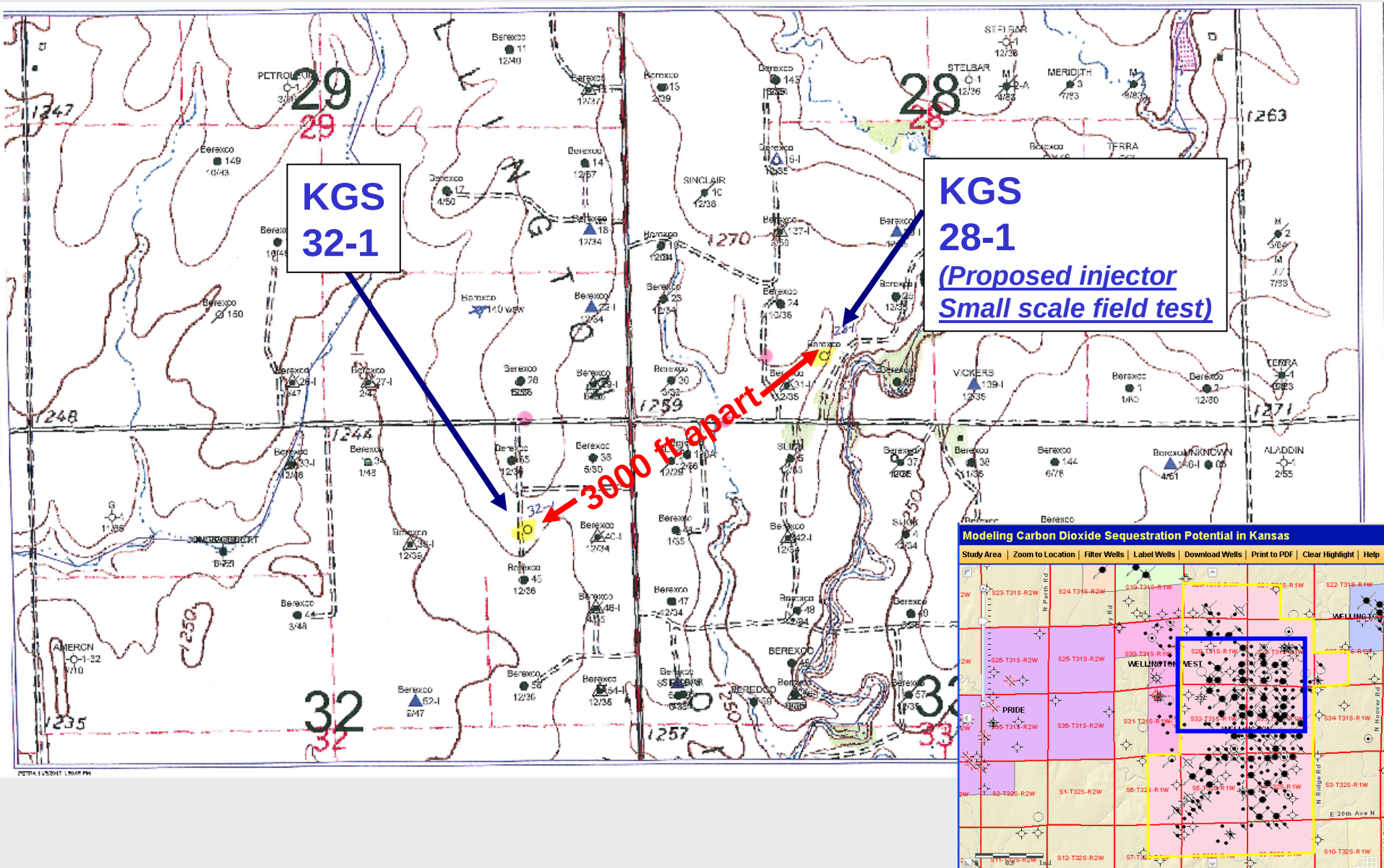
On the Midwest prairie in the United States, a BECCS plant that will be put into service in 2013 is under construction, lead by the Kansas Geological Survey. Drill holes for storage and monitoring were completed in 2011, leading down to the subterranean formations where the storage will take place. The next step is the construction of the facility for collection and road transport of carbon dioxide from an ethanol plant.

Photo: Dana Wreath

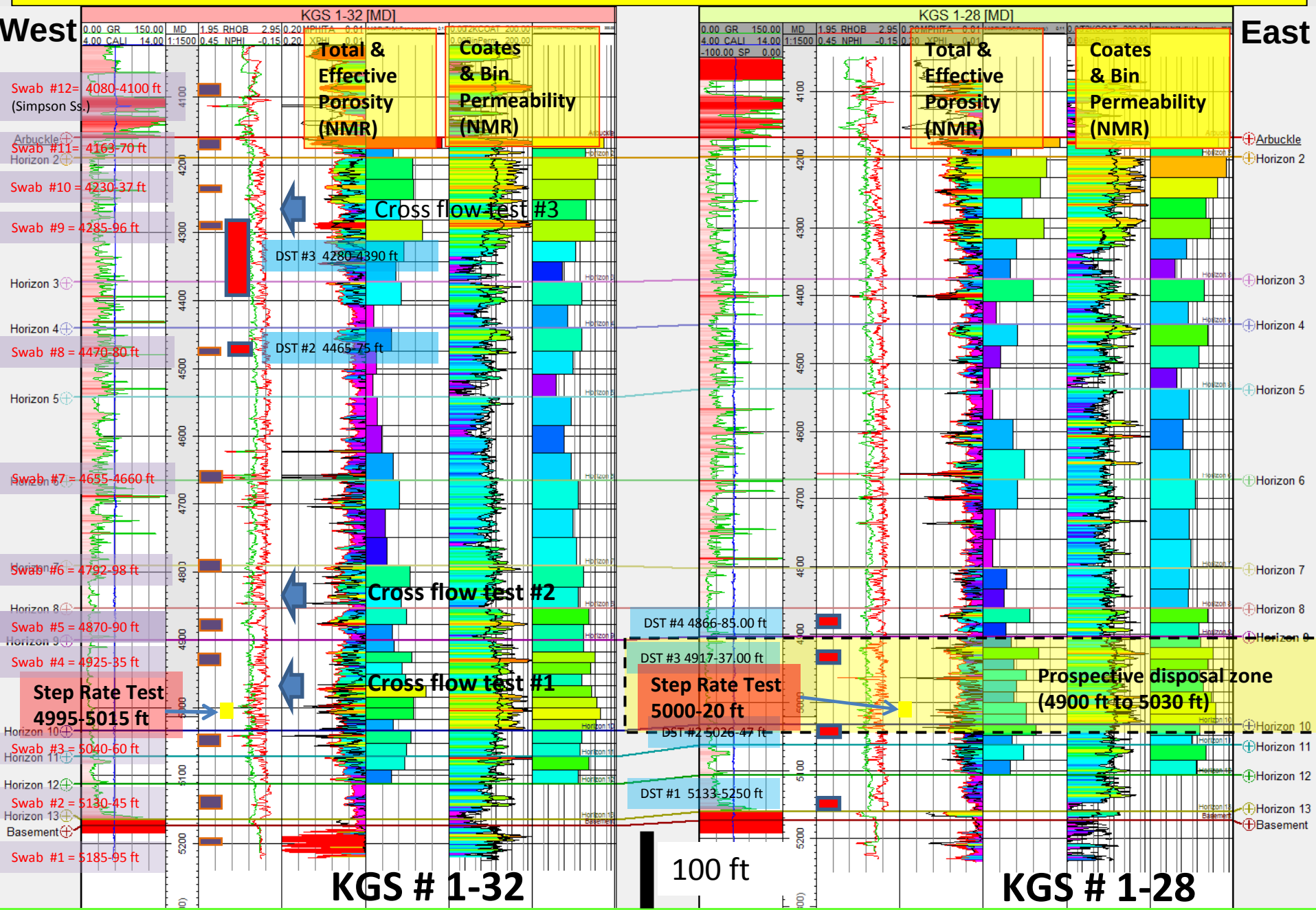
The project is part of the federal US government investments in research and demonstration of carbon capture and storage (CCS). The project has been awarded a grant from the U.S. Department of Energy, supplemented by funds from participating partners.

The geological formation where the carbon dioxide is to be stored is a sandstone aquifer at 1600 m of depth. The carbon dioxide is taken from a plant that produces ethanol from the durra cereal, which is grown on the surrounding fields in the dry and hot summer climate of Kansas.

Surface location of stratigraphic tests drilled in Wellington Field during Jan-Feb 2011

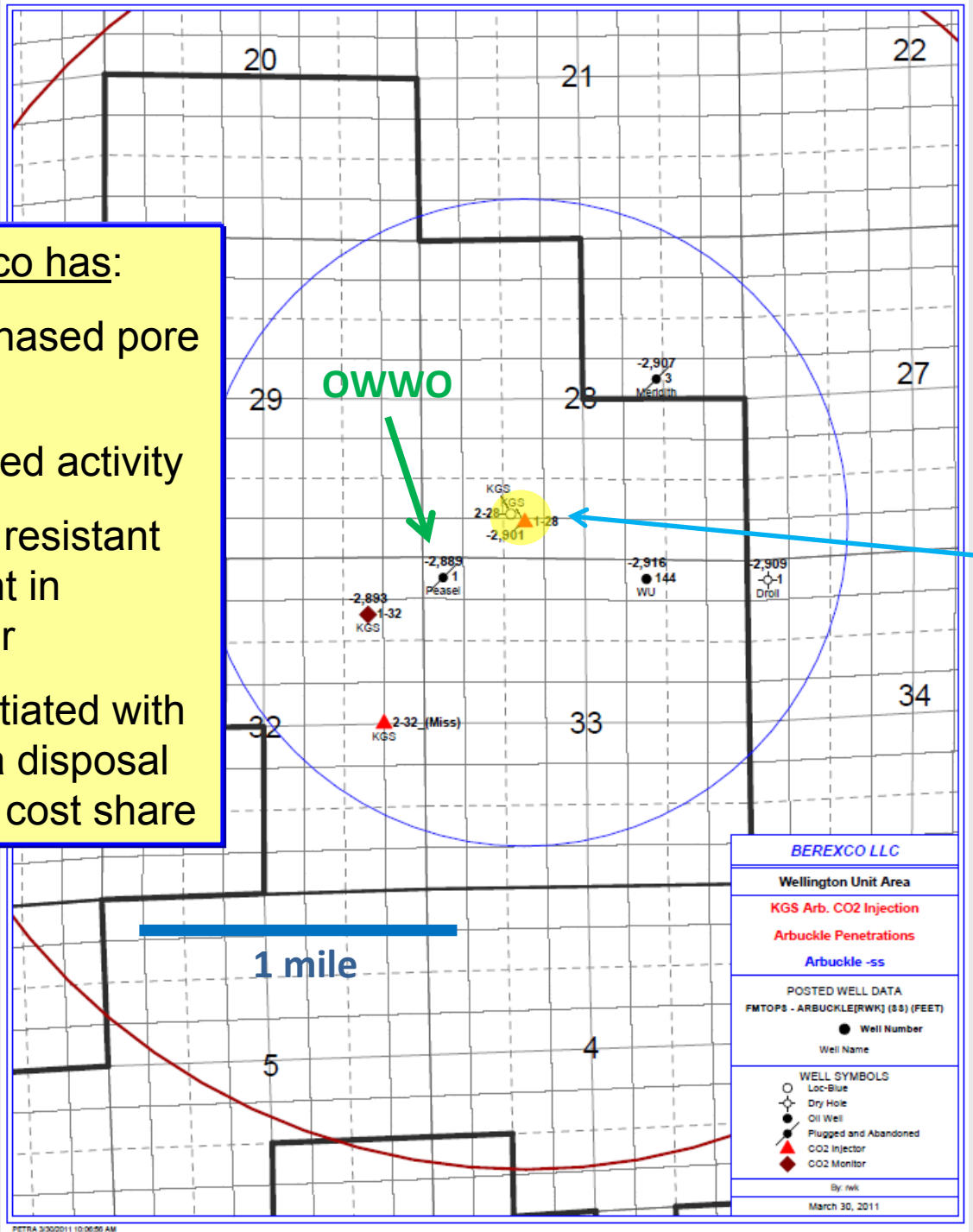


Cross section showing location of step rate test and proposed swab intervals in the Arbuckle



Preliminary upscaled hydrostratigraphic units in Arbuckle Group

Map showing boreholes that penetrate the Arbuckle saline aquifer in Wellington Field

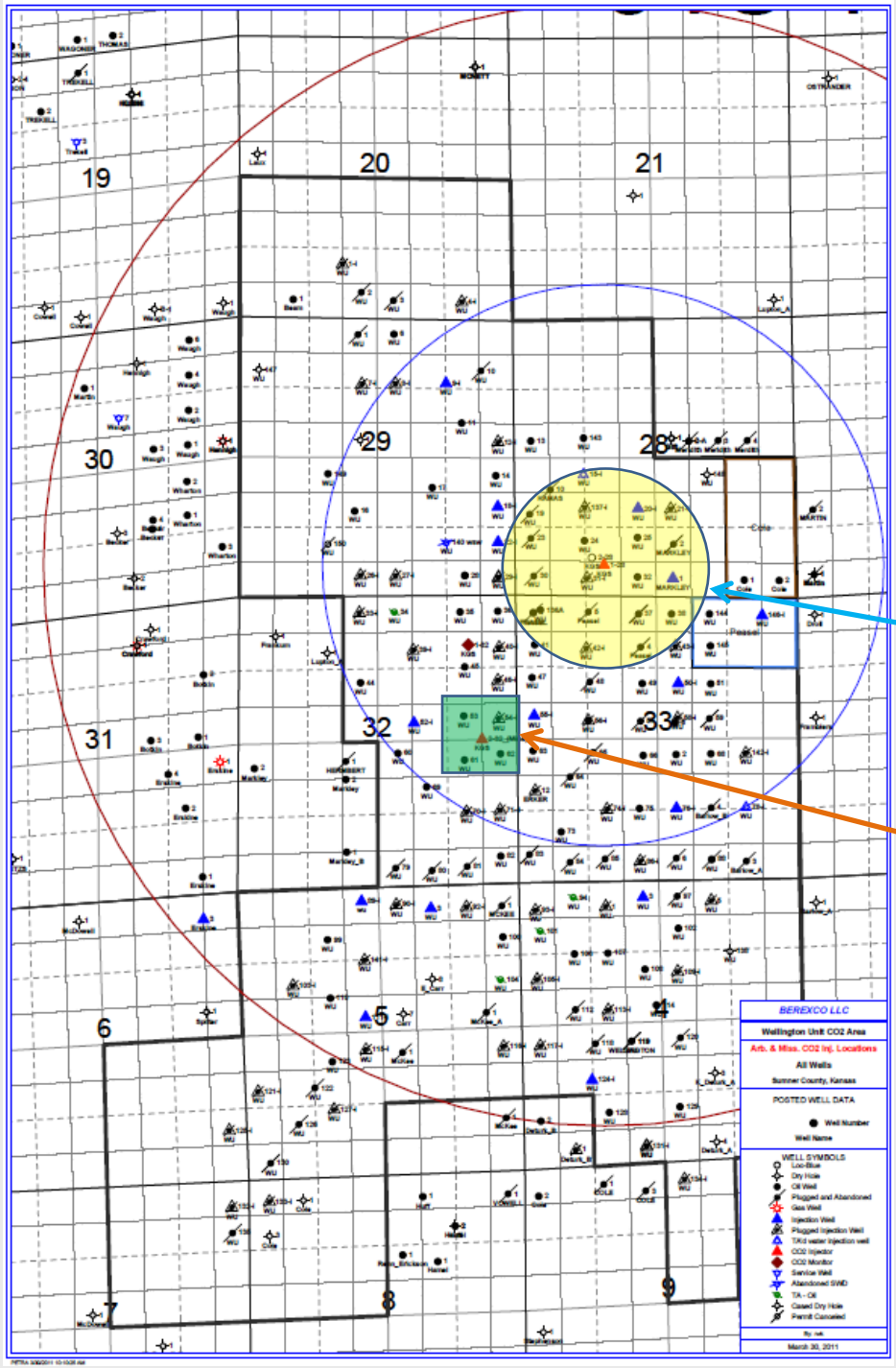


Berexco has:

- Purchased pore space
- Insured activity
- CO2 resistant cement in injector
- negotiated with DOE a disposal fee as cost share

- **Proposed monitoring borehole (#2-28) within 300 ft of the existing #1-28 borehole to be converted into CO_2 injector for small scale field test**

- **Yellow dot shows estimated size of CO_2 plume after injection of 40,000 tonnes in 120 ft interval of lower Arbuckle based on preliminary simulation results**



Map showing boreholes that penetrate into the Mississippian oil reservoir in Wellington Field

- Location of Mississippian boreholes to be monitored during and after CO_2 injection into the Arbuckle

- Location of Mississippian injection borehole and 5-spot pattern of producing boreholes

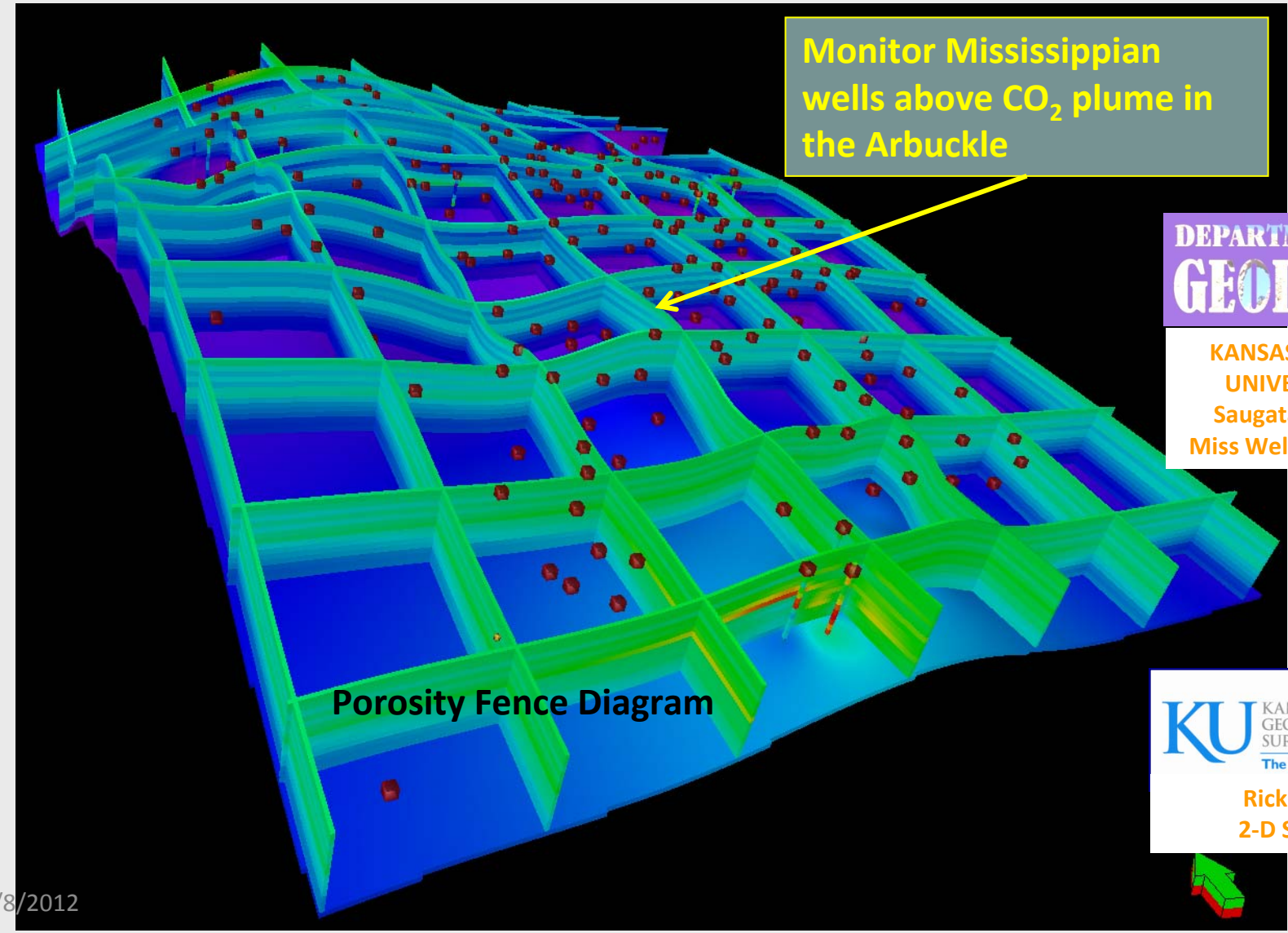
1 mile

Mississippian Reservoir Will Serve as Ideal Trap for Leaking CO_2

-- is underpressured (900 psi, 0.25 psi/ft) and blanket-like in distribution

-- will act to capture leaking CO_2 that might be lost from plume

-- if detect CO_2, run high resolution 2D seismic to characterize leakage



DEPARTMENT OF GEOLOGY

KANSAS STATE UNIVERSITY
Saugata Datta
Miss Well Monitor

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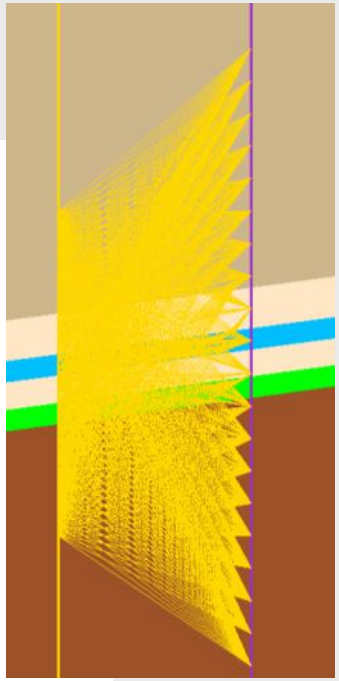
Rick Miller
2-D Seismic

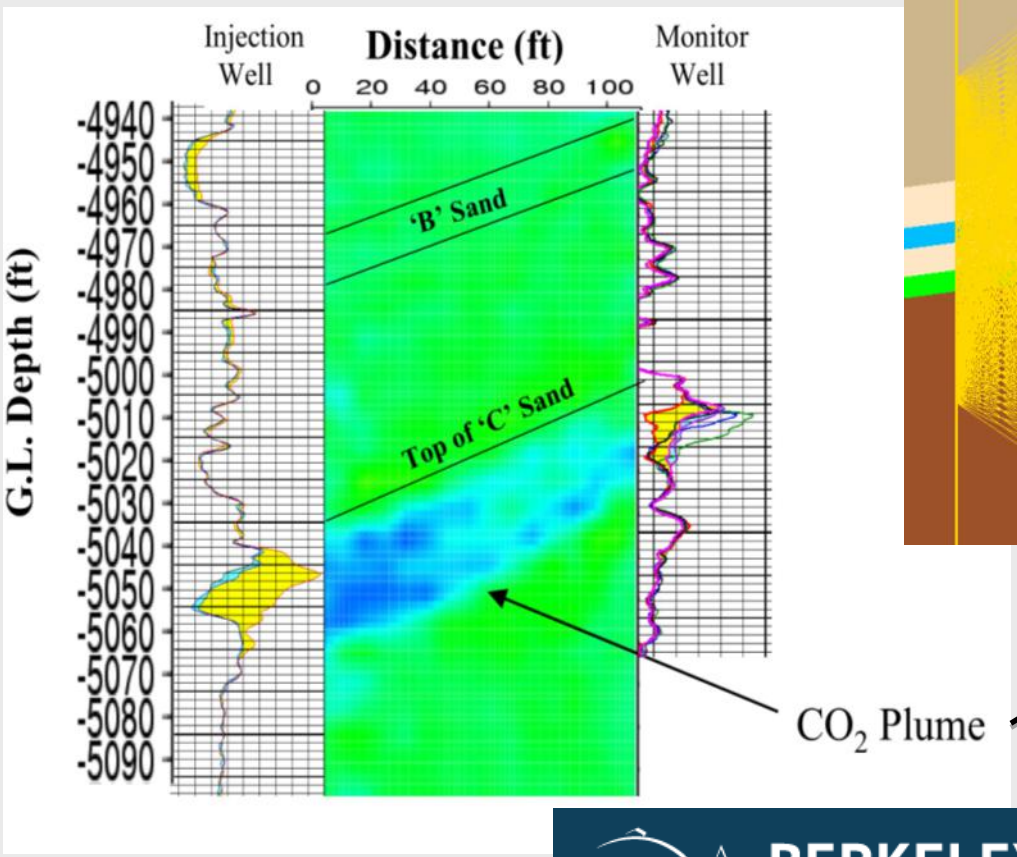
In Situ Monitoring of CO_2 Plume

Example Time Lapse Crosswell Imaging of CO2 Plumes

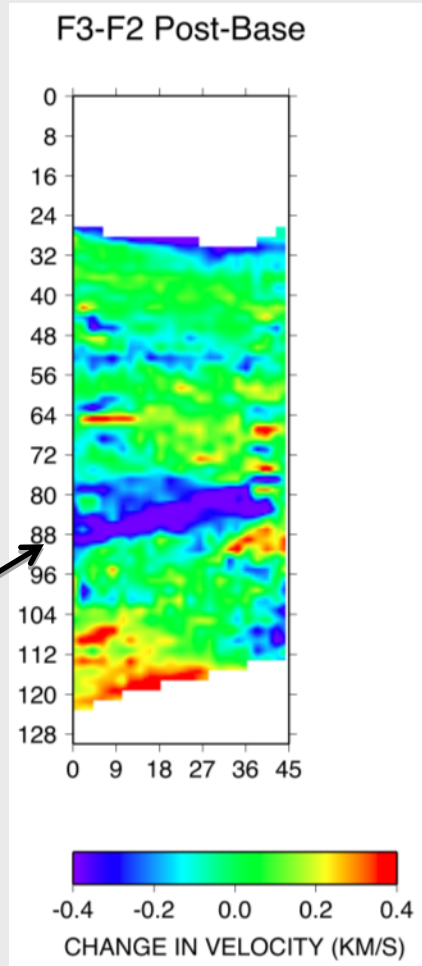
Schematic Crosswell



Frio-I 2004



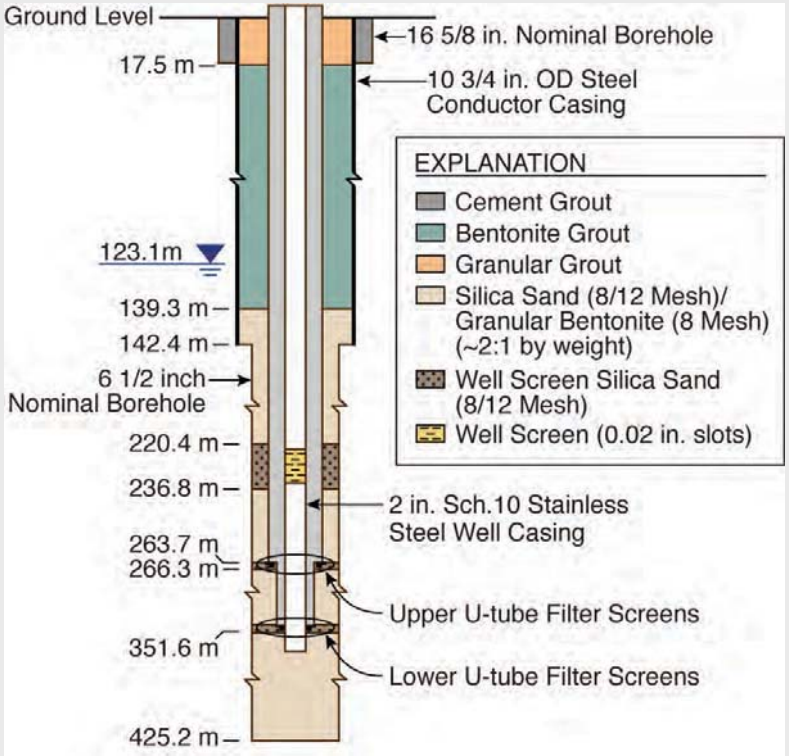
Cranfield 2010

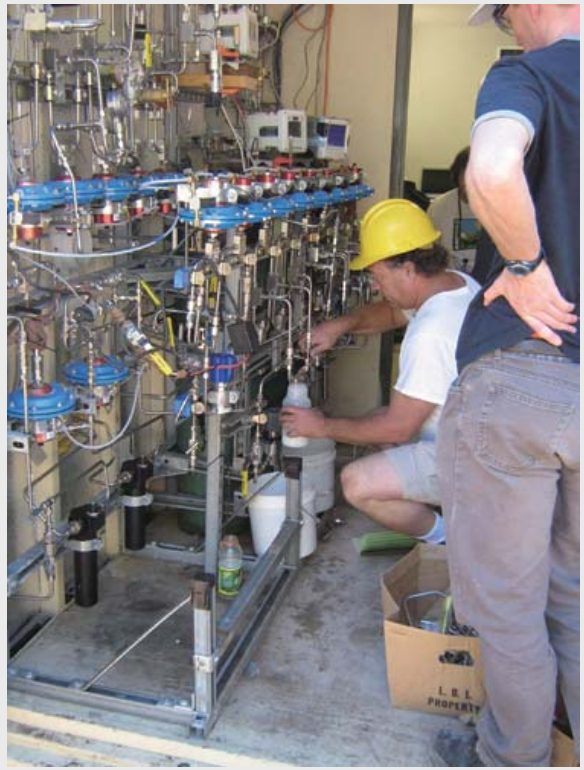


BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY

U-Tube In Situ Sampling of CO_2 Plume

- Handling of multiphase fluid collected at high frequency



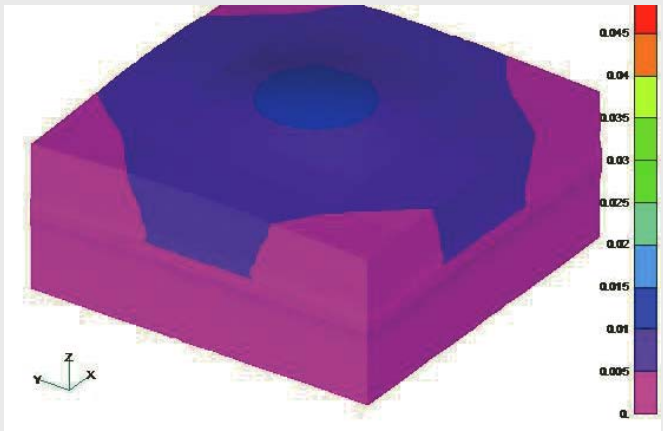


LiDAR and InSAR to Detect Any Surface Deformation Associated with CO_2 injection

Mike Taylor, University of Kansas

Wellington Project will use:

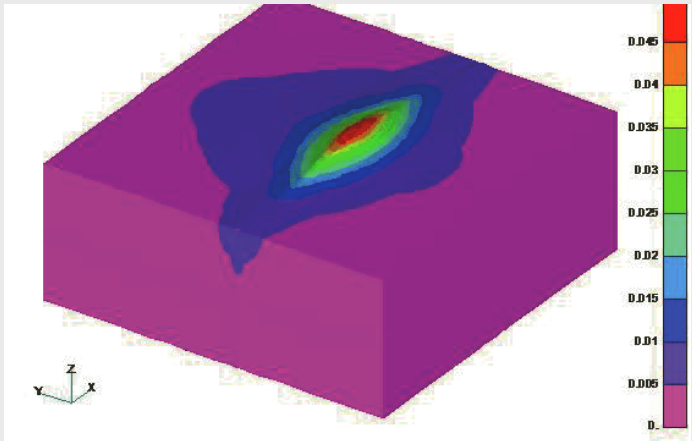
- **C-GPS**
- **IRIS seismometer**
- **Terra sar x (radar data)**
- **LiDAR**



Simulated vertical displacement (in meter) after 3 years of CO2 injection (top) without and (below) with a permeable fault intersecting the caprock.

- Injection depth =6000 ft
- Injection interval = 60 ft thick
- Max pressure ~10 Pa above ambient
- Injection rate = 1 MM tons per year
- Observed surface displacement = 10 mm

Modeling Ground Deformation at In Salah

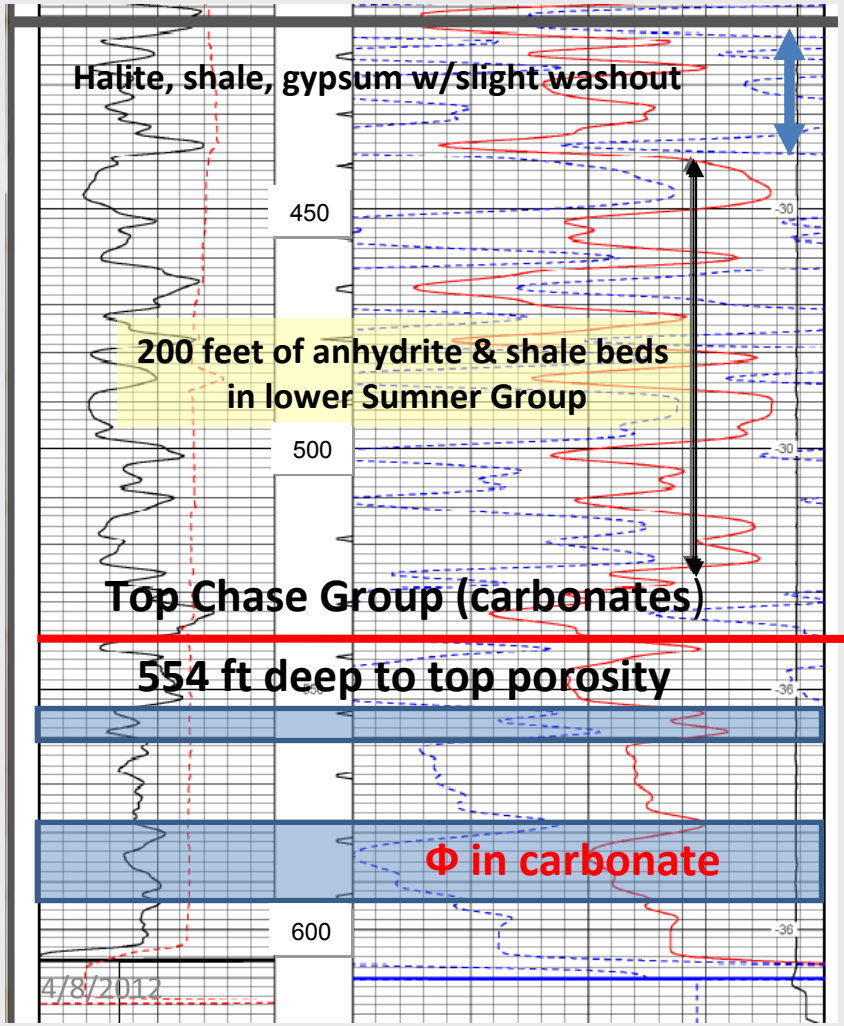


Coupled reservoir-geomechanical analysis of CO2 injection at In Salah, Algeria (CO_2 sequestration Project)
Rutqvista, Vascoa, Myera (2009)

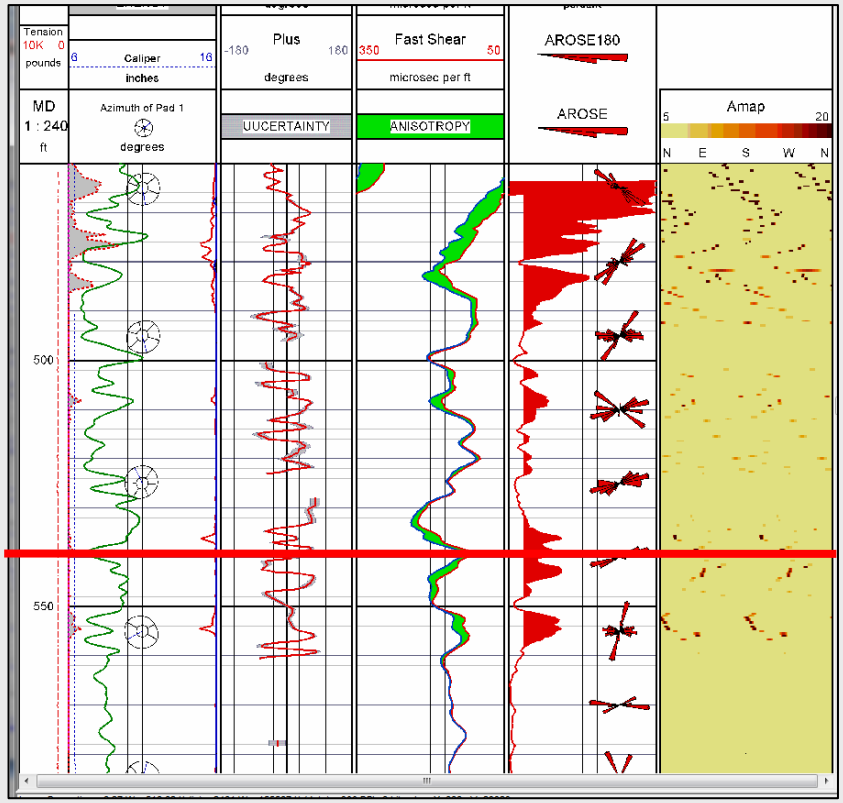
Shallow Evaporite Beds as Logged in KGS #1-32

→ Effectively isolates shallow freshwater aquifers from more deeply buried brine aquifer system

GR (black, solid) and caliper (dashed red)
sonic Δt (red solid), phi (blue dashed)



Full-waveform sonic



Shallow well field sample water from below and above the evaporite caprock

Conclude with Key Points

- ***CCUS* – Carbon Capture, Utilization, and Storage**
  - Kansas has major CO_2-EOR potential with saline Aquifer sequestration as additional asset beneath oil fields in southern Kansas
  - Manage CO_2 by building on existing infrastructure of viable, local petroleum industry
- **Managing CO_2 plume in deep saline aquifer**
  - CO_2 plume initially a supercritical free phase liquid that is eventually trapped in the aquifer
    - solution, small pores, and reaction with rock
  - Tailored computer simulations of CO_2 storage based on rock and fluid data for review and permitting
  - Monitor CO_2 plume with latest technology
    - Evaluate progress and compare to simulations
    - Demonstrate containment with off-the-shelf technology

Business Opportunities of a Class VI Geosequestration Well Realistic? - Yes