"Carbon Storage and Utilization in Kansas – Are We Ready?"

based on --

a) Characterization of CO_2 storage capacity southern Kansas evaluation of CO_2 sources and sinks (DE-FE0002056)

b) Small scale field test at Wellington Field, Sumner County (DE-FE0006821)

c) Arbuckle modeling with horizontal drilling (DE-FE0004566)

W. Lynn Watney & Jason Rush, Joint PIs

Jennifer Raney, Asst. Project Manager

Kansas Geological Survey

Lawrence, KS 66047

Oil and Gas Seminar

August 7, 2014

KU KANSAS GEOLOGICAL SURVEY The University of Kansas

Wellington Field Operator BEREXCO

NETL

Kansas Next Step KNS Connecting for Success

Finding and Obtaining Opportunities Lead to Success

KSCO2

Outline

1. Framing the opportunity for CO_2 utilization in the oil patch
2. Highlight current and potential CO_2 supplies
3. Opportunities, risks and uncertainties for CO_2-EOR
4. Brief summary of selected case studies that highlights approaches to next-generation CO_2-EOR applicable to Kansas oil reservoirs

1. Framing the opportunity for CO_2 utilization in the oil patch

NATIONAL ENERGY TECHNOLOGY LABORATORY

NETL

Improving Domestic Energy Security and Lowering CO_2 Emissions with "Next Generation" CO_2-Enhanced Oil Recovery (CO_2-EOR)

June 20, 2011

DOE/NETL-2011/1504
Activity 04001.420.02.03

U.S. DEPARTMENT OF ENERGY

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 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 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?**
  - Sustained oil prices
  - Improved reservoir characterization with the widespread use and availability of cost-effective 3D seismic
  - Improved engineering models and recovery technologies
  - All combined will likely overcome the decades of inertia that have faced the implementation of CO_2-EOR in Kansas

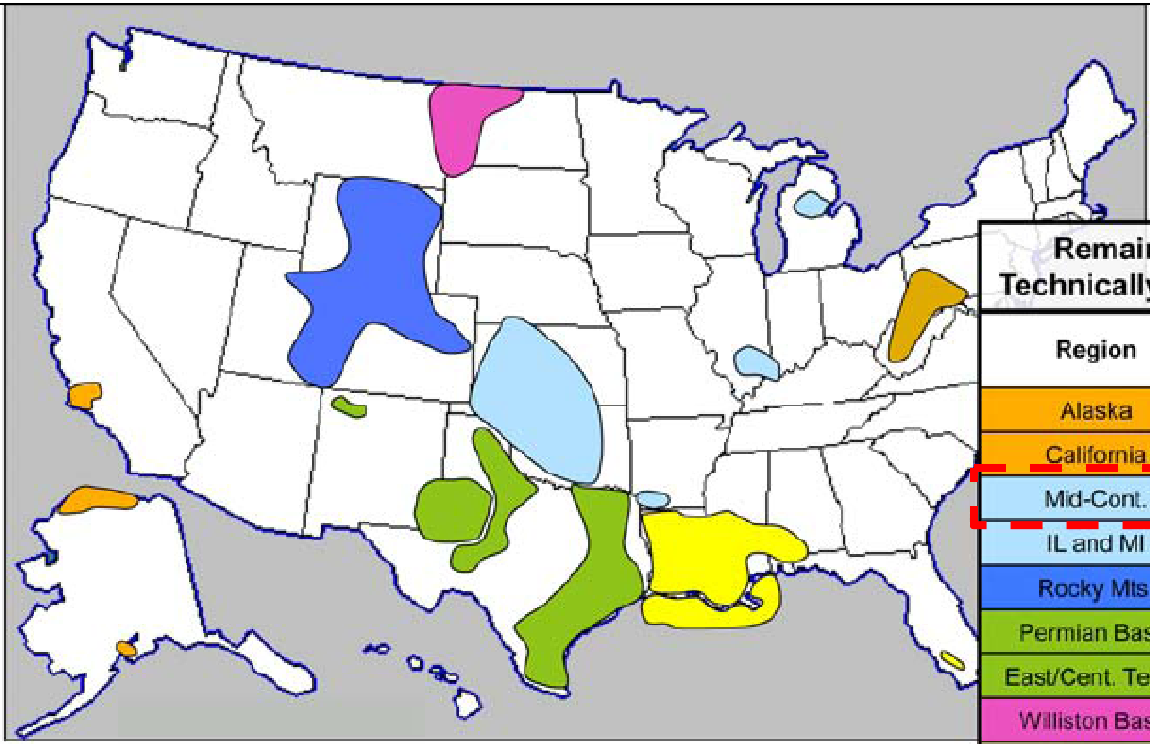
Are you ready to be part of this?

Utilization of CO_2 in Kansas

- Establish demand for CO_2 in the oil field
- Future use – develop scenarios for implementation and infrastructure
- Technical timeframe
  - Oil field and operator readiness
  - Field modeling and implementation plan to ensure success
  - Scenarios for aggregating CO_2 supply and distribution to the field
  - Economic incentives?

Kansas has considerable remaining technically recoverable oil reserves using CO_2

Potential Technically Recoverable Incremental Oil with "best practices" CO_2 EOR Technology



Source: ARI, February 2009

Remaining Oil in Place and Technically Recoverable Reserves

Remaining Oil in Place and Technically Recoverable Oil (BBls)		
Region	**ROIP***	**Technically Recoverable**
Alaska	45.0	12.4
California	57.3	6.3
Mid-Cont.	65.6	10.6
IL and MI	11.5	1.2
Rocky Mts.	22.6	3.9
Permian Basin	61.7	15.9
East/Cent. Texas	73.6	17.6
Williston Basin	9.4	2.5
Gulf Coast	27.5	7.0
LA Offshore	15.7	5.8
Appalachia	10.1	1.6
Total	**400**	**84.8**

* Remaining Oil in Place

Producible if costs, oil price and risks justify investment

http://www.netl.doe.gov/technologies/oil-gas/publications/EP/small_CO2_eor_primer.pdf

CO_2-EOR Potential in the MGA Region

February 26, 2012 I Washington D.C.

- Kansas holds more than **750 million barrels** of technical CO_2-EOR potential.
- Kansas has by far the largest oil resources in the MGA region.
- Economic results based on Hall Gurney field suggest an after-tax project IRR of about 20%.
- Kansas …would have access to the significant volumes of ethanol-based CO_2 in Nebraska, which produces approximately 6 million metric tons per annum.

750 million barrels of oil would utilize --

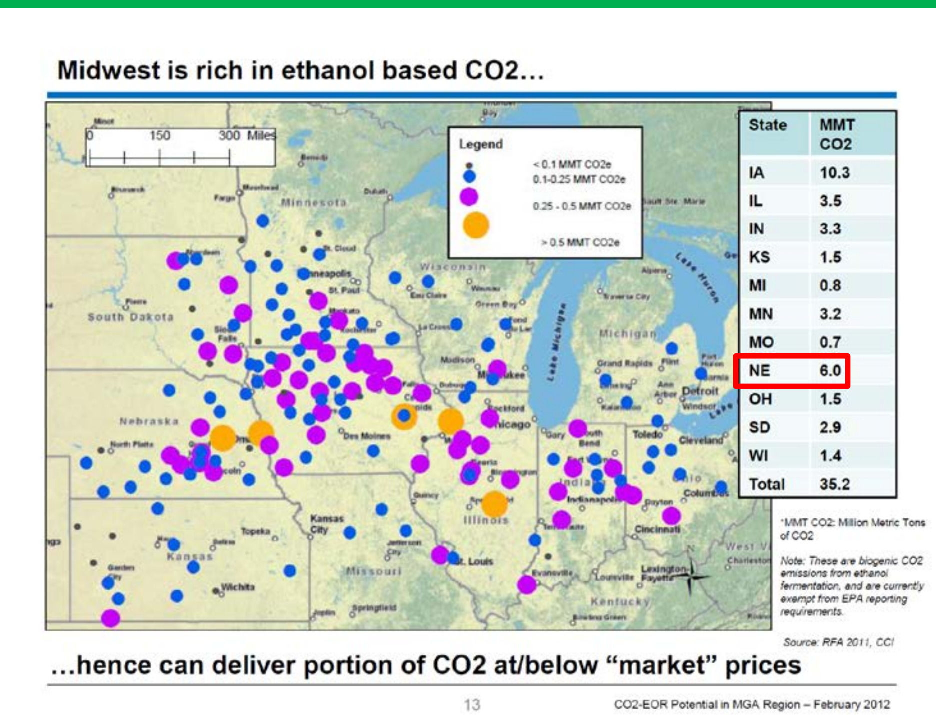
- **~240-370 million metric tons of CO_2 (*4.62-7.12 BCF CO_2*)**.
- **~30 years of a 500 MW coal-burning plant**

Basin	EOR potential (Mil bbl)	Net CO_2 Demand (MMT)	Direct Jobs Created
Illinois/Indiana	500	160 – 250	1,550 – 3,100
Ohio	500	190 – 300	1,550 – 3,100
Michigan	250	80 – 130	800 – 1,800
Kansas	750	240 – 370	2,300 – 4,600
TOTALS	**2,000**	**670 – 1,050**	**6,200 – 12,400**

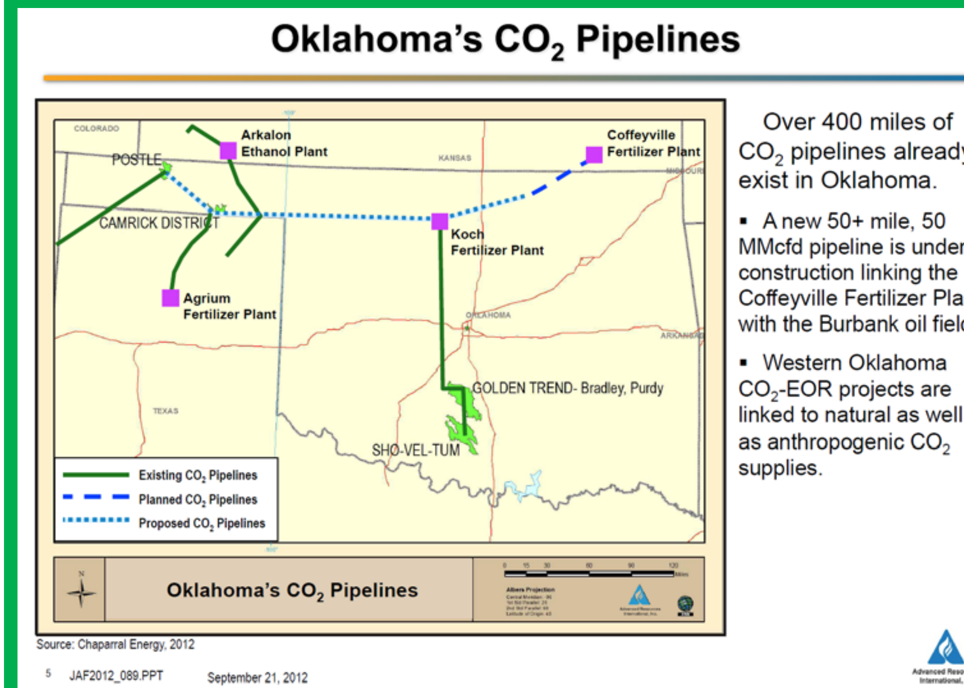
19.25	MCF/tonne

$2.00	cost per MCF
$38.50	**cost per tonne**

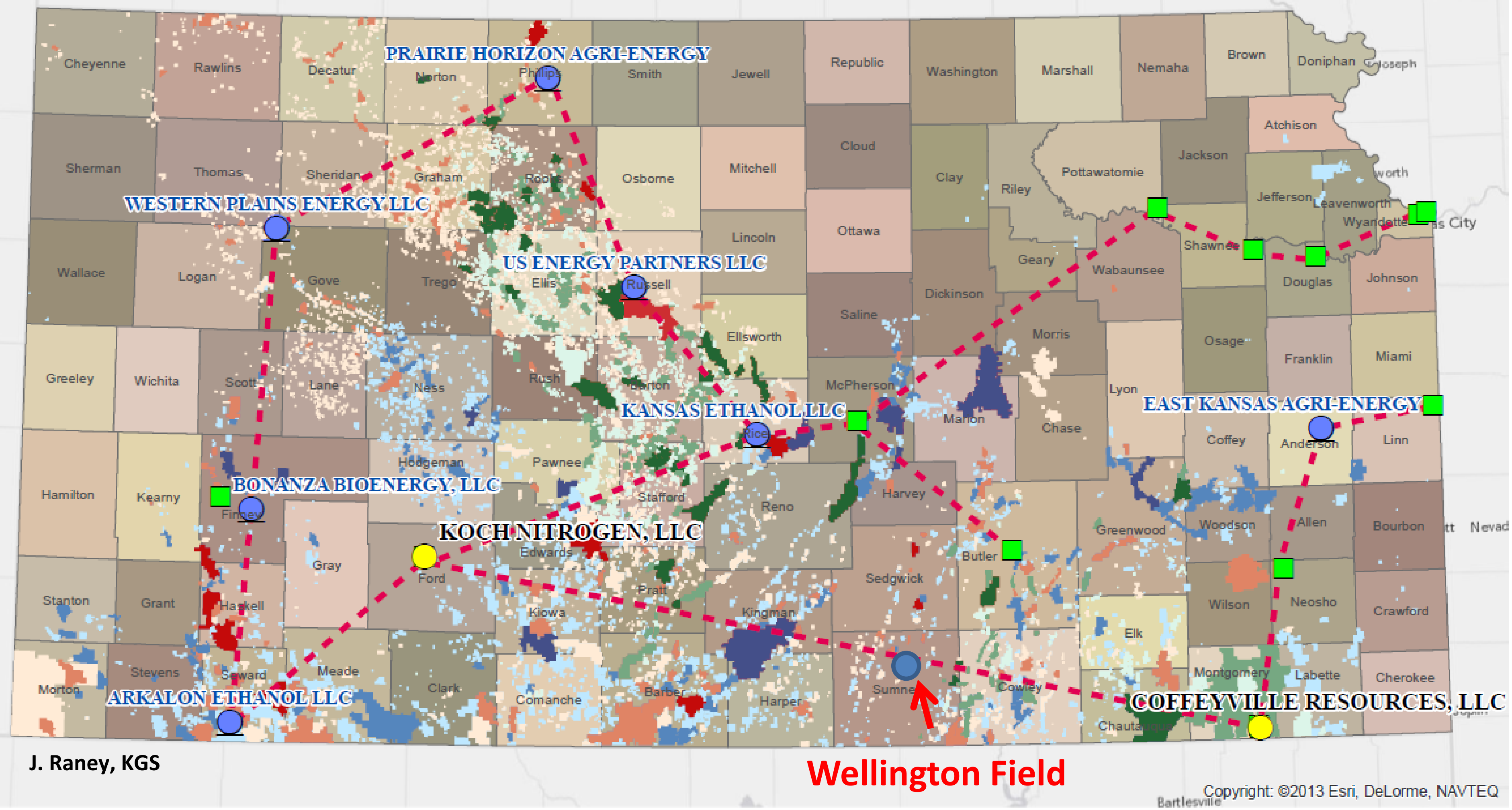
2. Highlight current and potential CO_2 supplies



State	MMT CO2
IA	10.3
IL	3.5
IN	3.3
KS	1.5
MI	0.8
MN	3.2
MO	0.7
NE	6.0
OH	1.5
SD	2.9
WI	1.4
Total	35.2



Major oil and gas reservoirs as candidates for CO_2-EOR and CO_2 sources in Kansas and a pipeline scenario



J. Raney, KGS

Source: USGS, Kansas Geological Survey, DASC

Cummulative Oil Produced (as of 2013)

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

Linde Group – A CO_2 supplier for the Wellington Field pilot CO_2 injection

Hammerfest LNG Project Norway – CO_2-Reinjection

I am taking the lead.

THE LINDE GROUP

World's first industrial project to deliver CO_2 separated onshore back offshore and injected into a reservoir

- Europe`s first export facility for liquified natural gas (LNG)
- Terminal and process plant on Melkøya island outside Hammerfest in northern Norway
- Annual LNG export: 5.67 billion sm³
- CO_2 - Content: 5.0% to 8.0 %
- CO_2 captured in onshore plant
- Conveyed back with subsea pipeline
- Storage underground
- Emission reduction of more than 50 %
- Norwegian CO_2-Tax: 50 Euro/ton

Praxair -- CO_2 supplier for Wellington Pilot

PRAXAIR

Upstream Oil and Gas

- **Enhanced Oil Recovery**
  - Over 30 years experience with Gas Displacement Recovery (GDR)
    - Nitrogen
    - Carbon Dioxide
  - More than 25 projects
- **Well Stimulation Services**
  - **Fracing**
  - **Wellbore damage cleanup**
- **CO_2/N_2 EOR Services**
  - Pilots
  - Injection test and huff-n-puffs
- **CO_2 Capture & Purification**

Exxon Hawkins Field,
85 MMscf/d 2,000 psi

Opportunities for utilizing CO_2 from power generation…

Mid-Kansas Electric Company in Hays
Summer 2014 Newsletter

Rubart Station engine-generator sets undergo extensive testing

From an outside view of Rubart Station, it appears that the majority of the work is complete at the new electric generating facility. However, inside major work and fine tuning continues on state-of-the-art technology.

All 12 of the 120 MW Caterpillar engine-generator sets have undergone early commissioning tests, such as firing the engines with natural gas but at no load, verifying proper fuel management and engine speed controls, measuring temperatures on numerous key engine components, and synchronizing the generators to the grid.

Rubart Station's gen-sets, the first of Caterpillar's G20CM34 units anywhere in the world, are in place awaiting commissioning tests. The natural gas-fueled reciprocating engines offer high availability, long life, low fuel consumption, and low maintenance requirements. All 12 gen-sets will be on-line by the end of September.

Each engine-generator set must then log at least several hours of operation at full load in order to produce enough engine heat to "run in" the engine prior to loading the catalyst into each engine's selective catalytic reactor module. Once the catalyst is loaded, each engine-generator set is operated at various load points to start and tune the urea injection system.

Simultaneous with all of these tests are countless other tests and checks for details, such as checking the adequacy of operating procedures, ensuring effectiveness of communications systems, verifying instrumentation accuracy, and validating control and alarm systems.

Once the project team accomplishes all of these tests and more, the facility will be taken through a formal battery of tests to demonstrate the ability to meet contract requirements, such as output, fuel efficiency, emissions performance, and reliability.

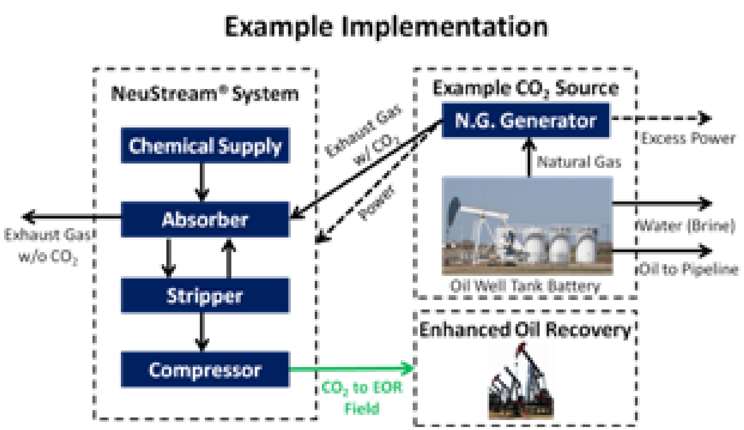
Even after verifying all these complicated tests on the individual units, staff will conduct more tests to verify that the facility is capable of meeting those same requirements running all 12 units simultaneously or any combination of unit operation.

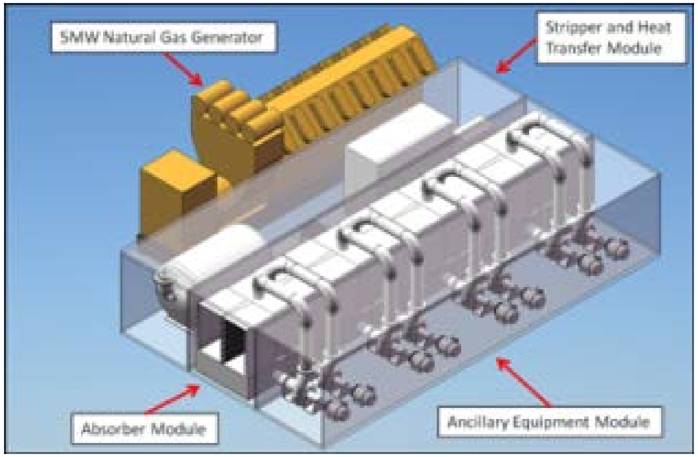
Rubart Station is an important system asset that will serve the needs of our Members and regional consumers, and by this fall all units will be available for service that will last for decades to come.

An Example of Onsite CO_2 Generation for EOR

1. **NeuStream® CO_2 systems for EOR** are readily adaptable to a range of CO_2 sources including steam generators, flare-gas burners, natural gas power generators and **diesel generators**. (*http://www.neustream.com/products/co2eor.html*)

2. **Alternatively the system can provide its own CO_2 source**. The modular, factory-built, design approach allows deployment in a range of sizes from 50 ton/day to over 1000 ton/day of EOR ready CO_2.
   A. • **50 to 1000 tons (17 MMCF) per day EOR quality CO_2**
   B. • Adaptable to any CO_2 source, or generates its own CO_2
   C. • Transportable system

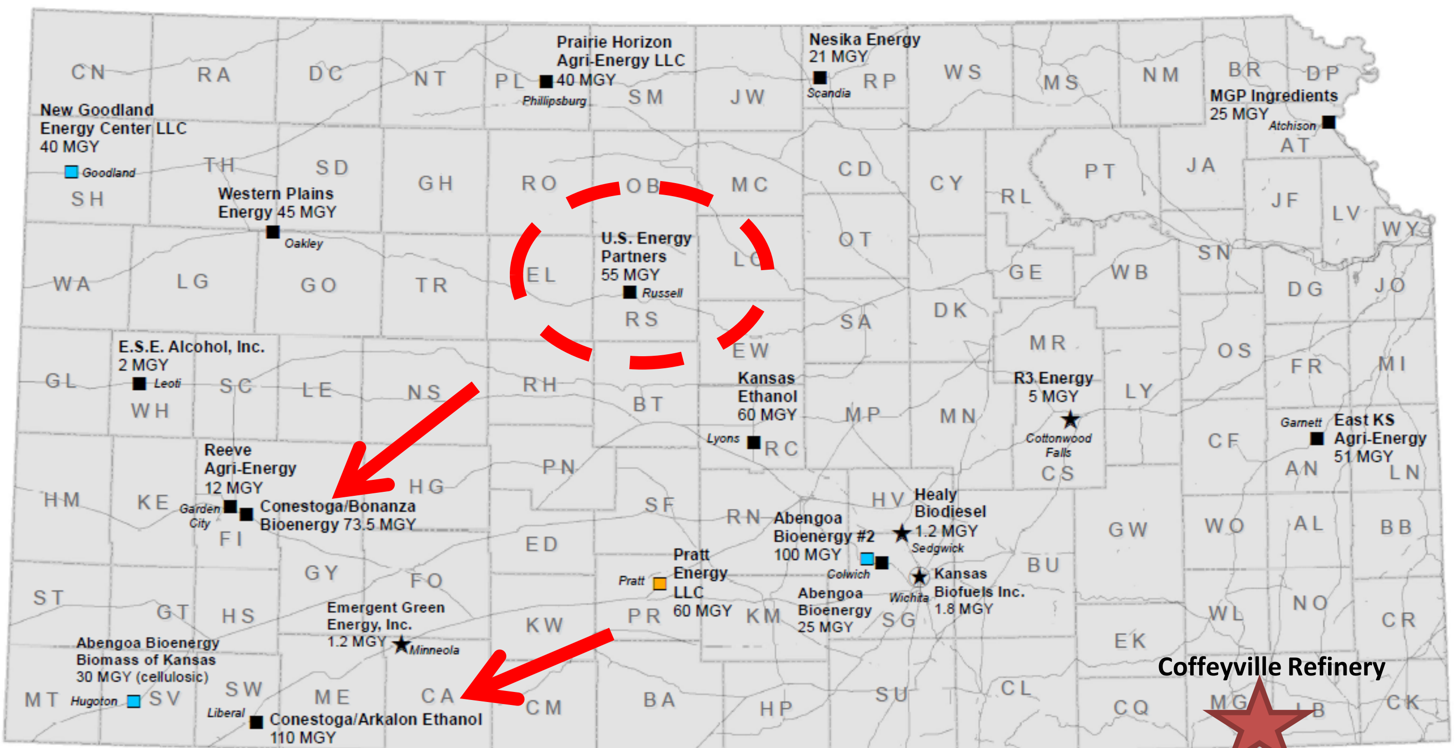




Products
*CO_2 for EOR
*CO_2 for Coal
*SO_x for Coal
*SO_x DSI
*Chemical
*Recovery
*NO_x Add-On

Existing anthropogenic CO_2 sources being used for EOR!

Ethanol and Biodiesel Plant Activity in Kansas
September 2012



Kansas
State of Kansas

MGY = Millions of gallons per year of permitted capacity. Capacities courtesy of Kansas Department of Health and Environment and the Kansas Department of Revenue.

* Permitted and Permit Pending codes refer to KDHE Bureau of Air and Radiation – Air Construction permits.

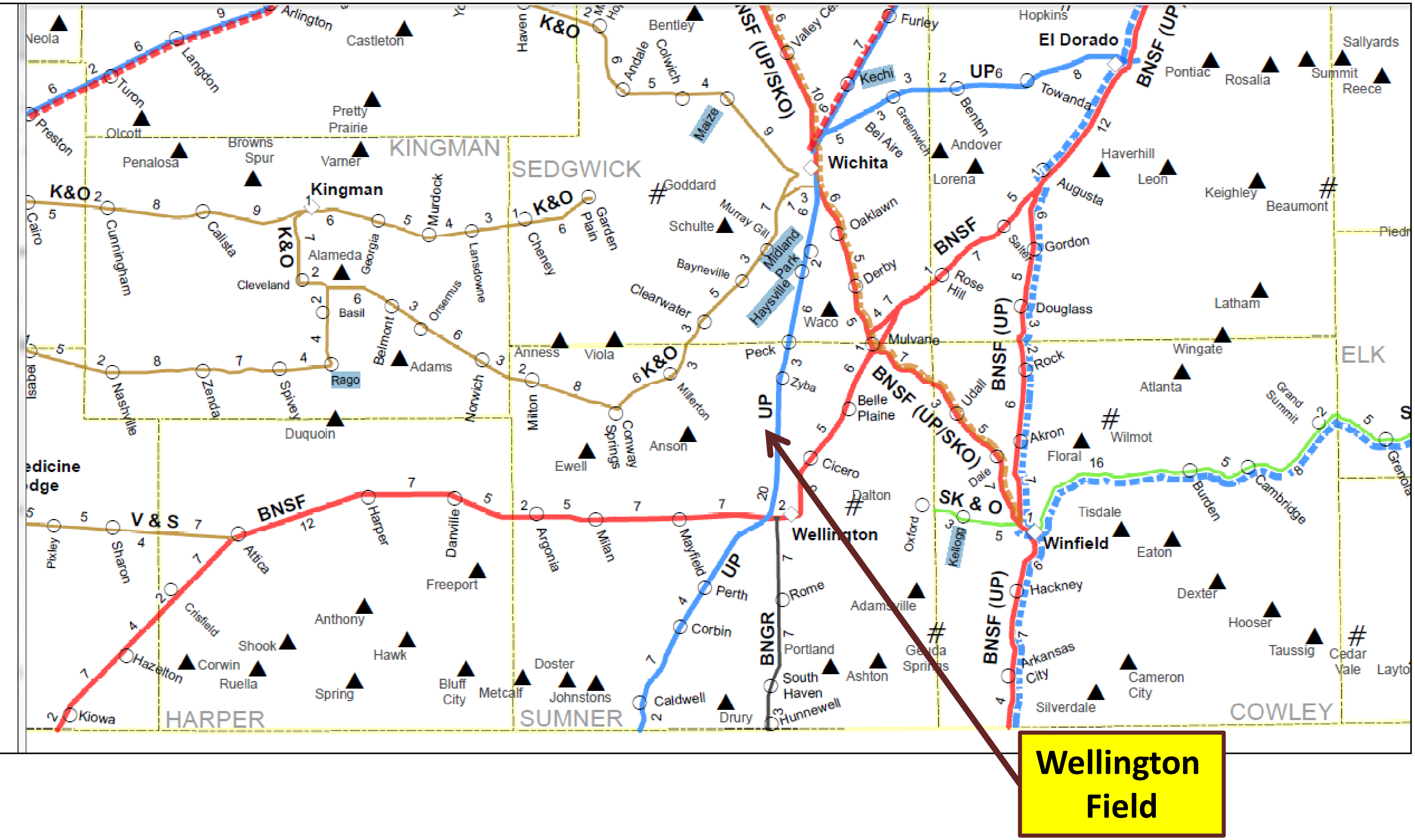
Ethanol Plants

- ■ Existing: 12 plants, 519.5 MGY
- ■ Under Construction: 3 plants, 170 MGY
- ■ Permitted*: 0 plants, 0 MGY
- ■ Permit Pending*: 1 plants, 60 MGY
- ⊠ Idle: 0 plants, 0 MGY

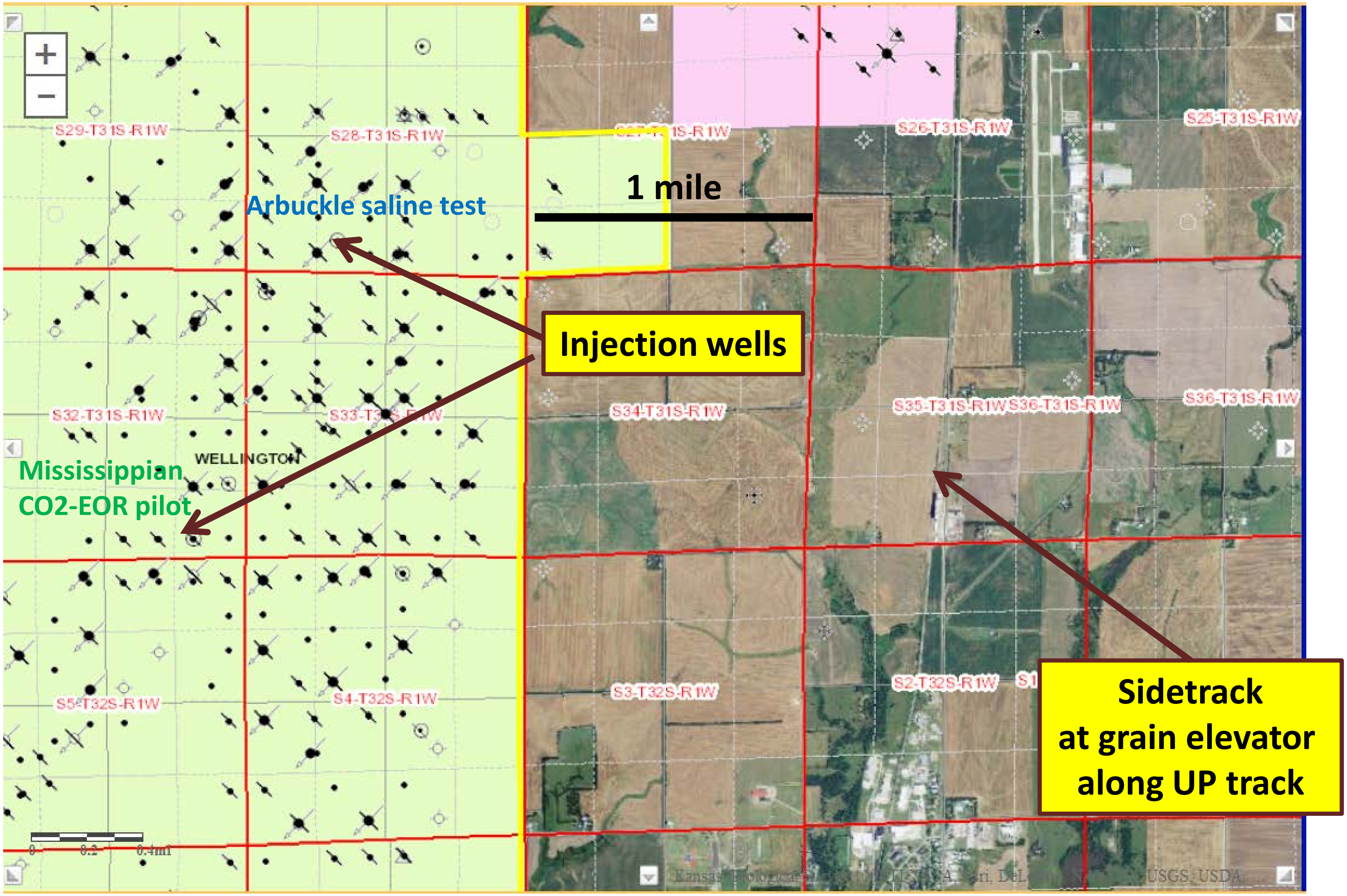
Biodiesel Plants

- ★ Existing: 3 plants, 7.4 MGY
- ★ Under Construction: 0 plants, 0 MGY
- ★ Permitted*: 0 plants, 0 MGY
- ★ Permit Pending*: 0 plants, 0 MGY
- ★ Idle: 1 plant, 1.8 MGY

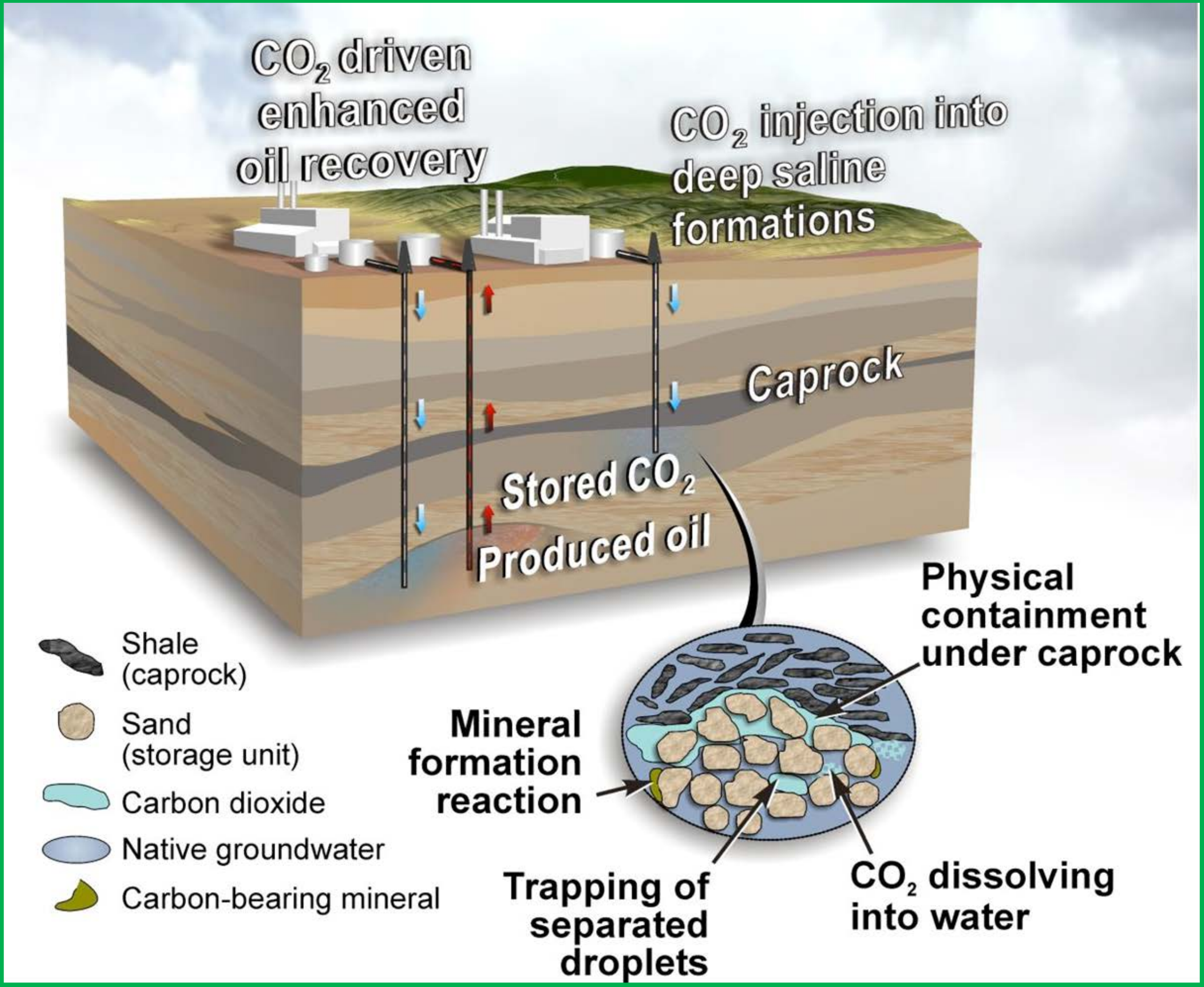
Rail map – South-Central Kansas to examine potential to ship CO_2 by rail to Wellington Field



Potential to deliver CO_2 by train and run short pipeline to Wellington Field



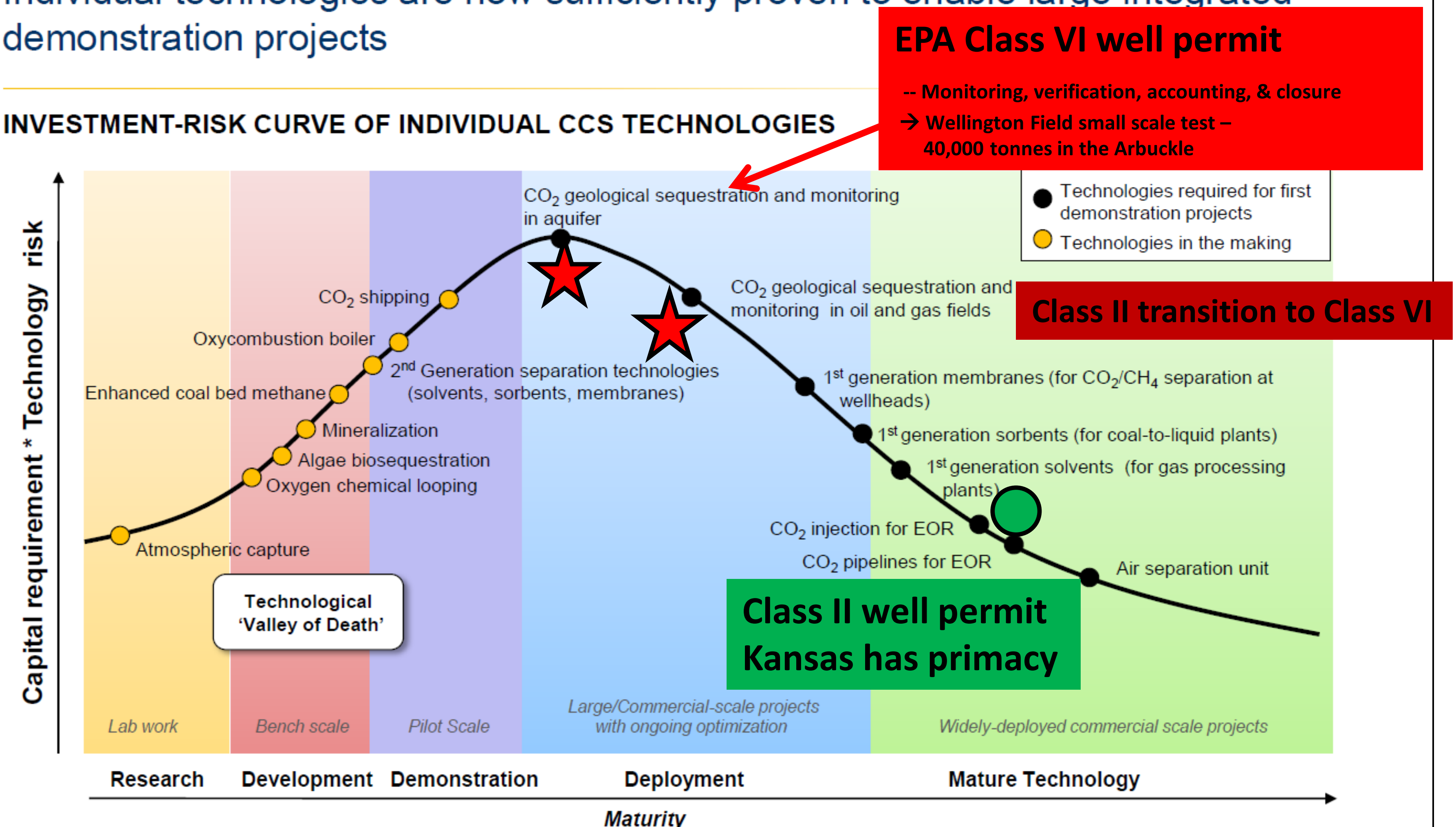
3. Opportunities, risks and uncertainties for CO_2-EOR



Carbon storage in saline aquifers currently has high technical risk; CO_2-EOR low risk

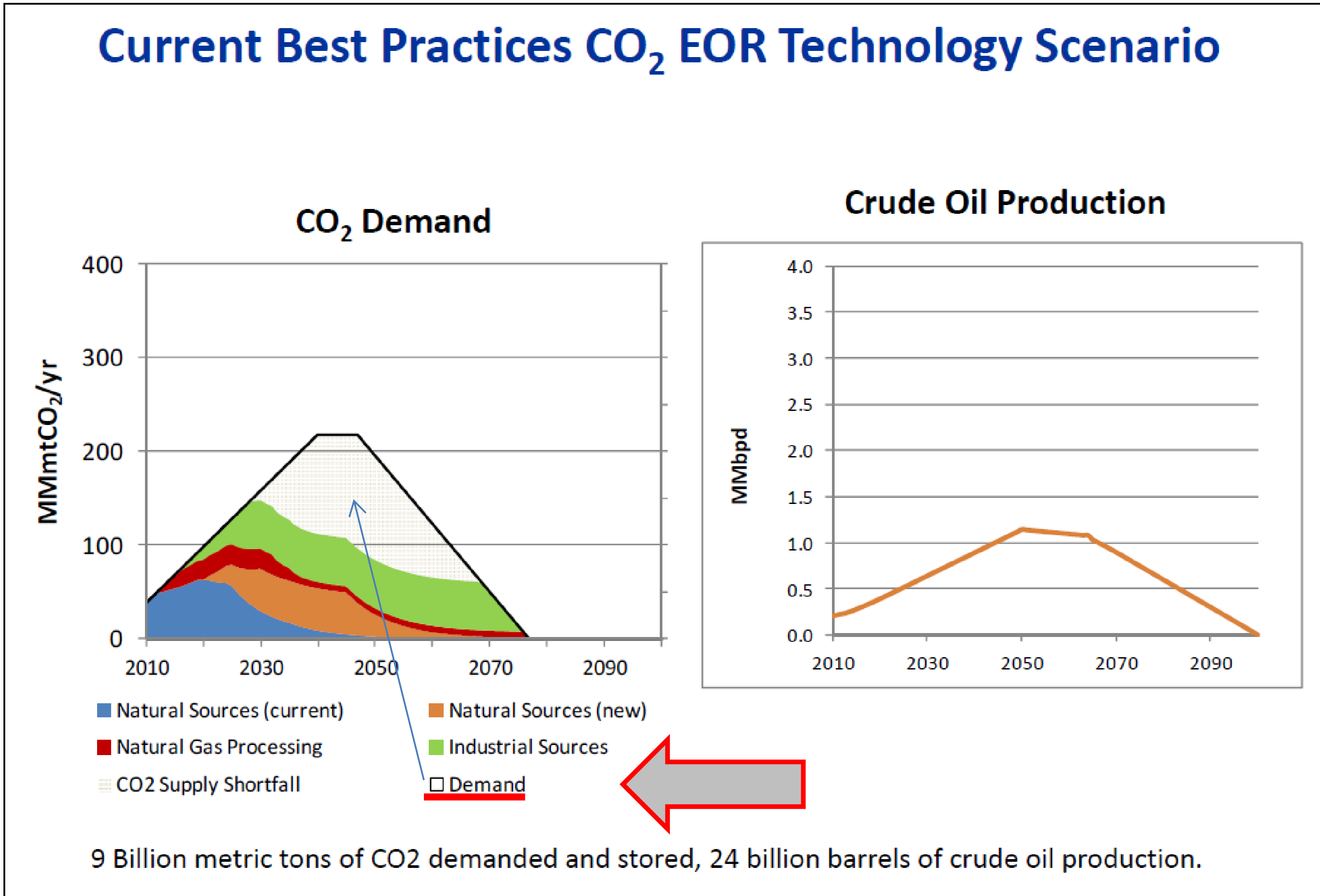
Individual technologies are now sufficiently proven to enable large integrated demonstration projects

INVESTMENT-RISK CURVE OF INDIVIDUAL CCS TECHNOLOGIES



Source: SBC Energy Institute

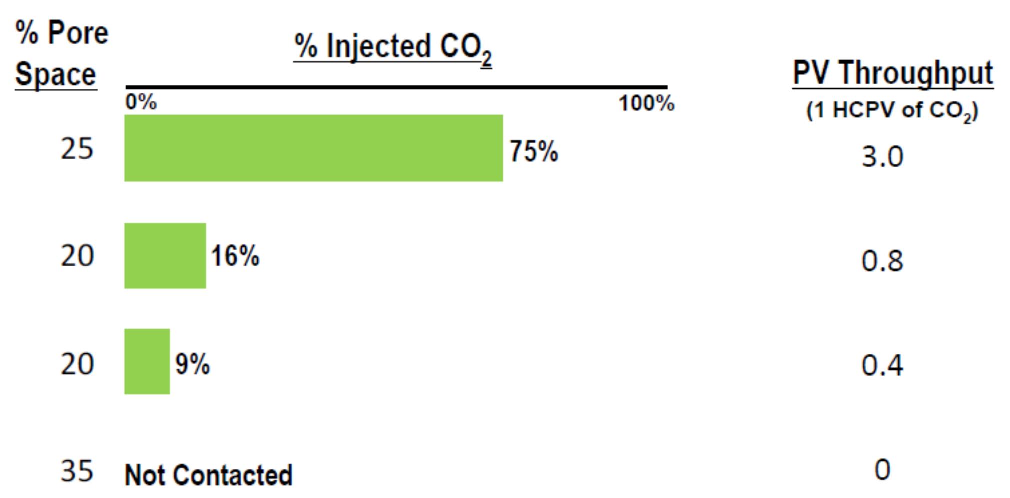
Next generation CO_2-EOR methods and anthropogenic CO_2 are essential to sustain this type of oil recovery in U.S. beyond 2030



Phil DiPietro, 2013, Carbon Dioxide Enhanced Oil Recovery in the United States, DOE-NETL

Next Generation CO_2-EOR is needed to ***improve efficiencies of oil recovery and CO_2 storage***

Example of Channeling of CO2 in an Oil-Bearing Formation



Source: Modified by Advanced Resources, based on data from Wasson Denver Unit CO2 flood observation pilot (Goodyear and Jensen, 2011).

CO2 Efficiency: Entrapment and Stabilization of CO_2 in Reservoirs

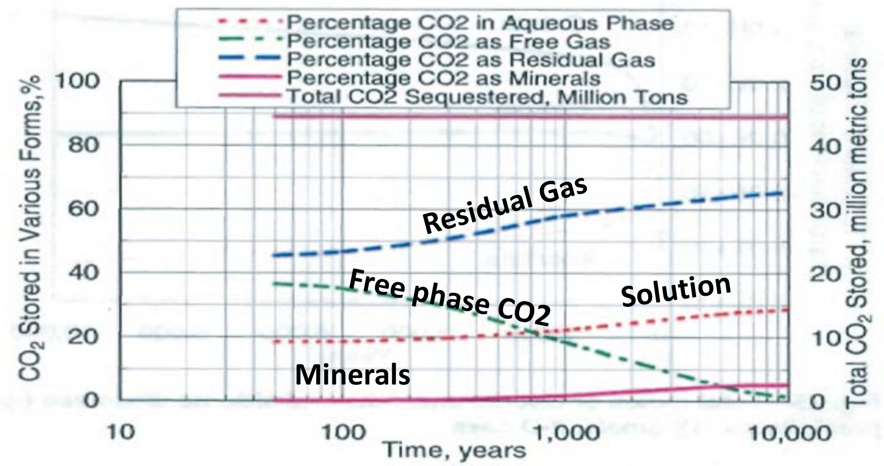
(…besides forming oil bank)

Injected CO_2 gets entrapped (stored) in the reservoir in 4 different ways – estimated by reactive transport models and reaction kinetics, modeled via compositional fluid flow simulators →

based on field and lab measurements of rock and brine

- Colleagues in Kansas & California -- A. Scheffer, R. Barker, C. Jackson, B. Huff, B. Campbell, M. Vega, K. Leslie, S. Datta, J. Roberts, D. Fowle, S. Carrol, M. Smith, M. Fazelalavi, E. Holubnyak, T. Birdie, J. Doveton

- **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)**

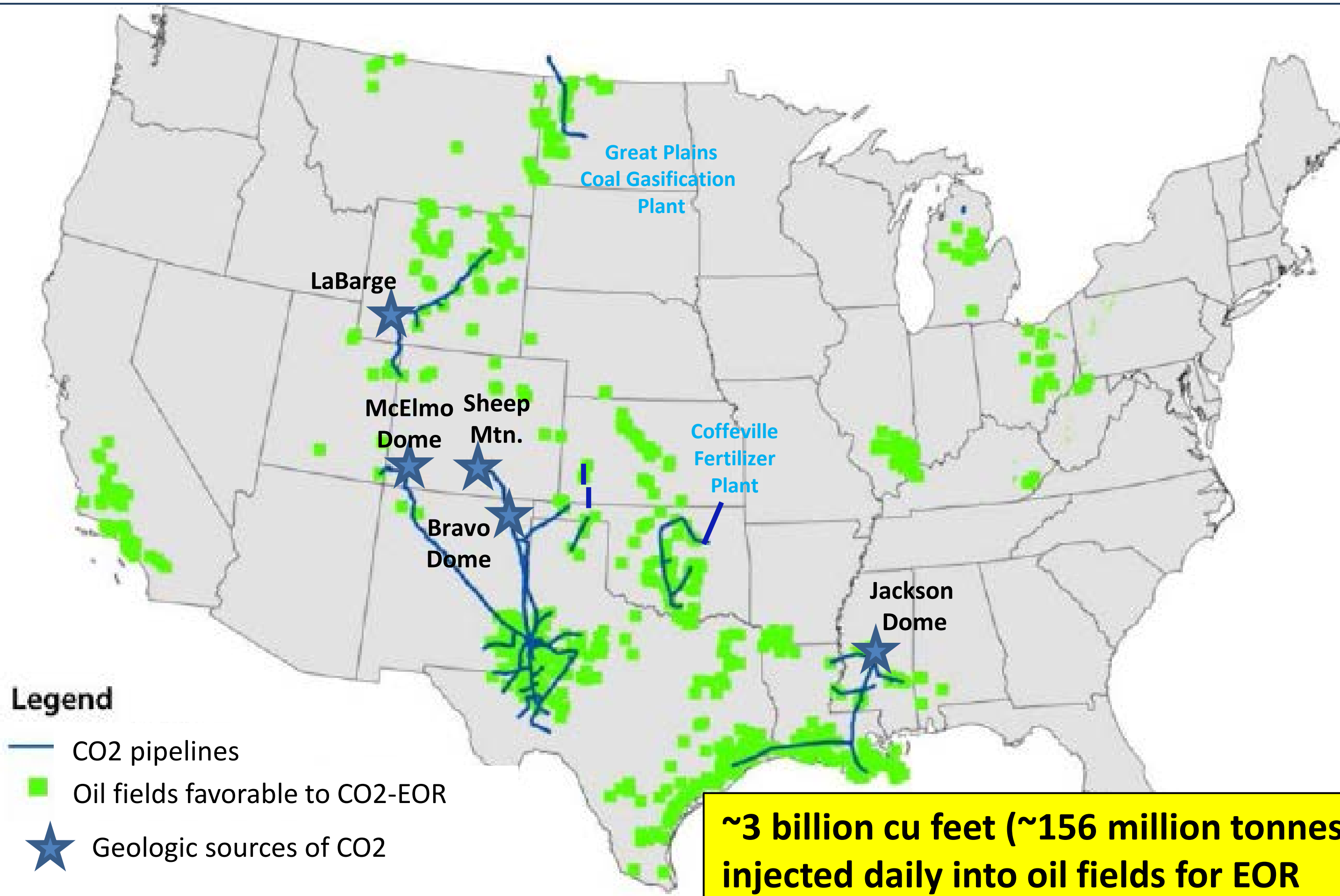


Ozah, 2005 – In situ CO_2 distribution after 50 years of injection

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%***

Kansas oil and gas fields are currently isolated from the major regional CO_2 pipeline systems … when will this change?

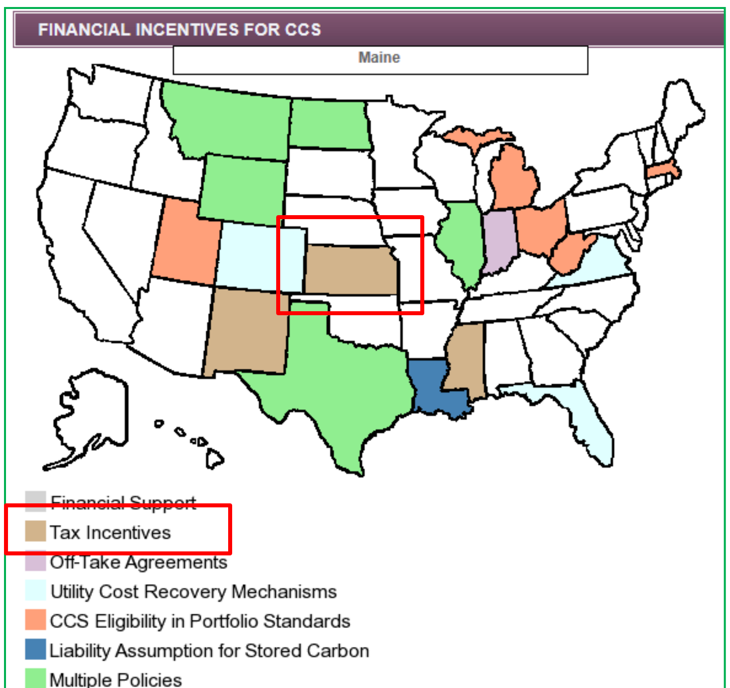


~3 billion cu feet (~156 million tonnes) CO_2 injected daily into oil fields for EOR

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

Government Incentives

Kansas H.B. 2419 creates tax incentives for carbon capture and storage, namely income tax deductions for the amortization of CCS equipment costs and property tax exemptions.



HOUSE BILL No. 2419

AN ACT enacting the carbon dioxide reduction act; providing for income tax reductions and property tax exemptions; providing for regulation of carbon dioxide injection wells; amending K.S.A. 2006 Supp. 79-32,117, 79-32,120 and 79-32,138 and repealing the existing sections; also repealing K.S.A. 2006 Supp. 79-32,117l.

Be it enacted by the Legislature of the State of Kansas:

New Section 1. Sections 1 through 7, and amendments thereto, may be cited as the carbon dioxide reduction act.

New Sec. 2. (a) As used in sections 2 through 5, and amendments thereto:

(1) "Carbon dioxide injection well" means any hole or penetration of the surface of the earth used to inject carbon dioxide for underground storage or for enhanced recovery of hydrocarbons and any associated machinery and equipment used for such injection of carbon dioxide. "Carbon dioxide injection well" does not include underground storage.

(2) "Commission" means the state corporation commission.

(3) "Underground storage" means any underground formation where carbon dioxide is injected for sequestration.

(b) For the purposes of protecting the health, safety and property of the people of the state, and preventing escape of carbon dioxide into the atmosphere and pollution of soil and surface and subsurface water detrimental to public health or to plant, animal and aquatic life, the commission, on or before July 1, 2008, shall adopt separate and specific rules and regulations establishing requirements, procedures and standards for the safe and secure injection of carbon dioxide and maintenance of underground storage of carbon dioxide. Such rules and regulations shall include, but not be limited to: (1) Site selection criteria; (2) design and development criteria; (3) operation criteria; (4) casing requirements; (5) monitoring and measurement requirements; (6) safety requirements, including public notification; (7) closure and abandonment requirements, including the financial requirements of subsection (e); and (8) long-term monitoring.

http://www.c2es.org/us-states-regions/policy-maps/ccs-financial-incentives

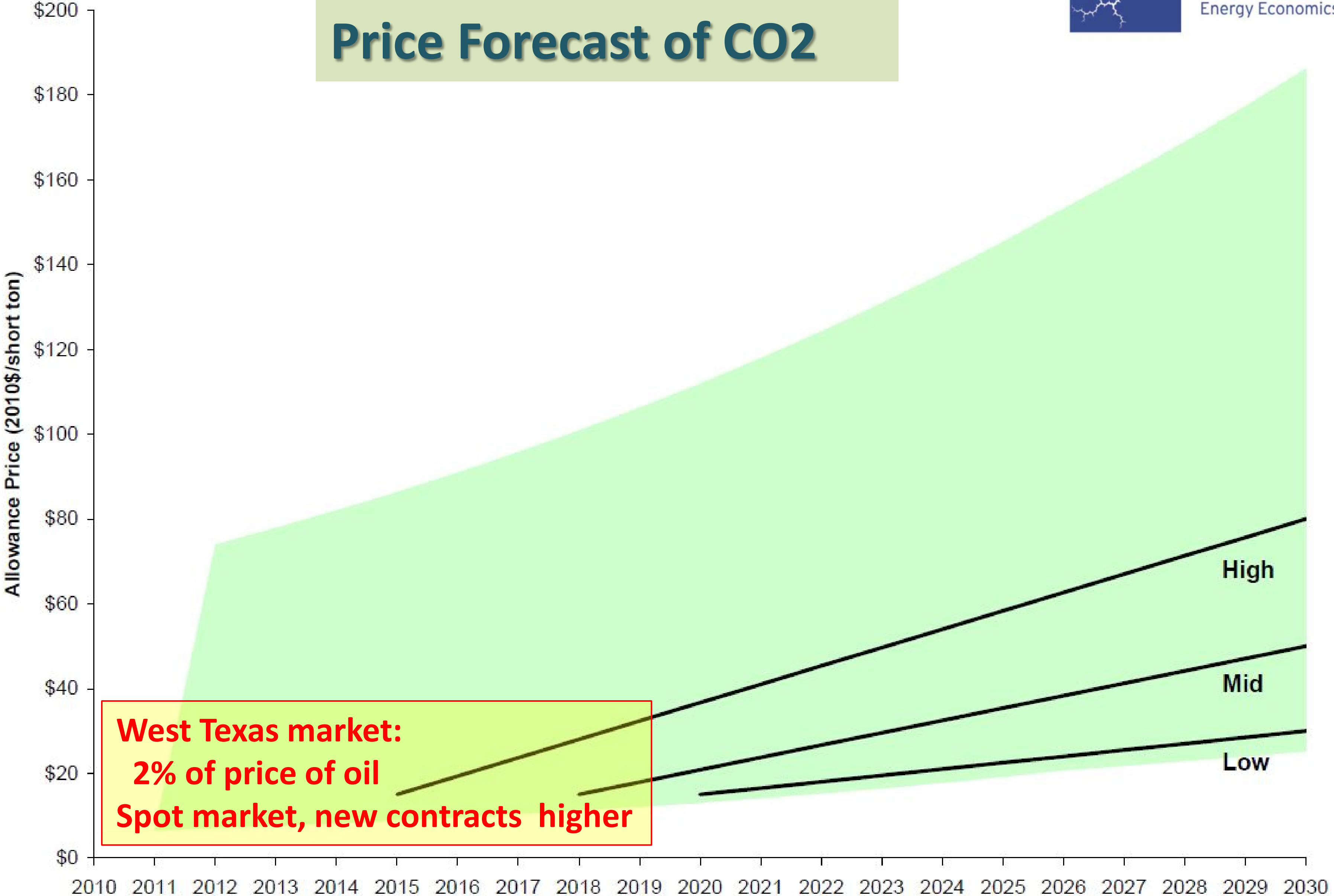
But, we need more CO_2 . . . and we need to bring the costs of capture and transport down. . .

NEORI CO_2 Capture & Transport Cost Assumptions ($/tonne)

	Transportation Cost	Core Scenario Capture Cost	Core Scenario + Transp. Costs (A)
Power Plant Tranche	**($/tonne)**	**($/tonne)**	**($/tonne)**
		(30-year Payback)	
Pioneer - First of a Kind Projects	$10	$60	$70
Projects #2-#5	$10	$50	$60
Nth of a Kind (Projects #6-onward)	$10	$45	$55
Industrial - Low Cost Tranche	**($/tonne)**	**($/tonne)**	**($/tonne)**
		(15-Year Payback)	
Pioneer- First of a Kind Projects	$10	$28	$38
Projects #2-#5	$10	$28	$38
Nth of a Kind (Projects #6-onward)	$10	$28	$38
Industrial - High Cost Tranche	**($/tonne)**	**($/tonne)**	**($/tonne)**
		(15-Year Payback)	
Pioneer- First of a Kind Projects	$10	$55	$65
Projects #2-#5	$10	$45	$55
Nth of a Kind (Projects #6-onward)	$10	$35	$45

http://neori.org/NEORI_CoalGen2012.pdf

Price Forecast of CO2



Synapse Energy Economics, Inc.

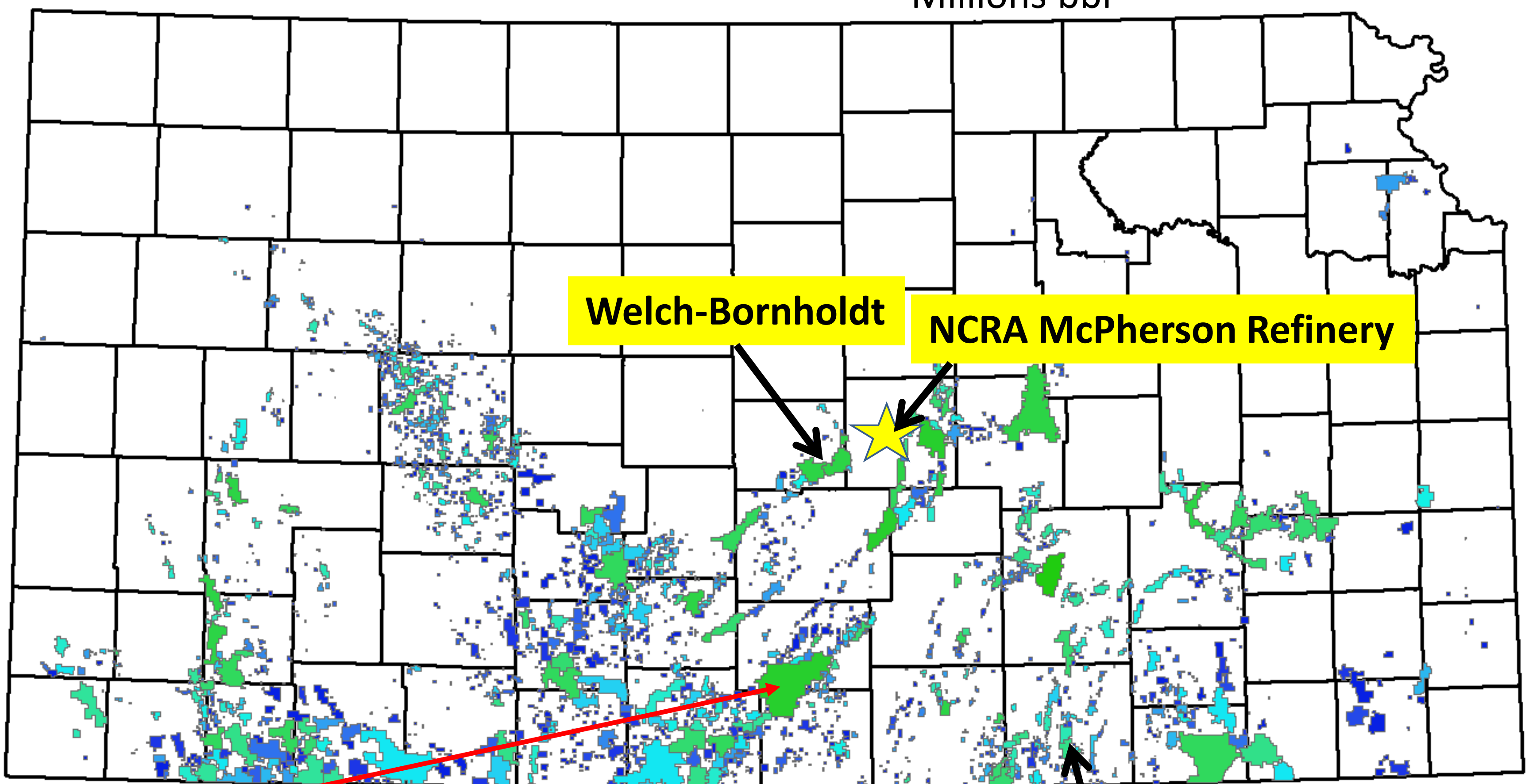
DOE-FE0002056

Mississippian Oil and Gas Producing Fields in Kansas

Cumulative Oil & Gas
in southern Kansas
1,180 million (M) bbls oil +
3,880 Billion (B) cu. ft of natural gas

> 88MBO	> 1MBO	> .5MBO

Millions bbl



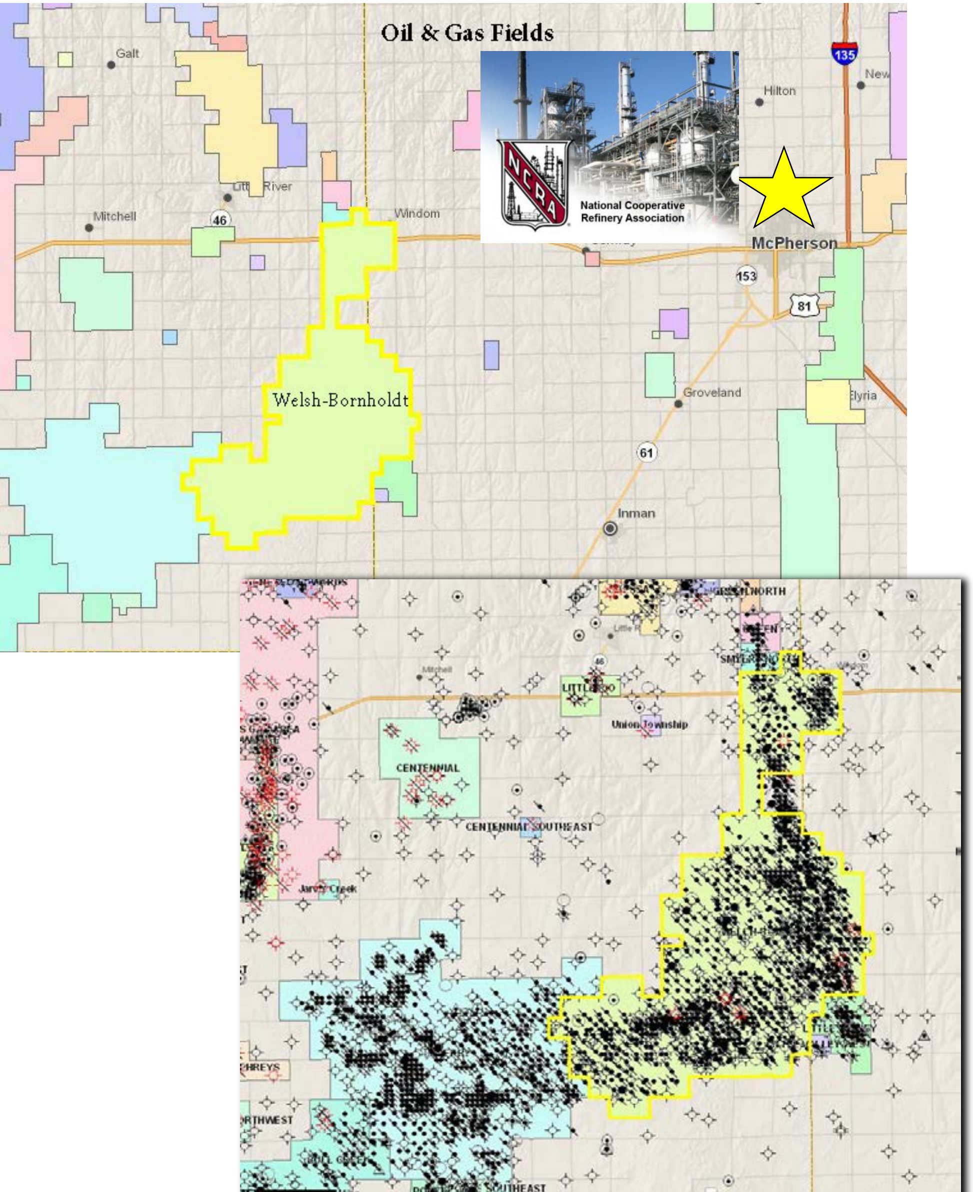
Spivey-Grabs Basil - largest Mississippian oil field in Kansas
- 69 MM BO & 841 BCFG
- promising for future CO_2-EOR after CH4 produced

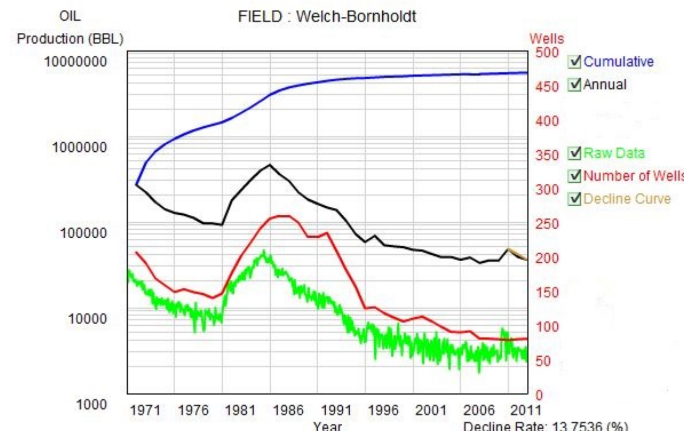
Welllington Field

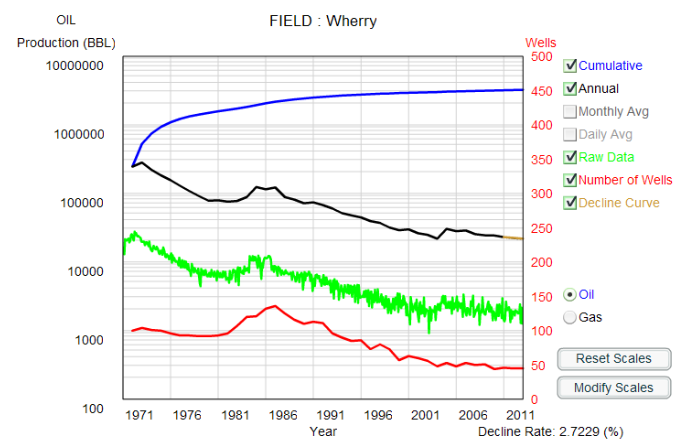
Gerlach, Sept. 2011

Welch-Bornholdt-Wherry Field

McPherson & Rice Counties – near McPherson Refinery







- 60+ million bbls cumulative production
- 80 active wells
- Producing zones – Mississippian, Basal Pennsylvanian, and Lansing Kansas City

Economic viability

- **$500-$1,000 million investment on ammonia plant will yield ~ $50 million in annual profits***

- **+50% potential income* from waste CO2 byproduct**

$50 million + $25 million

= $75 million potential annual profits

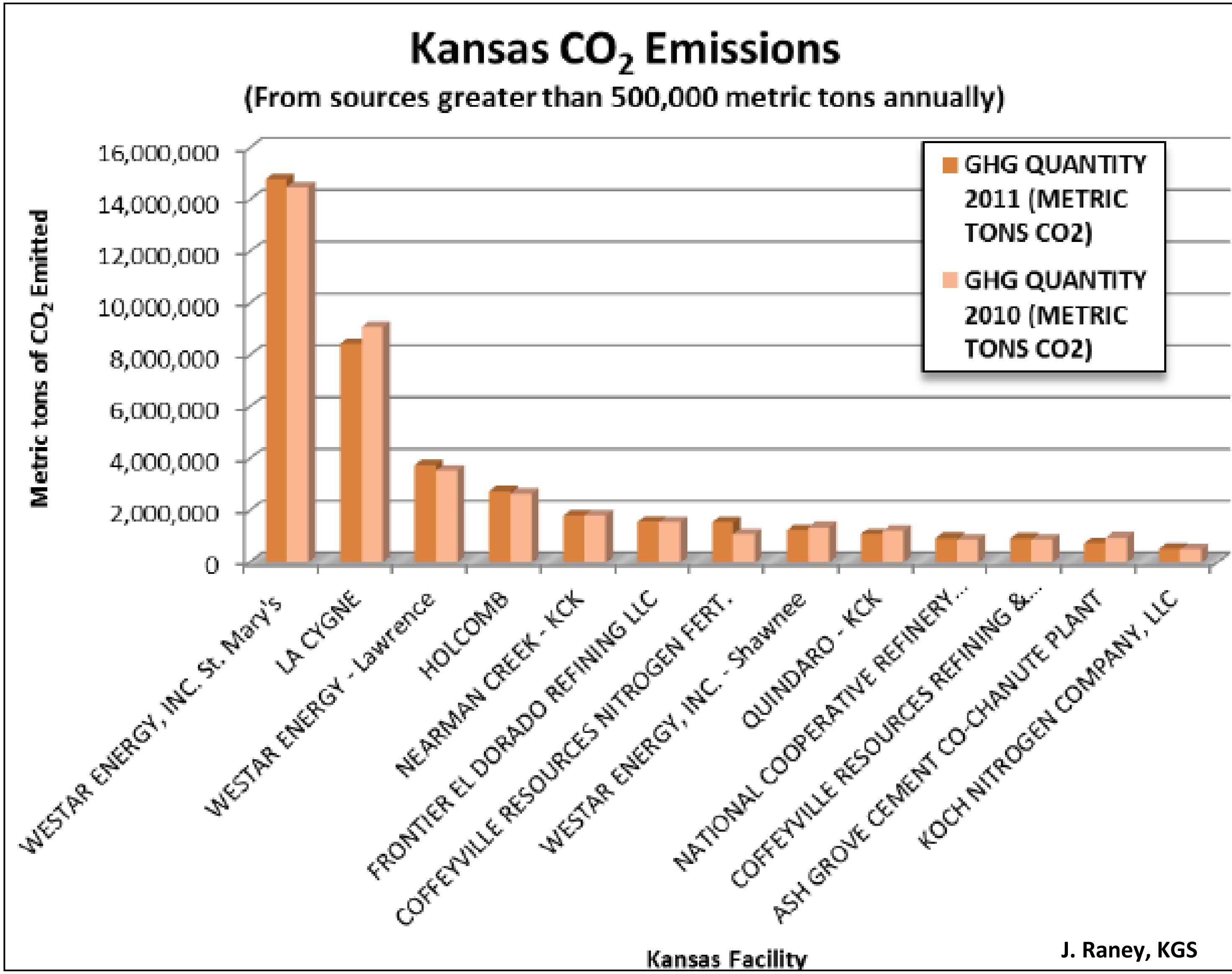
<u>Market for CO2</u>:

- CO_2 Utilization in Enhanced Oil Recovery (EOR)
- Geologic resources in Kansas for CO2 disposal
- Existing infrastructure within petroleum industry

***assuming 5-10% ROI**
***assuming $25 per ton CO2 & 1 million tons annual production (dotyenergy.com)**

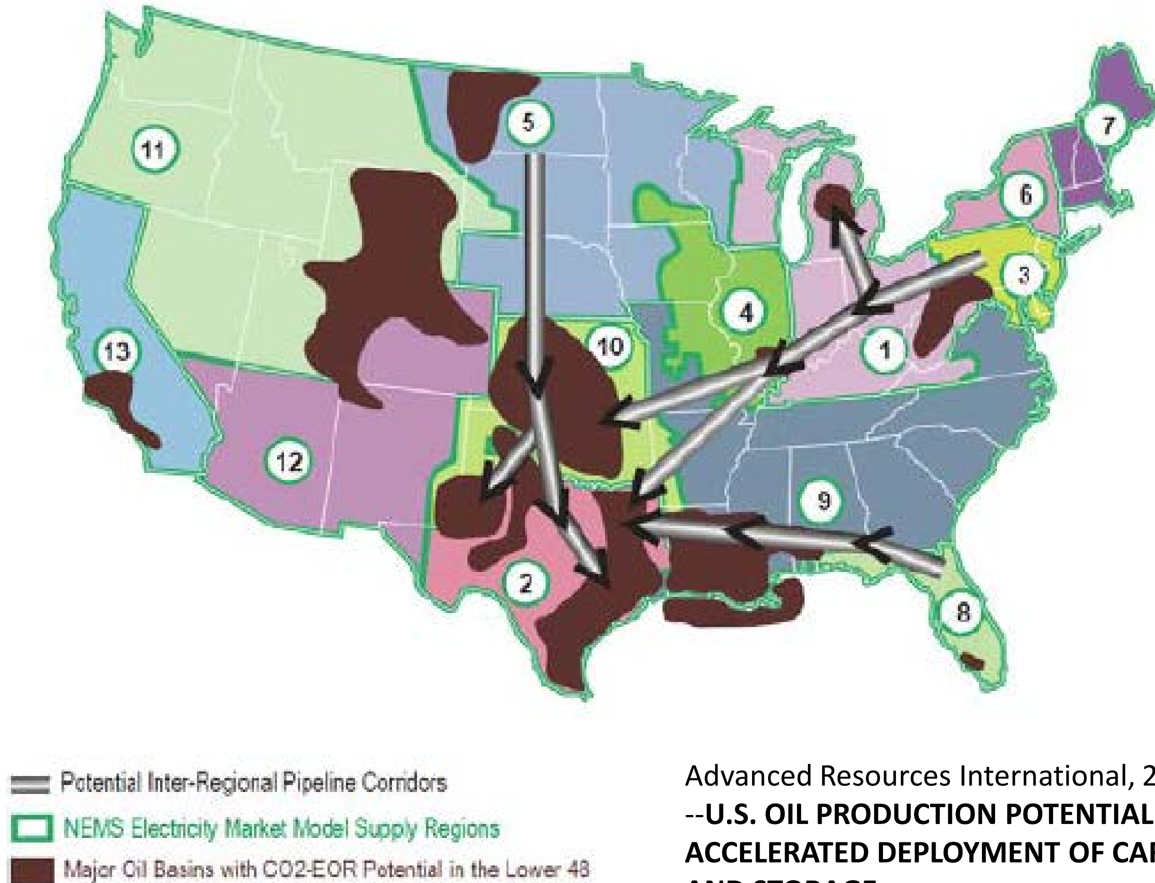
Role of Anthropogenic CO_2

- Due to limits of natural CO_2 supply, CO_2 will necessarily come from man-made sources such as ammonia, ethanol, refinery, and power plants
- Their utilization will require varying but large capital investments in addition to preparing oil fields to receive the CO_2
- Success will require all of the stakeholders including CO_2 suppliers, oil companies, local and state policy makers, and the research community
- Unified understanding of the potential CO_2 supply, oil resources, field readiness
  - infrastructure requirements, field readiness
  - financial and human resource needs, and
  - environmental and regulatory guidelines and incentives



Total Kansas 2012 CO2 emissions from point sources = 44.5 million metric tons (846 BCF)/yr.
http://ghgdata.epa.gov/

Kansas could become a hub to receive CO_2 by regional pipeline systems to serve EOR

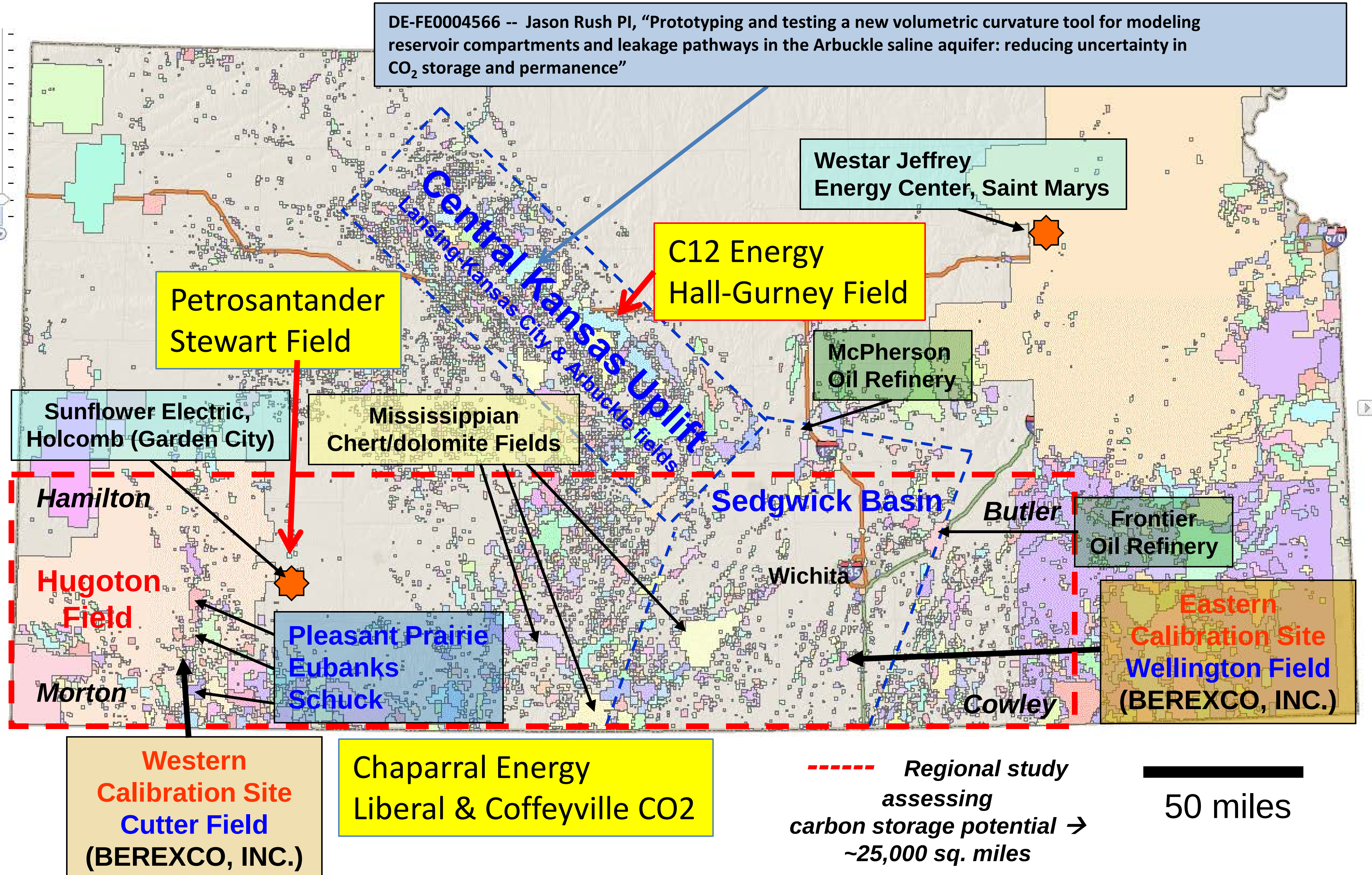


Advanced Resources International, 2010, White Paper --**U.S. OIL PRODUCTION POTENTIAL FROM ACCELERATED DEPLOYMENT OF CARBON CAPTURE AND STORAGE**

Dooley, Dahowski, and Davidson, 2010, CO2-driven Enhanced Oil Recovery as a Stepping Stone: to What? PNNL Rpt-19557.

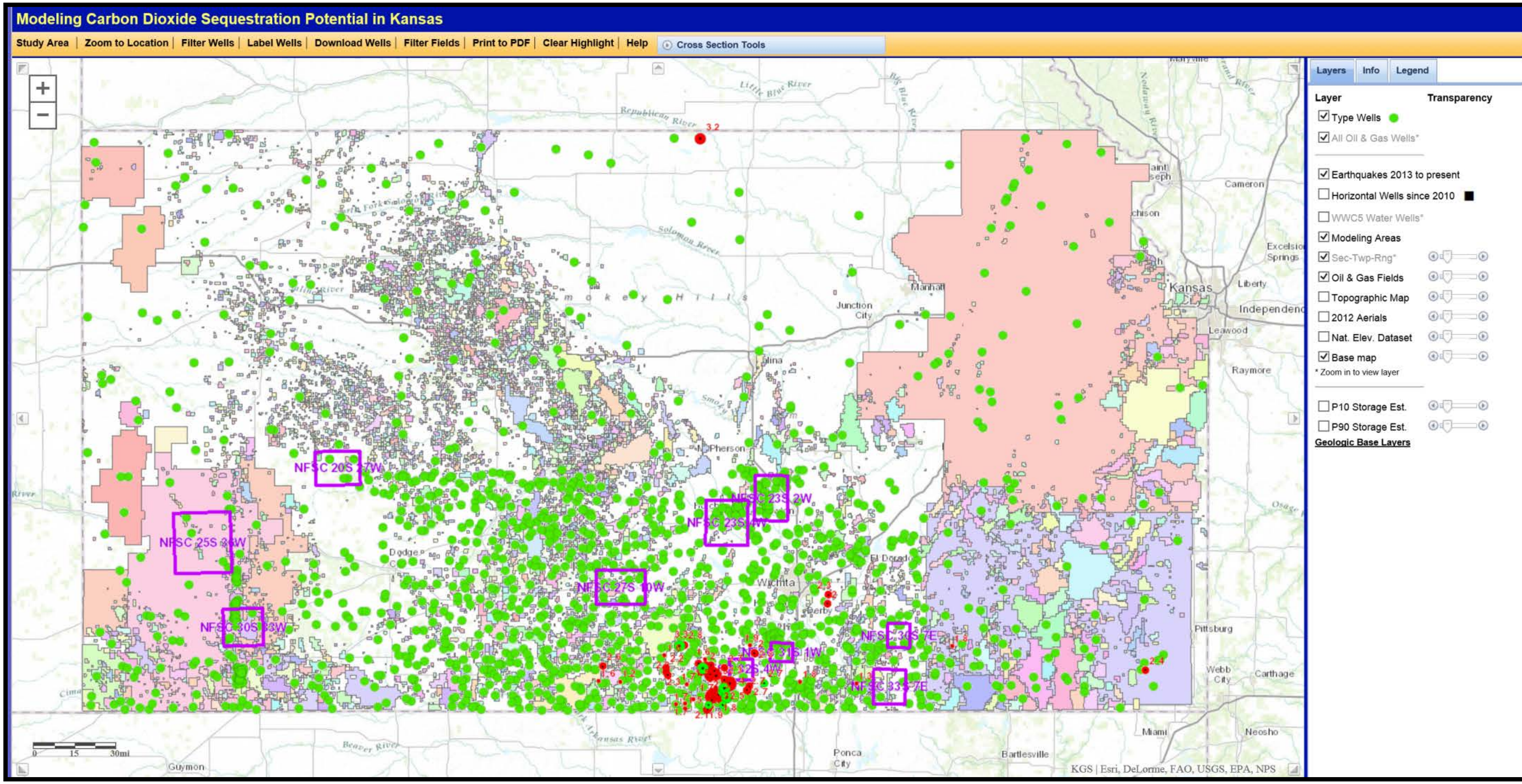
4. Brief summary of selected case studies that highlights approaches to next-generation CO_2-EOR applicable to Kansas oil reservoirs

CO_2-EOR Field Implementation Sites and Study Areas



CO_2 Oil & Gas Mapper With Type Logs (green)

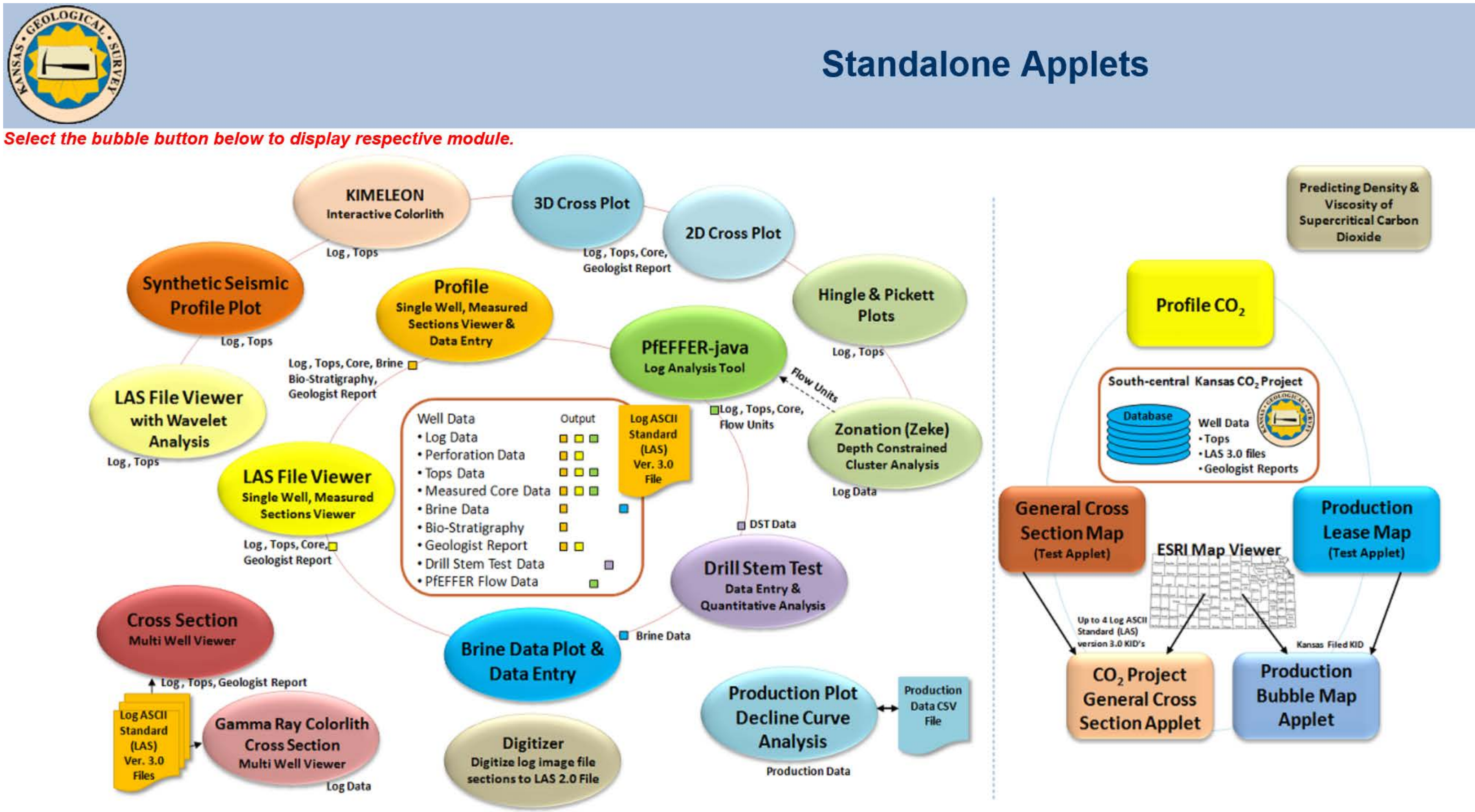
access to well and lease data and assist in screening of fields



http://maps.kgs.ku.edu/co2

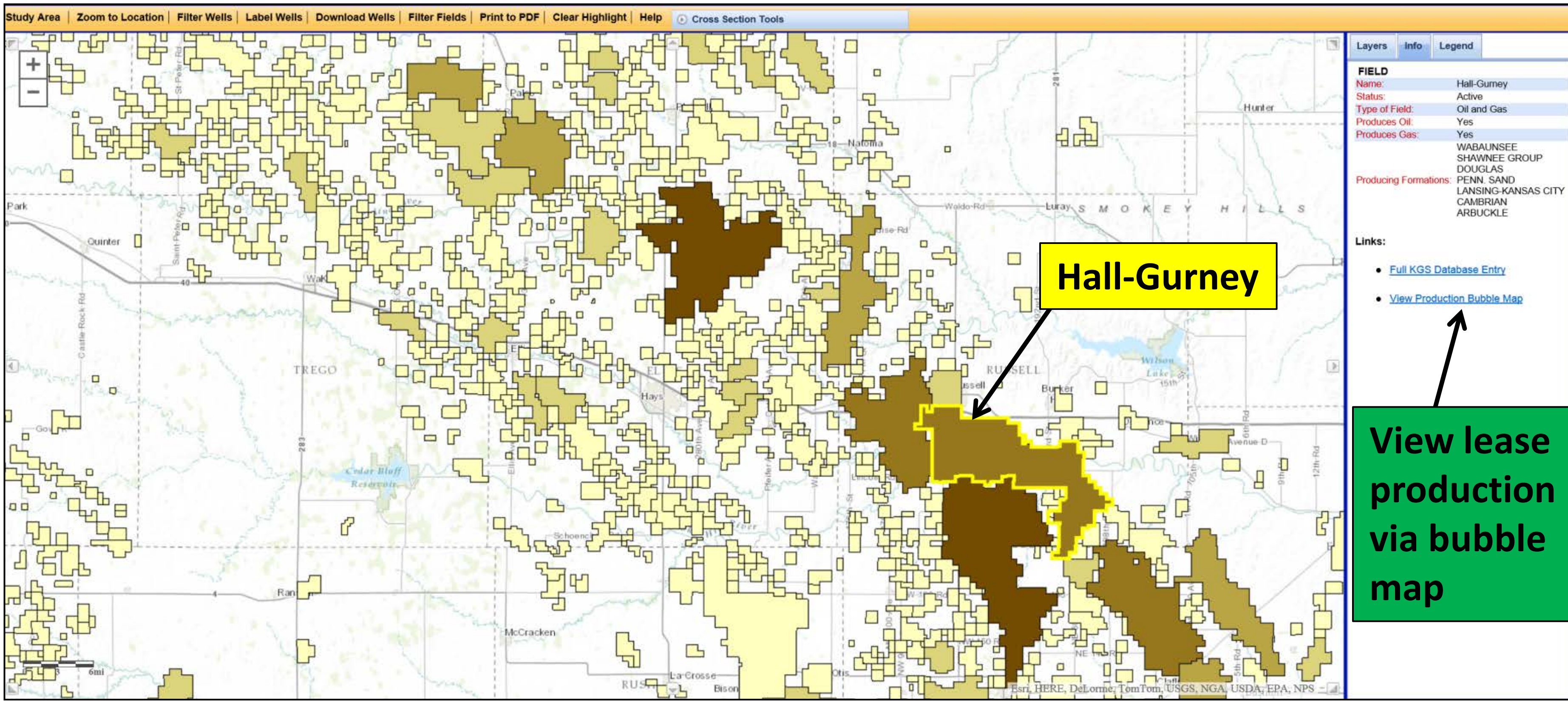
Java Applets (freeware)

-- assist in geoengineering analysis of reservoirs



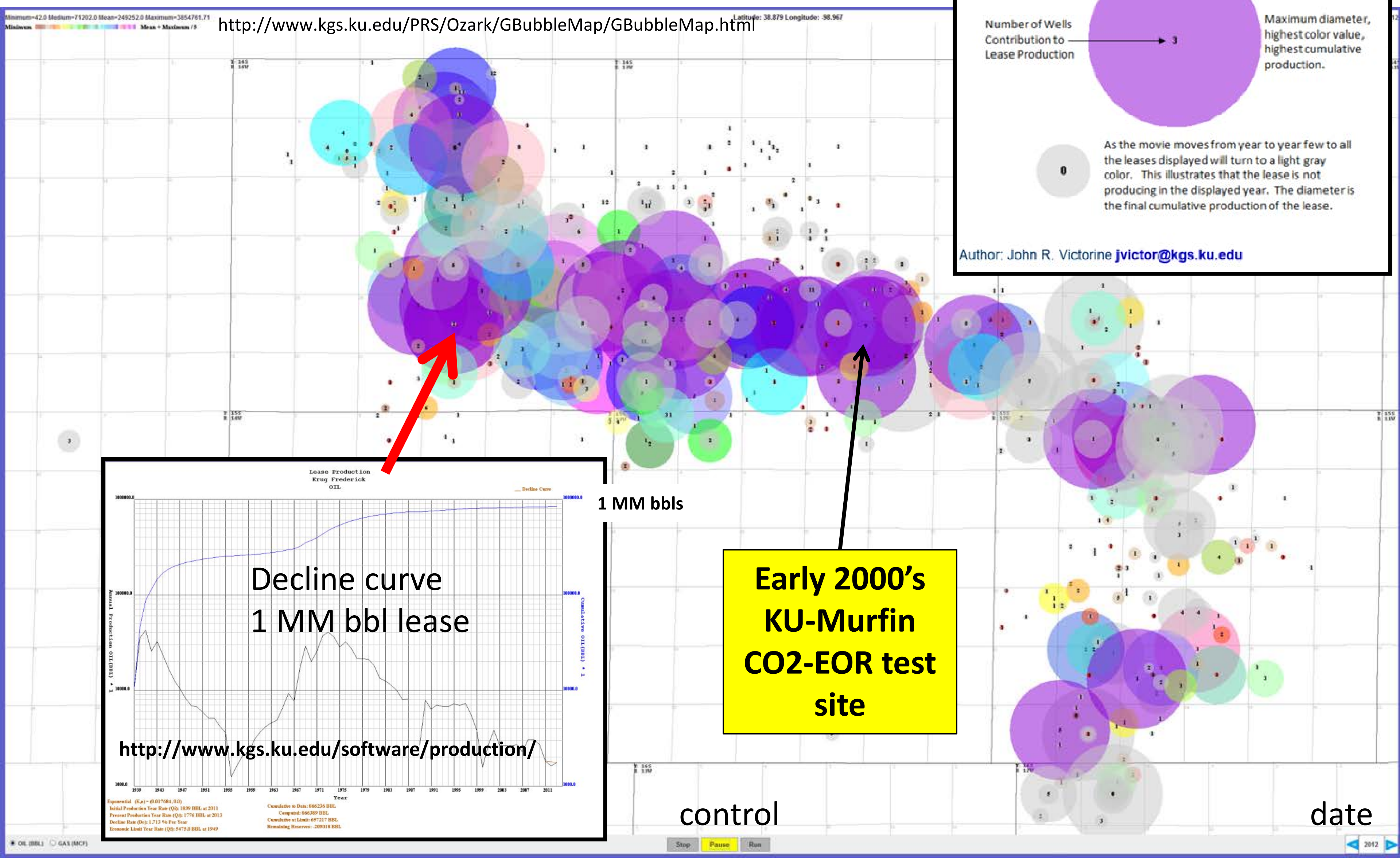
http://www.kgs.ku.edu/Gemini/Tools/Tools.html

CO_2 and Oil & Gas Mapper
Cumulative Oil Fields with LKC Production

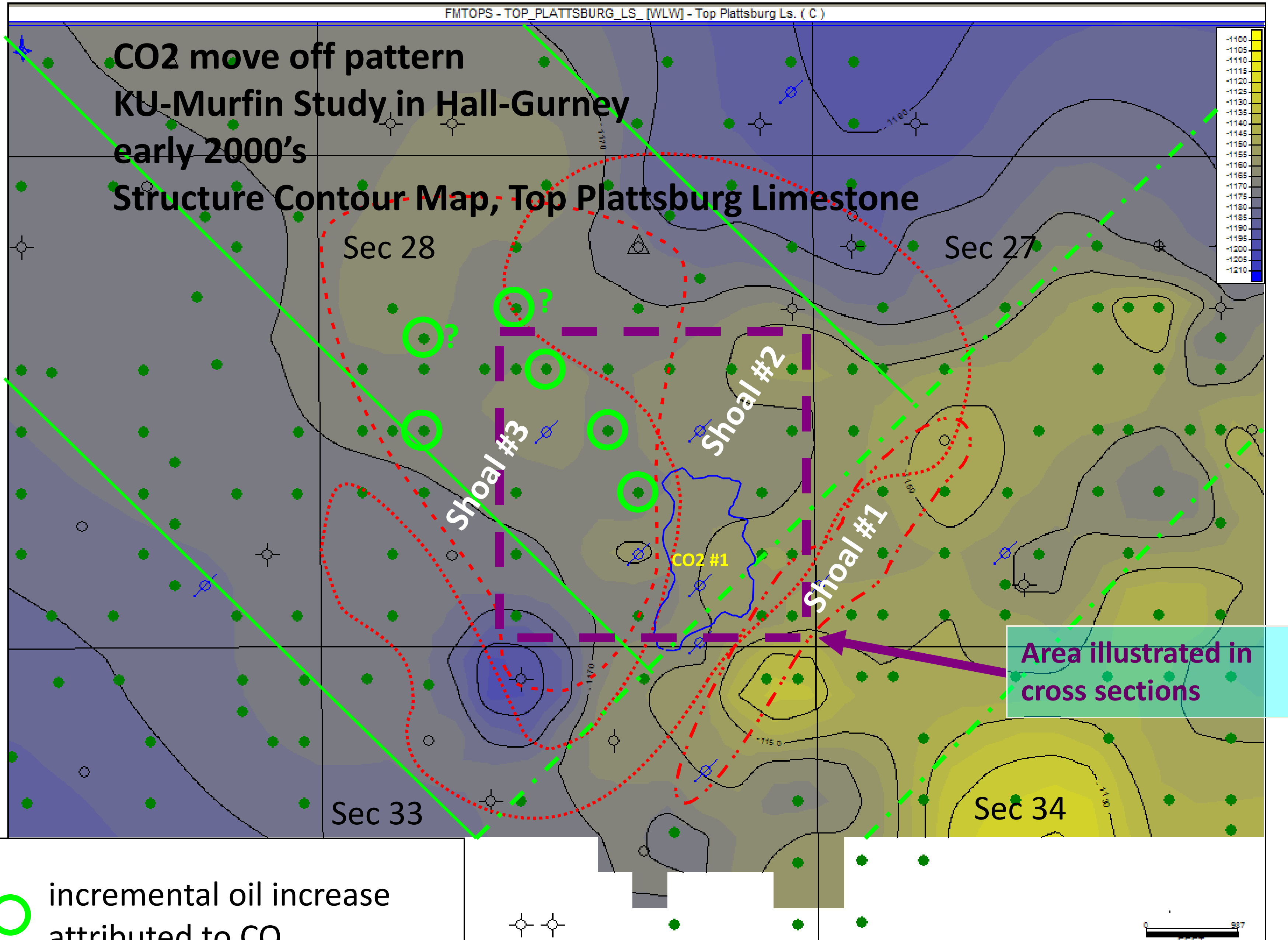


Northwest Kansas

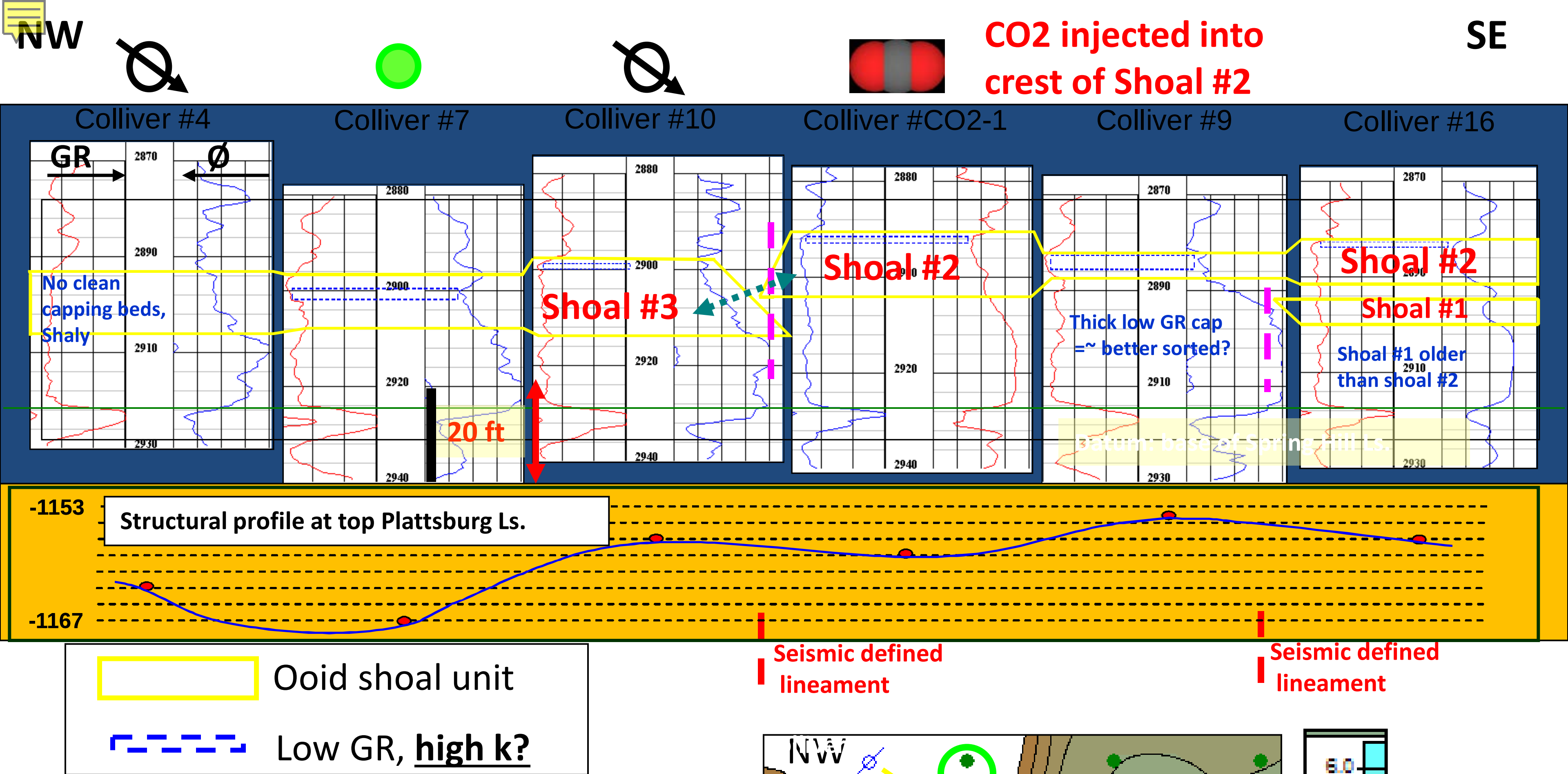
Cumulative Oil Lease Production Hall-Gurney Field, 2012

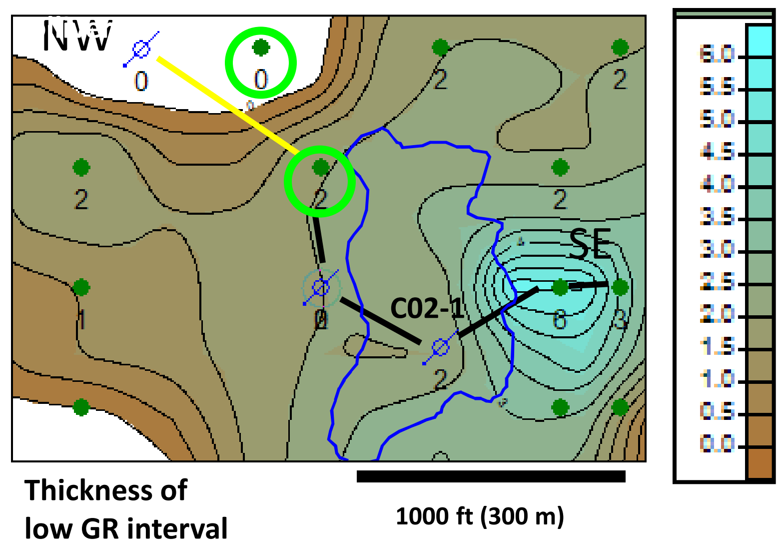


CO2 move off pattern
KU-Murfin Study in Hall-Gurney
early 2000's
Structure Contour Map, Top Plattsburg Limestone



incremental oil increase attributed to CO_2





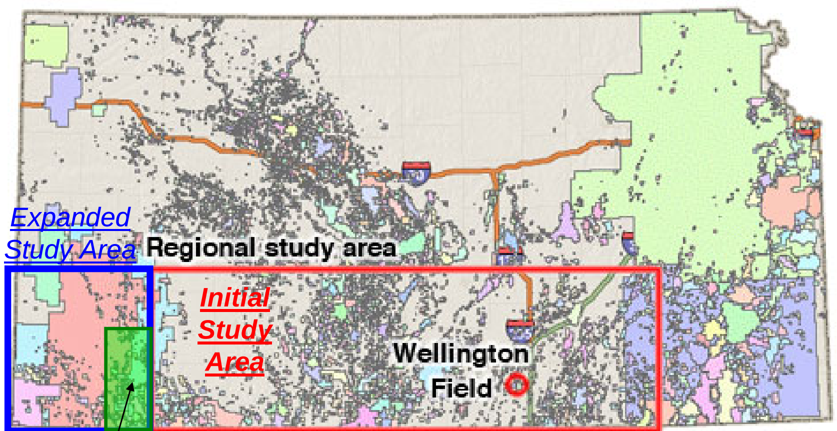
- Colliver #4 (*injector*)– (cuttings) dominant fine gr. tight ooid grainstone – *elevated GR*
- Colliver #7 (new oil)– (cuttings) bioclastic, oolitic pkst-grnst. with some interparticle Ø, forams, crinoids, encrusters; 40% ooid – thin clean GR
- Colliver #CO2-1 (CO_2 injection) and Colliver #16 (upper) – (cored) oomoldic grainstone, clean porous (shoal #2); Shoal #1 in well #16; finer grained and less porous, lower permeability -- #2 lowest GR, youngest shoal

Southwest Kansas CO2 EOR Initiative
Chester and Morrow Reservoirs

Western Annex to Regional CO2 Sequestration Project (DE-FE0002056) run by the Kansas Geological Survey

The SW Kansas part of project

- CO2 EOR technical feasibility study – Chester IVF and Morrow
- Part of larger KGS-industry CCS and EOR study
- Will not inject CO2 – paper study only
- Get fields in study "CO2-ready"



Six Industry partners:

- Anadarko Petroleum Corp.
- Berexco LLC
- Cimarex Energy Company
- Glori Oil Limited
- Elm III, LLC
- Merit Energy Company

Support by:

Sunflower Electric Power Corp.

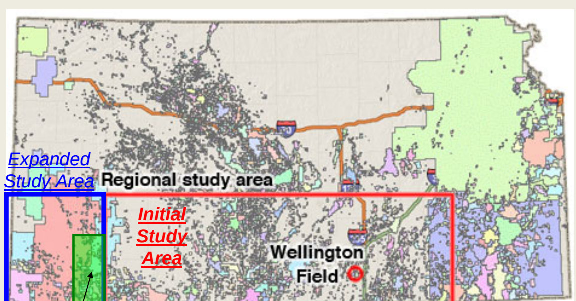
Technical Team:

	Project Role	Company
Martin Dubois	Team Lead, geo-model	Consultant - IHR LLC
John Youle	Core & depo-models	Consultant - Sunflower
Ray Sorenson	Data sleuth & advisor	Consultant
Eugene Williams	Reservoir engineering	Williams Petrol. Consultants
Dennis Hedke	3D Seismic	Consultant - Hedke & Sanger
Peter Senior	Reservoir modeling	MS student
Ken Stalder	Geotech	IHR, LLC
Susan Nissen	3D Seismic	Consultant
Lynn Watney	Project PI	KGS
Jason Rush	Project PI	KGS
John Doveton	Log Petrophysics	KGS
Paul Gerlach	Data support	Consultant - Charter

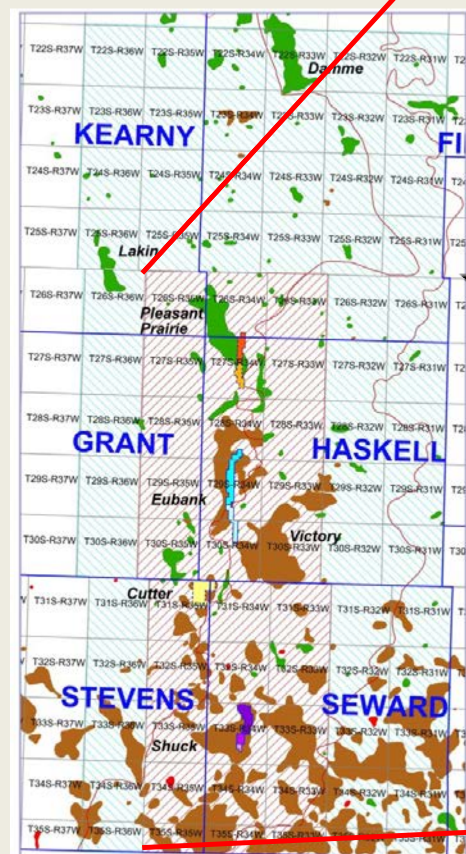
Southwest Kansas CO_2-EOR Initiative

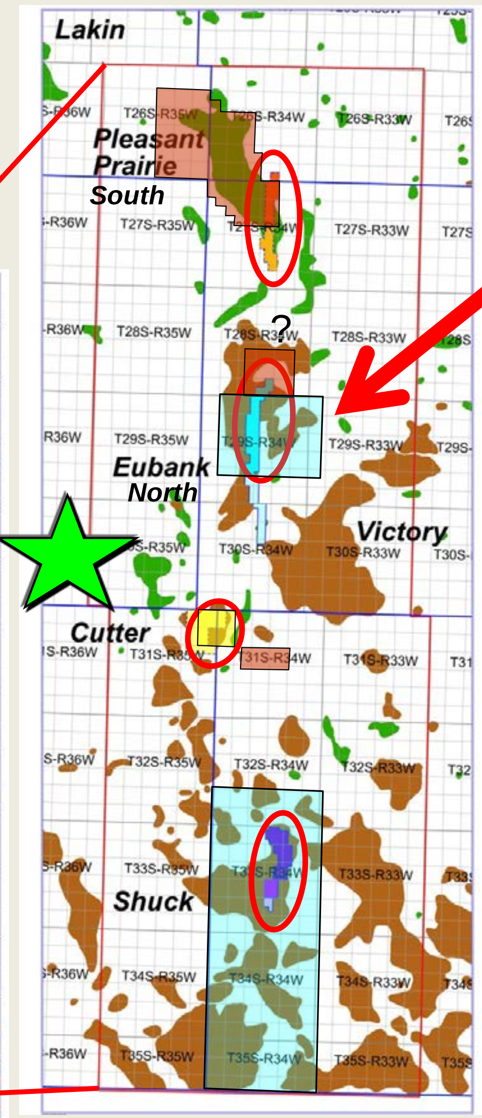
Evaluate CO_2 sequestration potential in Arbuckle Group saline aquifer and
CO_2-EOR in four fields in southwestern Kansas – Anadarko, Berexco, Cimarex, Glori, Elm III, Merit

Southwest Kansas CO2 Consortium (*Western Annex*)



CO2 EOR Study

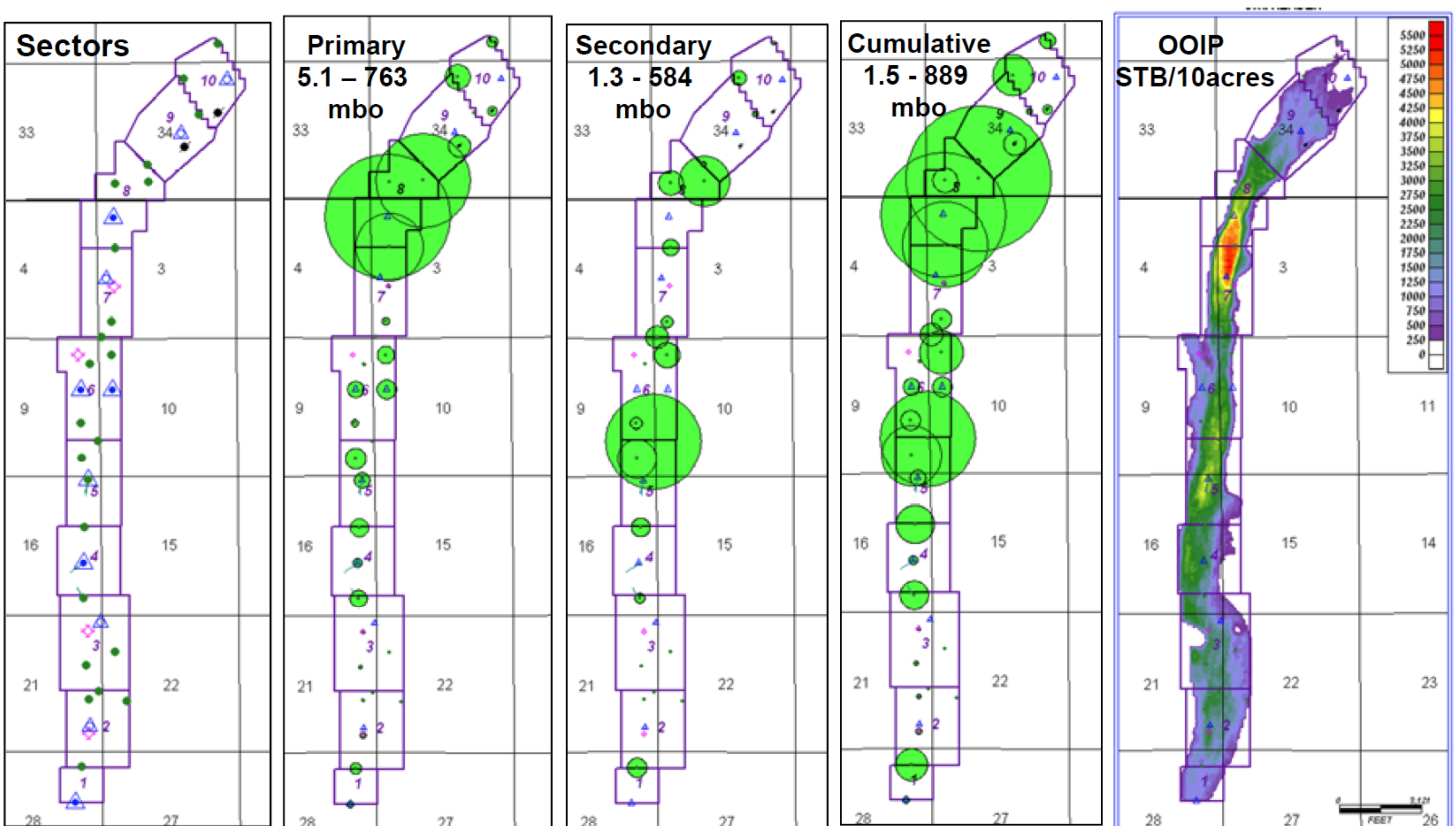




KANSAS GEOLOGICAL SURVEY
The University of Kansas

Oil production unevenly distributed in valleys

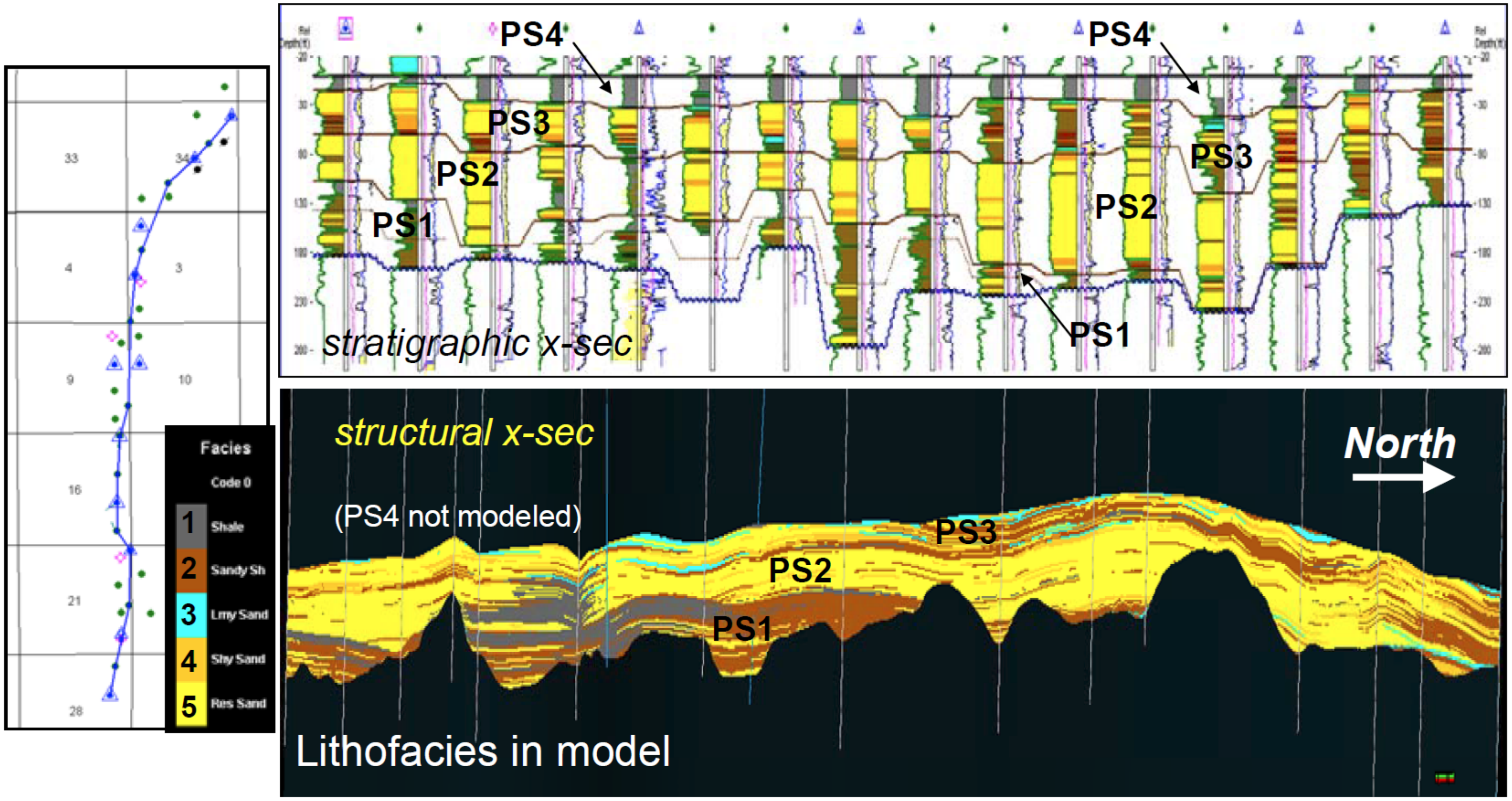
shown by well and OOIP in North Eubank unit



Dubois, Youle, and Williams, in prep.

Reservoir heterogeneity-- stratigraphically complex

-- Four Parasequences in North Eubank unit



Sandstone = yellow; Sandy shale = brown; Gray = shale

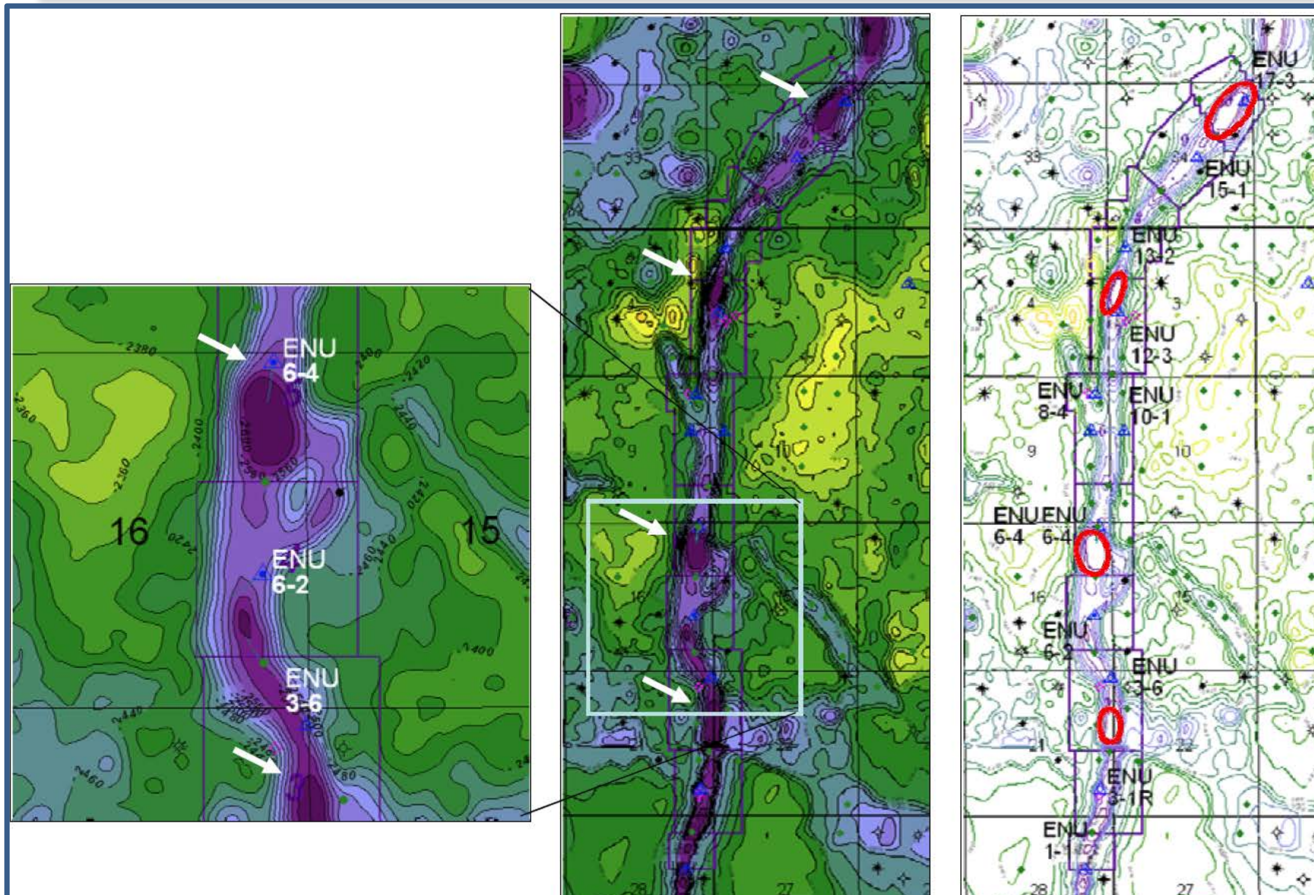
Length of section ~ 5 miles

Dubois, Youle, and Williams, in prep.

Seismic depth maps, Top Meramec and location of probable sinkholes in North Eubank unit

--- sinkholes possibly responsible for loss of injected water → **limit injection pressures**

1. By 2011 water injection exceeded production by approximately one million barrels per year.
2. The reservoir system was significantly under-pressured, having an original BHP of 1572 psig.
3. Normal BHP for the reservoir depth would be 2350 psi (5500 ft deep x 0.43 psi/ft).
4. Rock fracture pressure is likely to be approximately 3500 psi if the fracture gradient is 0.65 psi/ft.
5. Fractures and conduits were not open until reservoir pressure exceeded approximately 2500 psi



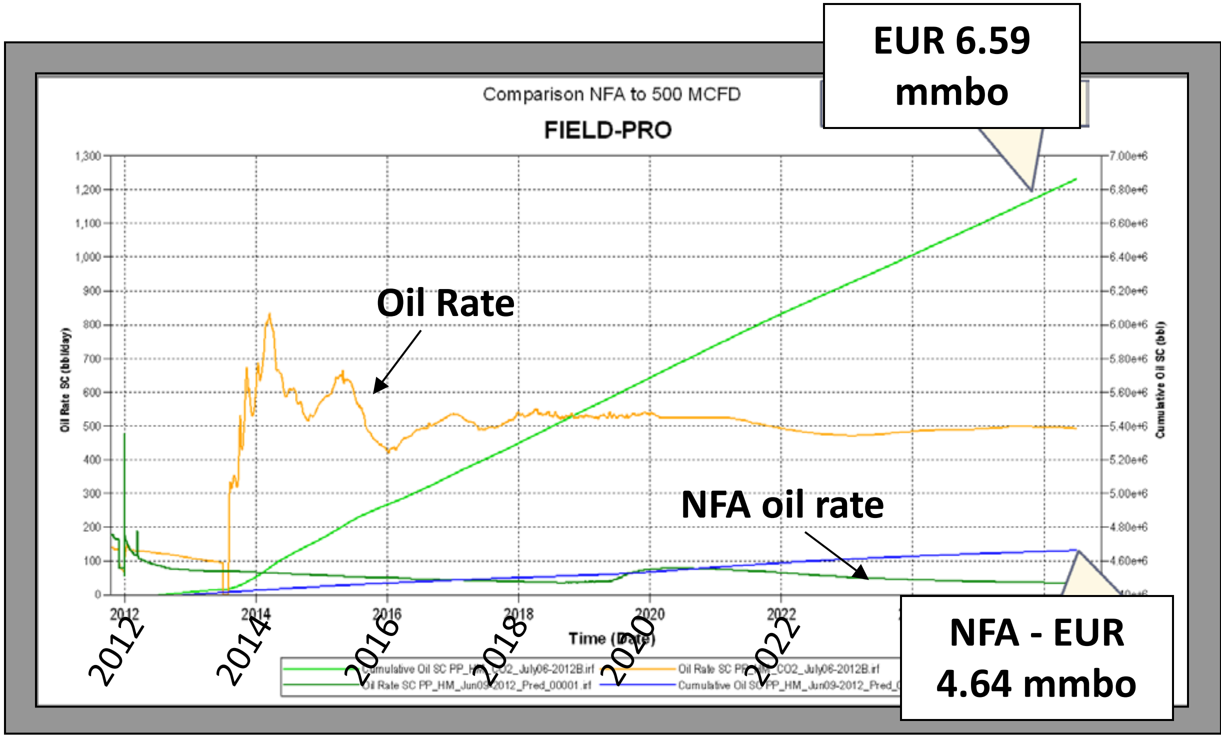
Reservoir simulations done with four suspected leak points

Dubois, Youle, and Williams, in prep.

CO_2 EOR Projections – Pleasant Prairie South Field

Assumptions:

1. Convert WIW to CO2 IW
2. Oil wells as is
3. Inject 5 mmcfd CO2, not exceeding bhp 2600 psi
4. Continuous CO2, no WAG
5. Injection = production
6. No optimization



13 years injection

Projections:

OIL (mmbo)

Cumulative 2011	4.48
NFA cum. 2026	4.64
CO2 case cum.	6.59
Increment. CO2	1.95
Cum. 2012-2026	2.11

CO2		*mm tons*
CO2 injected (mmcf)	23.7	1.38
CO2 produced (mmcf)	13.2	0.77
CO2 sequestered (mmcf)	10.5	0.61
Gross utilization (mcf/bo)	11.2	
Net utilization (mcf/bo)	5.0	

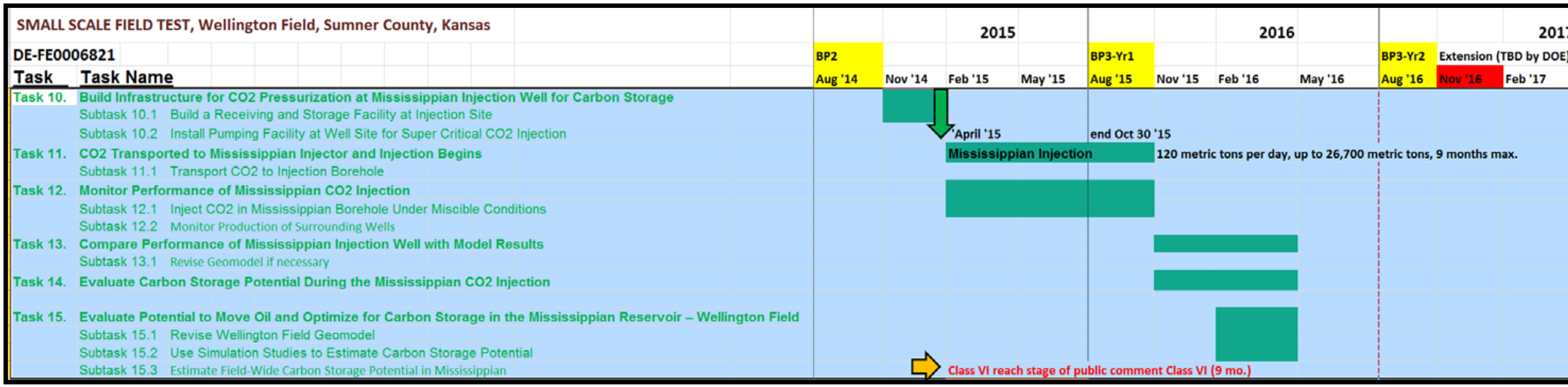
assume 56% CO2 is recycled

RF as *f* (OOIP)

Primary	15.8%
Secondary	15.8%
CO2	13.3%
	45.0%

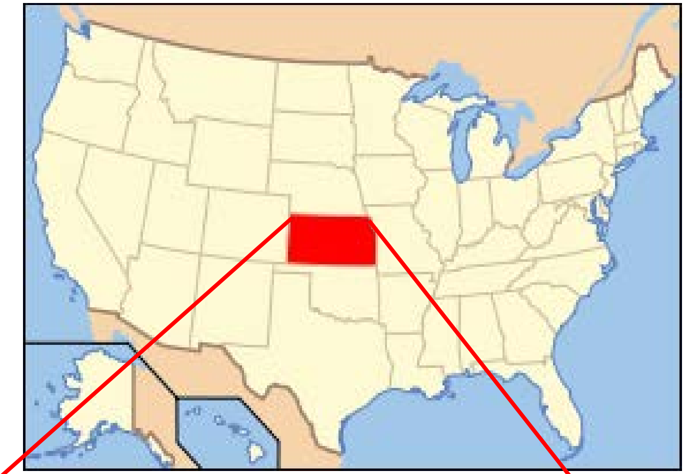
SMALL SCALE FIELD TEST
Wellington Field, Sumner County, Kansas

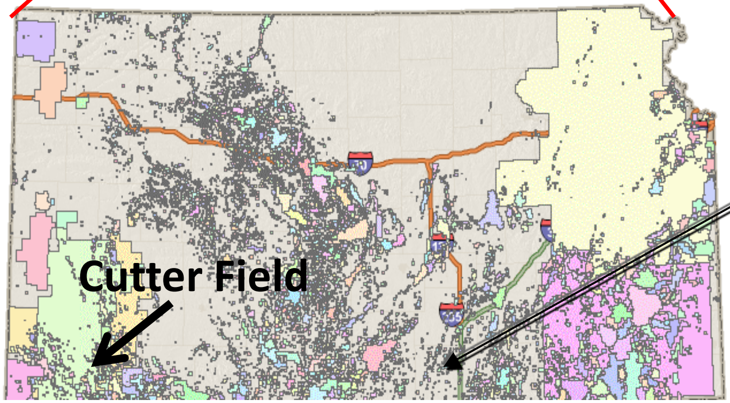
Awaiting permission from DOE to commence field work on September 1, 2014



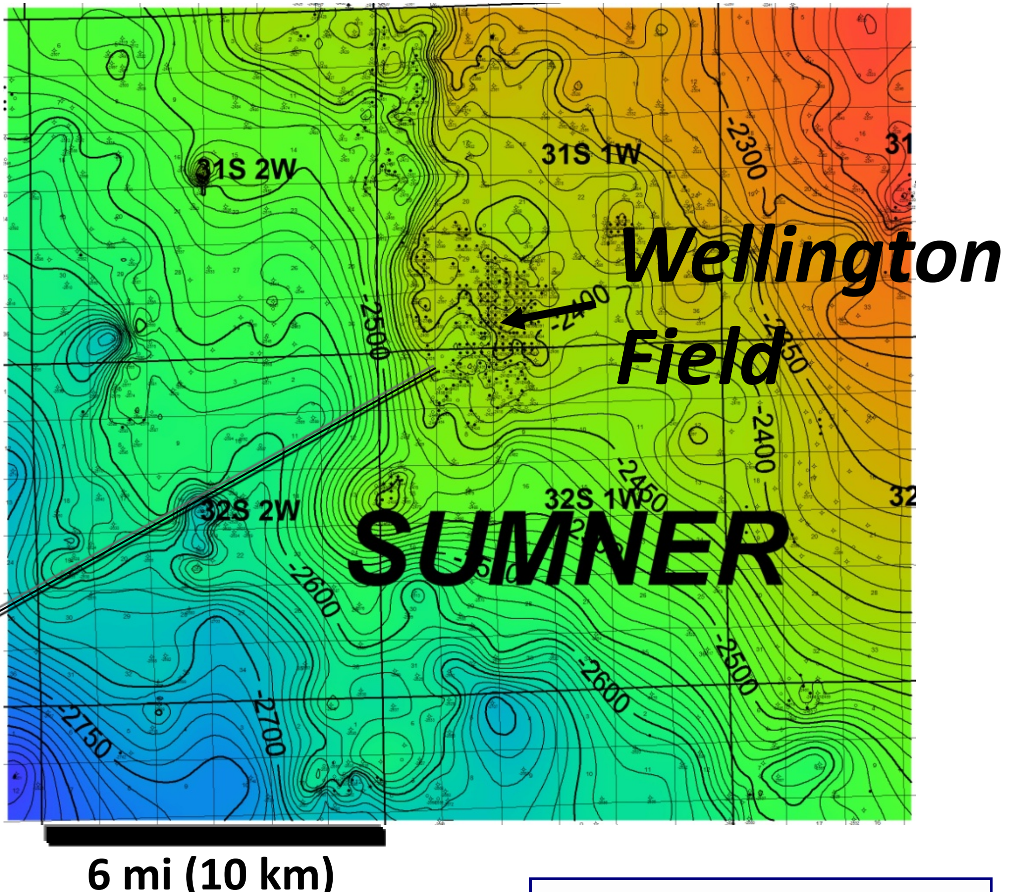
- <u>Beginning April 2015 --Inject 26,000 tonnes of CO_2</u> into Mississippian oil reservoir to demonstrate CO2-EOR and 99% assurance of storage with MVA
- InSAR, CGPS surface deformation
- 15 seismometers and 3 active 3-component accelerometers – possibly monitor low energy fluid movement and far-field earthquakes in region
- Monitor produced fluids for tracers, CO2, aqueous geochemistry

Wellington Field
Site of Proposed Small Scale Field Test



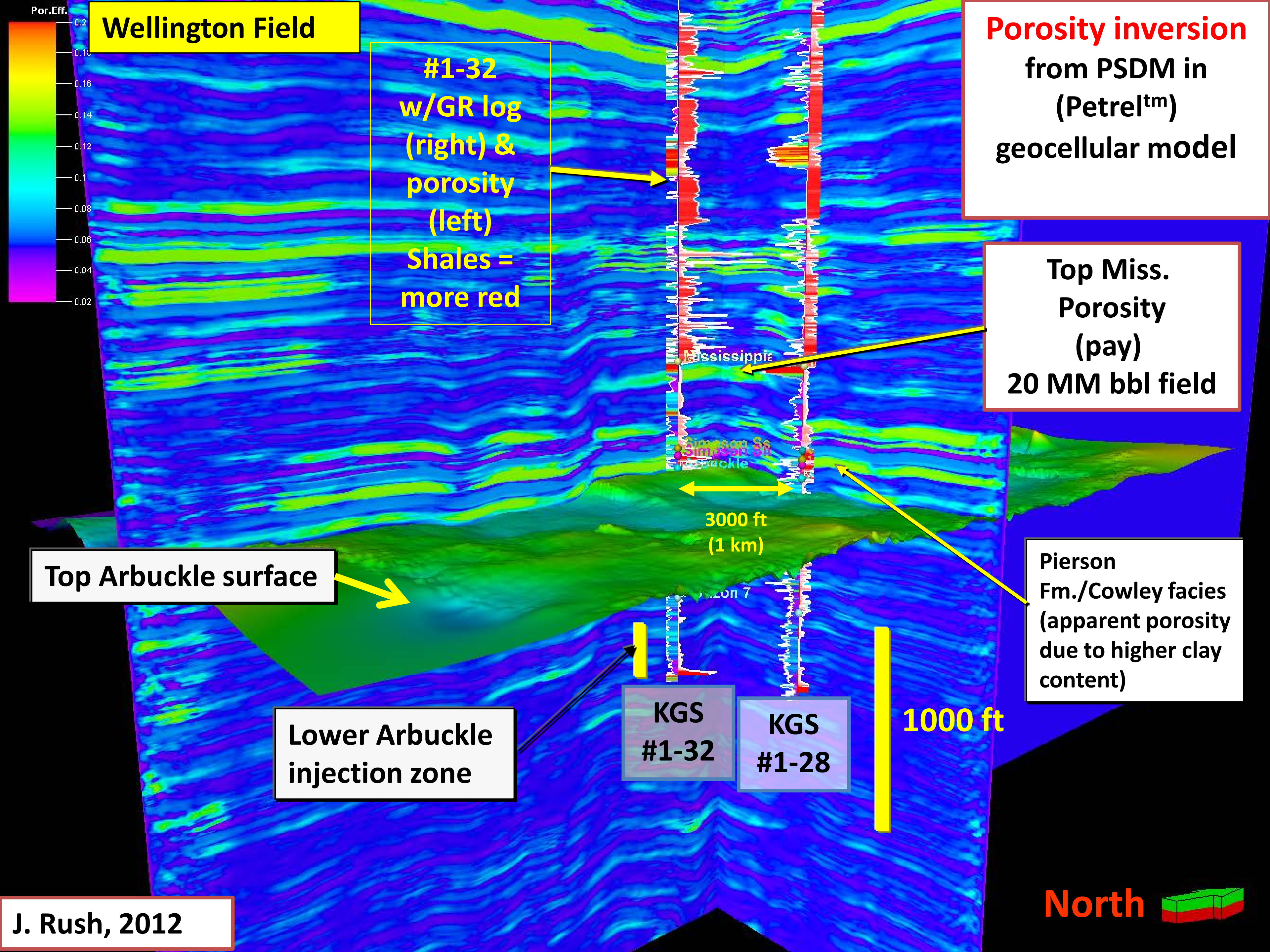


Top Mississippian Structure, 10 ft C.I.

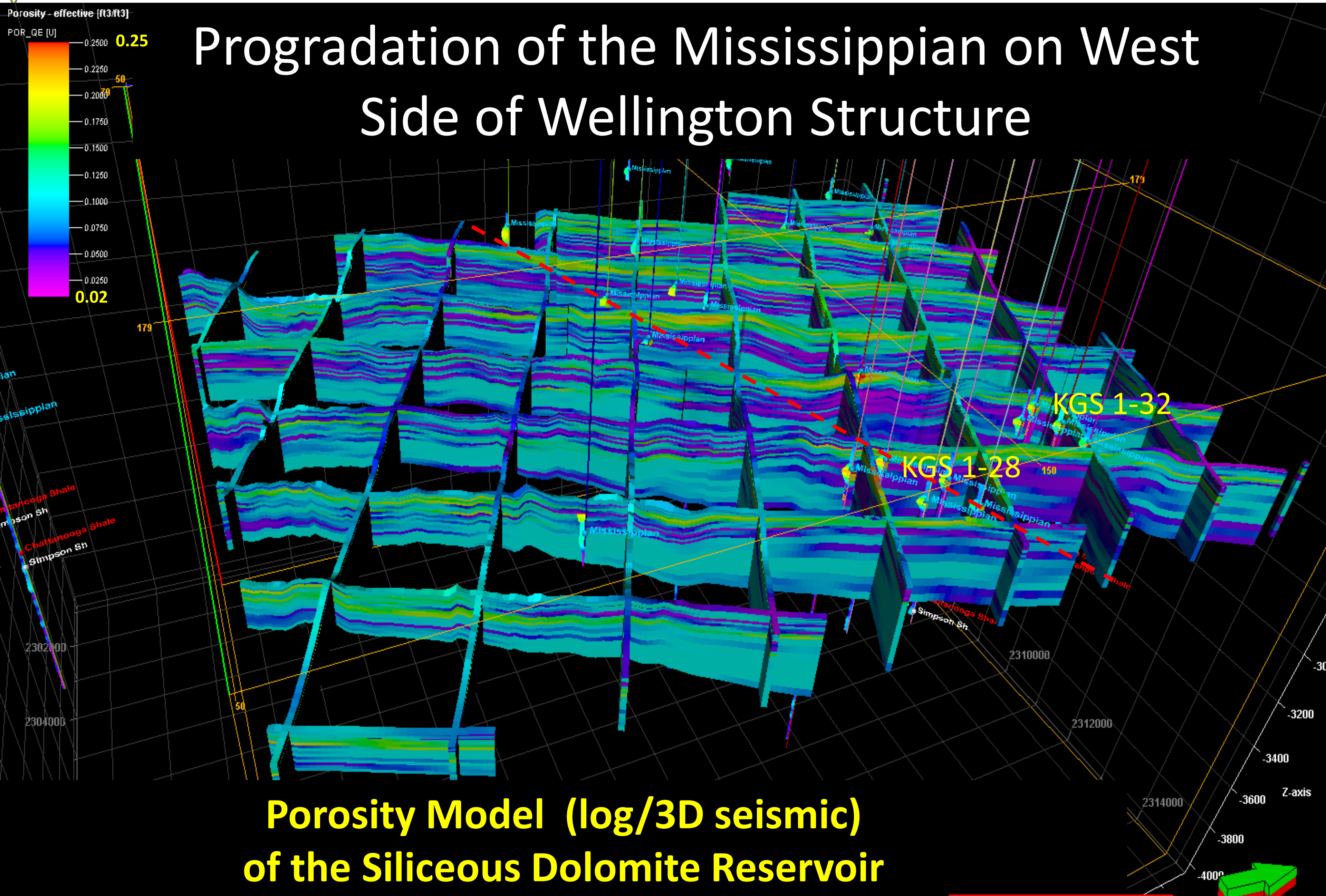


20 MM Barrel Oil Field above Arbuckle Group

KANSAS GEOLOGICAL SURVEY
The University of Kansas


Por.Eff.
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
Wellington Field
#1-32 w/GR log (right) & porosity (left) Shales = more red
Porosity inversion from PSDM in (Petrel™) geocellular model
Top Miss. Porosity (pay) 20 MM bbl field
3000 ft (1 km)
Top Arbuckle surface
Pierson Fm./Cowley facies (apparent porosity due to higher clay content)
Lower Arbuckle injection zone
KGS #1-32
KGS #1-28
1000 ft
J. Rush, 2012
North

Progradation of the Mississippian on West Side of Wellington Structure

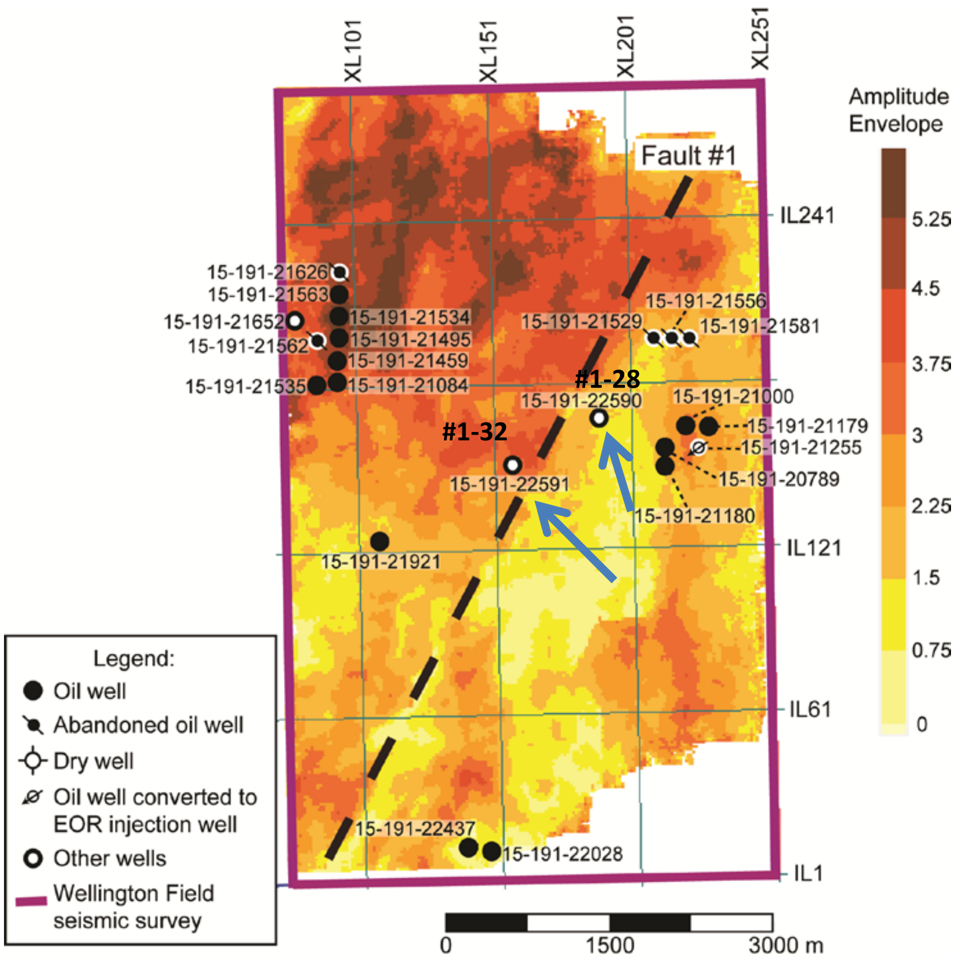


Porosity Model (log/3D seismic) of the Siliceous Dolomite Reservoir Upper Mississippian, Wellington Field

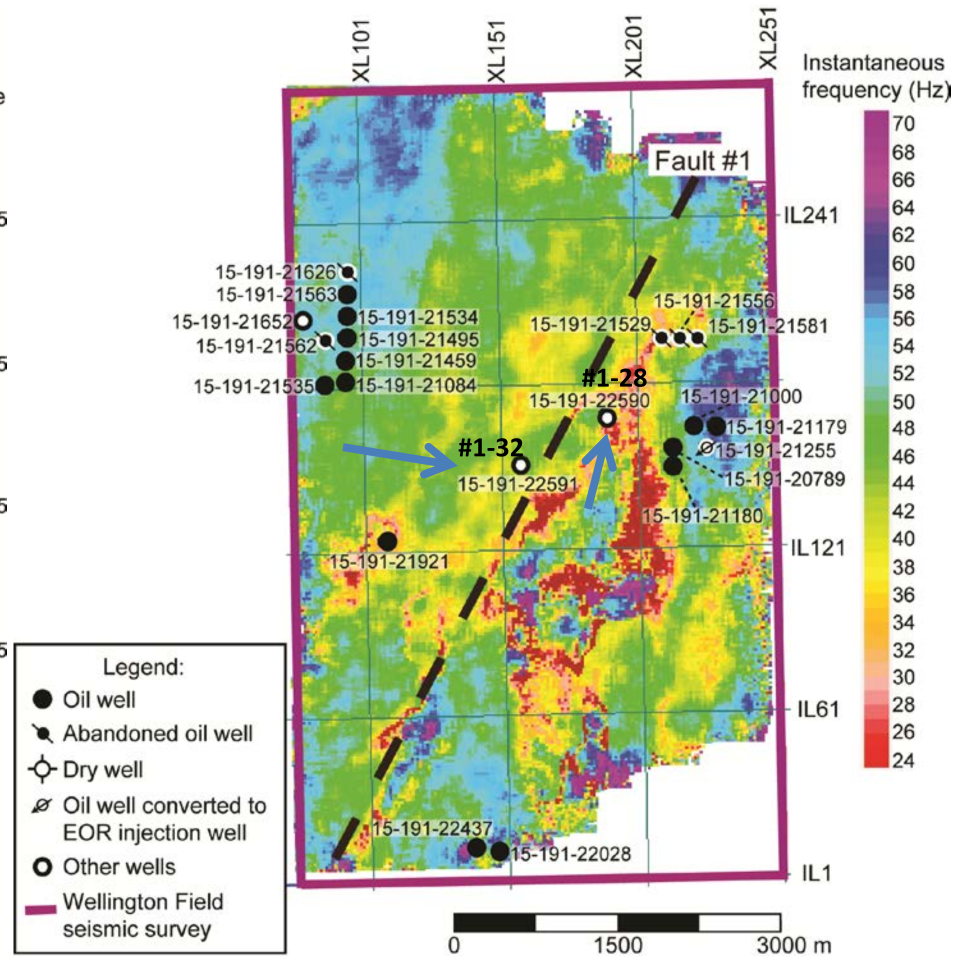
Rush, KGS

Instantaneous seismic attributes

Ayrat Sirazhiev, M.S. Geology, 2012



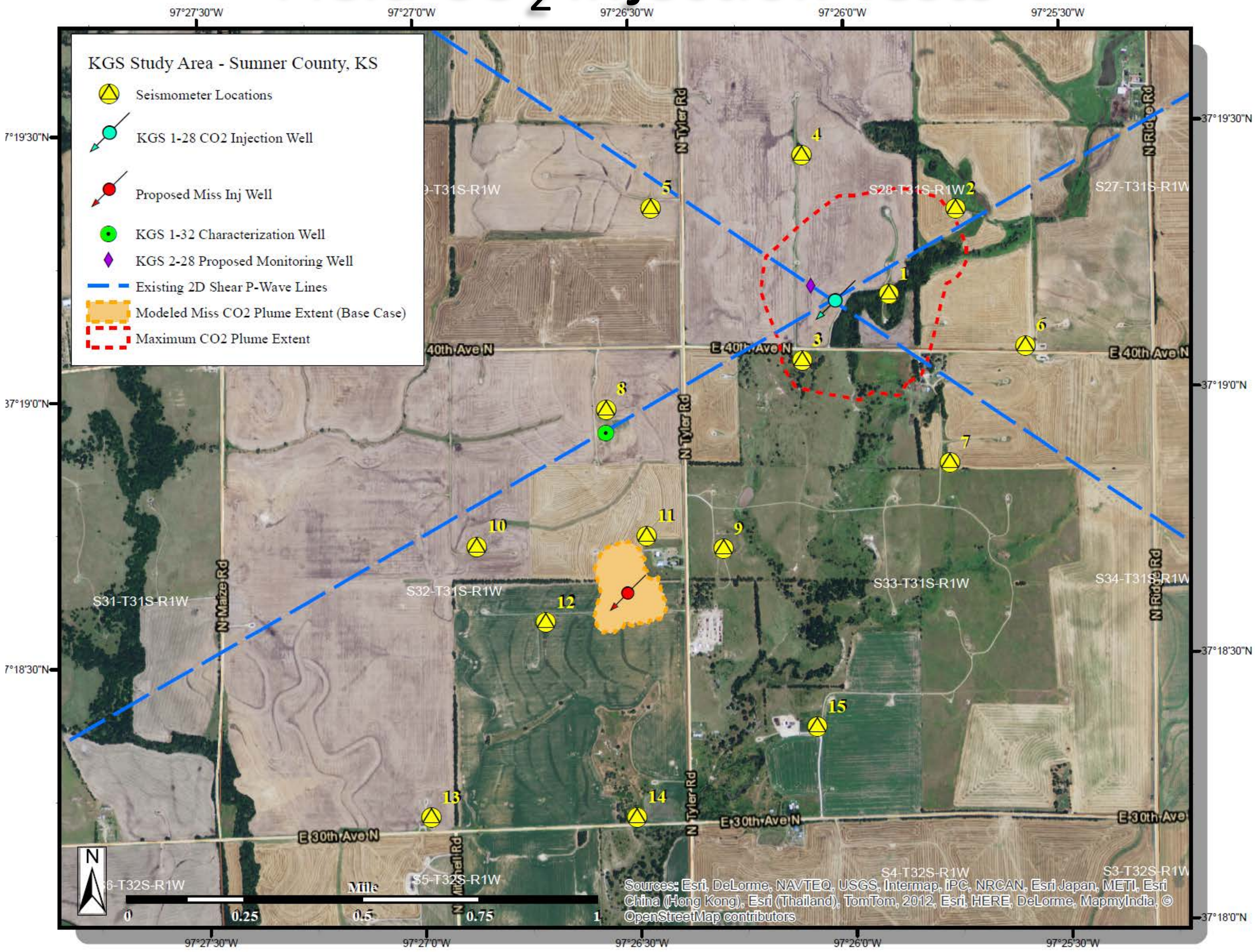
Amplitude envelope map of the Mississippian reflection



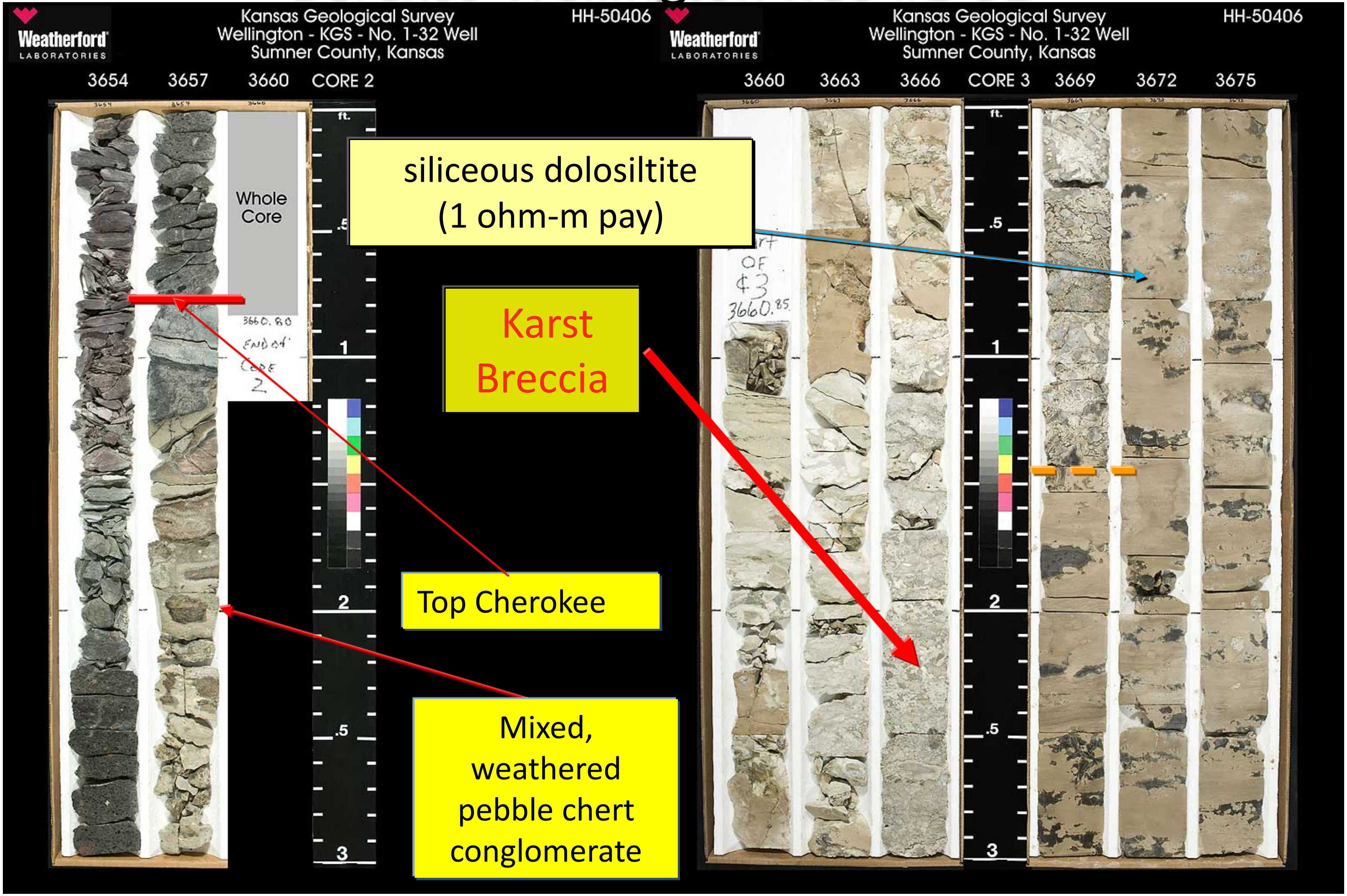
Instantaneous frequency map of the Mississippian reflection

Can we relate real data seismic amplitude and frequency to reservoir thickness as it has been suggested by the modeling?

Extensive monitoring network Wellington Field CO_2 Injection Tests

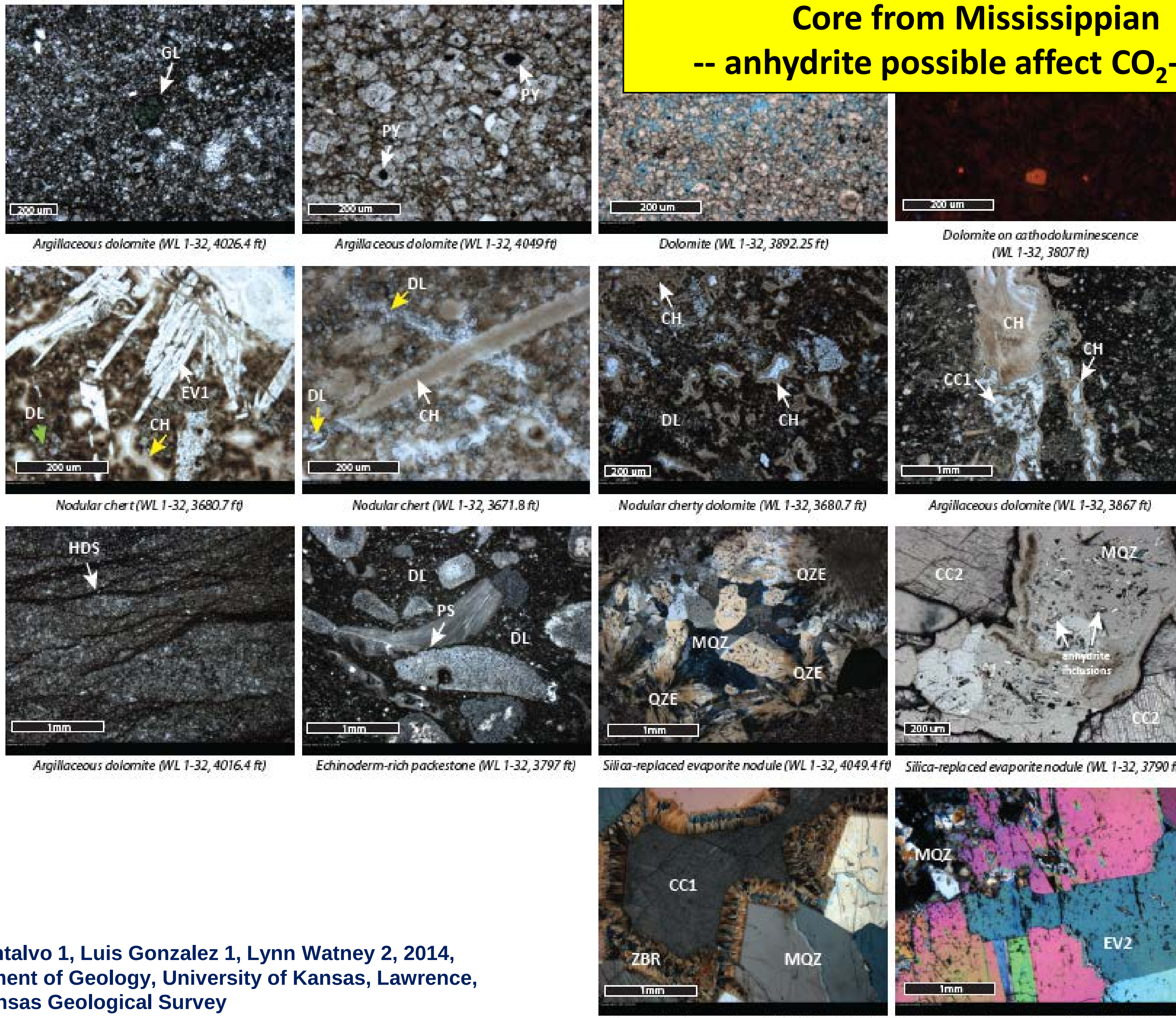


Mississippian pay zone in Berexco Wellington KGS #1-32



Petrography, Berexco Wellington KGS #1-32 Core from Mississippian -- anhydrite possible affect CO_2-foam

Diagenetic facies and textures



Argillaceous dolomite (WL 1-32, 4026.4 ft)

Argillaceous dolomite (WL 1-32, 4049 ft)

Dolomite (WL 1-32, 3892.25 ft)

Dolomite on cathodoluminescence (WL 1-32, 3807 ft)

Nodular chert (WL 1-32, 3680.7 ft)

Nodular chert (WL 1-32, 3671.8 ft)

Nodular cherty dolomite (WL 1-32, 3680.7 ft)

Argillaceous dolomite (WL 1-32, 3867 ft)

Argillaceous dolomite (WL 1-32, 4016.4 ft)

Echinoderm-rich packestone (WL 1-32, 3797 ft)

Silica-replaced evaporite nodule (WL 1-32, 4049.4 ft)

Silica-replaced evaporite nodule (WL 1-32, 3790 ft)

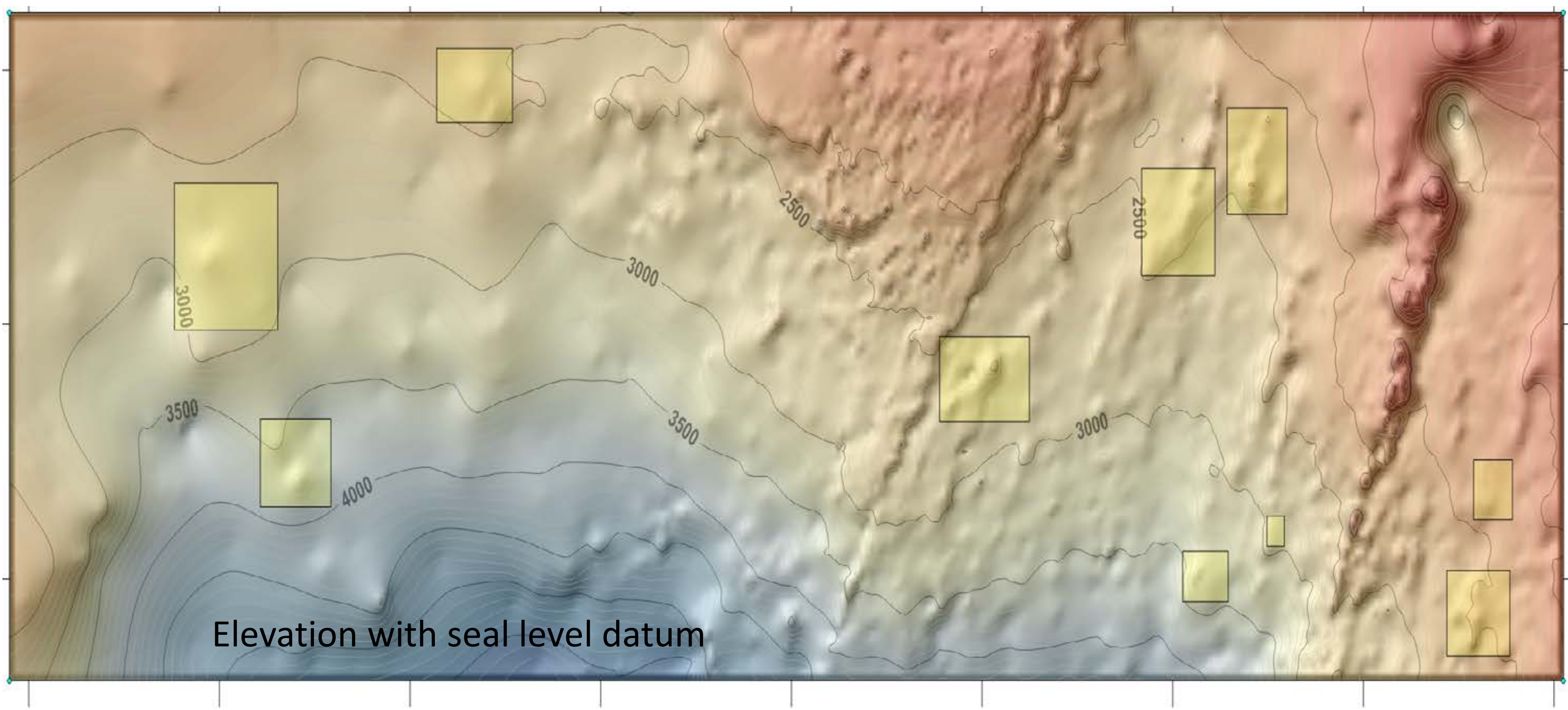
Silica-replaced evaporite nodule (WL 1-32, 3857.5 ft)

Silica-replaced evaporite nodule (WL 1-32, 3689 ft)

Luis G. Montalvo 1, Luis Gonzalez 1, Lynn Watney 2, 2014,

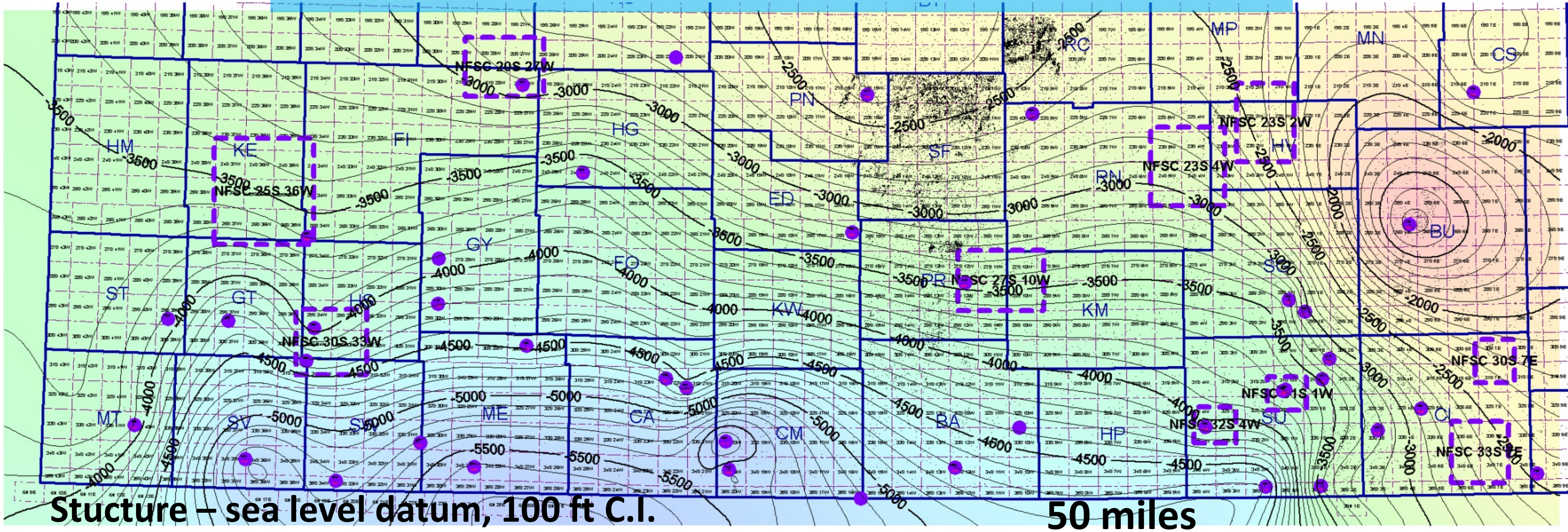
1) **Department of Geology, University of Kansas, Lawrence, KS, Kansas Geological Survey**

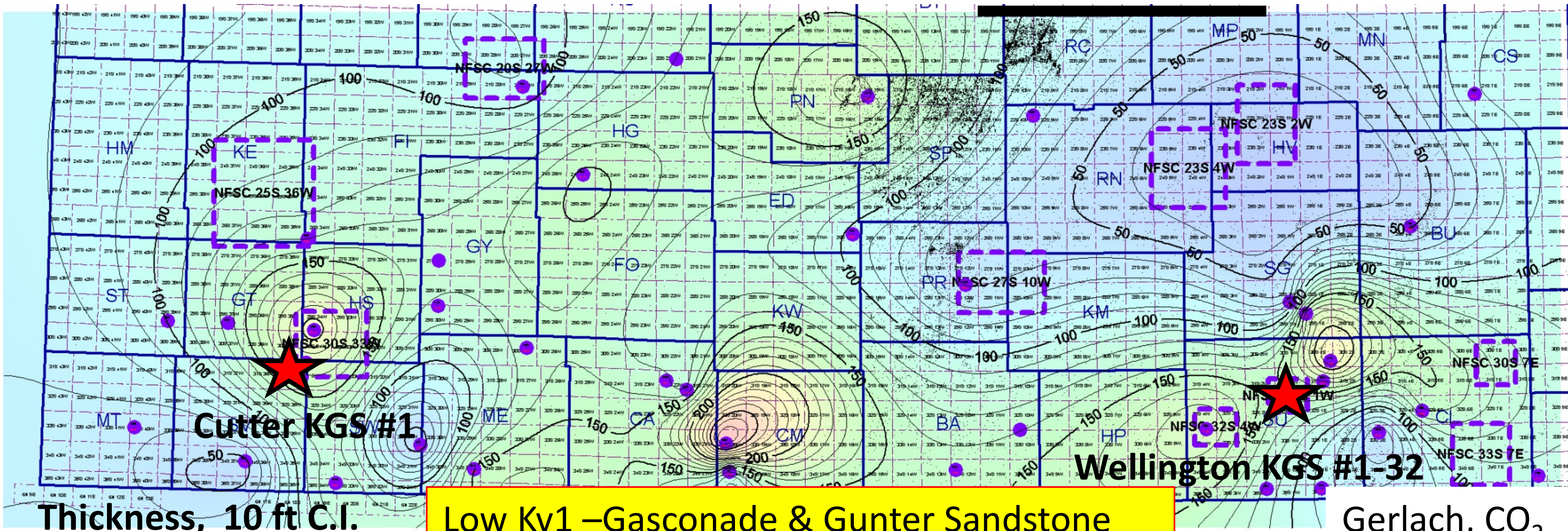
Mega Model CO_2 Storage Capacity of the Arbuckle in Southern Kansas (25,000 mi^2)



- 10 local modeling sites including Cutter and Wellington fields
- Simulation of entire 25,000 mi2 based on estimation of rock properties

Lower Flow Unit For Regional Modeling in Arbuckle Group
25,000 mi² in southern Kansas

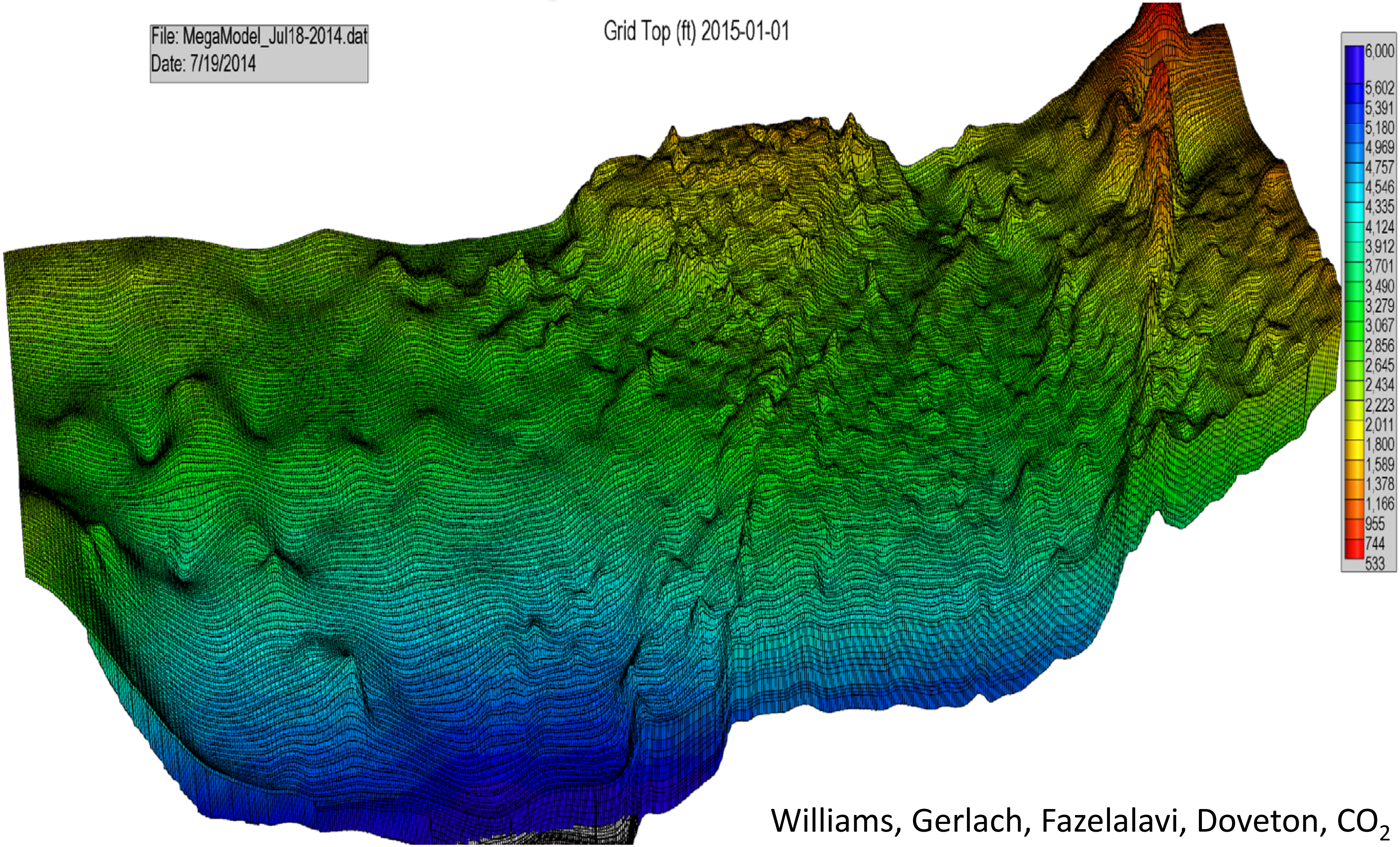




Low Kv1 –Gasconade & Gunter Sandstone

Gerlach, CO_2

Initial Coarse Grid 7/18/2014
Arbuckle, Southern Kansas



Williams, Gerlach, Fazelalavi, Doveton, CO_2

Implementing Large-scale CCUS in Kansas (A)

- **Key Ingredients**
  - CO_2 supply – sources and transportation
  - CO_2 utilization -- Readiness and needs
  - Aggregation of CO_2 supply and CO_2 utilization in Kansas oil fields
- **Economic incentives for CO_2 capture and CO_2 suppliers**
- **Regulation**
  - Well and Field permitting
  - Primacy of Class VI Injection permitting and implications of using added storage for CO_2 beneath the oil reservoir in deep saline aquifers
- **Environmental Concerns**
  - Secure CO_2 storage
  - Induced seismicity

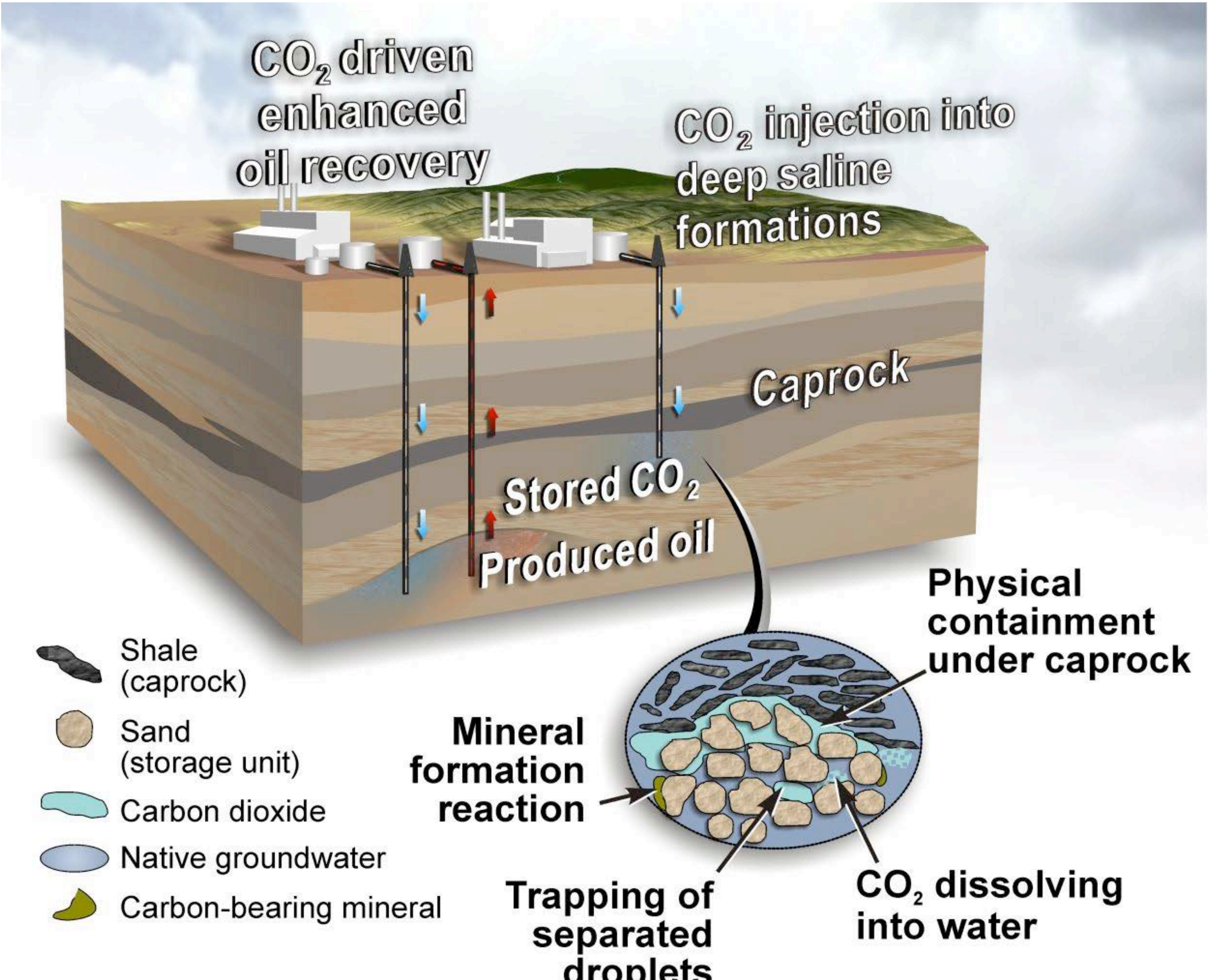
Implementing Large-scale CCUS in Kansas (B)

- **Working with CO_2 suppliers to get CO_2 to Kansas oil fields**
- **Refine KGS interactive CO_2 oil and gas mapper for access to key information**
  - Highlight and extract cumulative oil; pressure; temperature; oil gravity
    - Screen and highlight candidate fields/plays for CO_2 miscibility, total field and lease performance, recoverable reserves and CO_2 requirements (volume and rates)
  - CO_2-EOR resources via interactive map of Kansas oil fields utilizing web apps to analyze the data "*on the fly*"
- **Scoping models of oil fields to forecast technical success and favorable economics**
- **Apply results of CO_2 test injection at Wellington Field (DE-FE0006824)**
  - and model results of four fields (Shuck, Eubanks, Cutter, and Pleasant Prairie South) in SW Kansas (DE-FE0002056)

Implementing Large-scale CCUS in Kansas (C)

- **Engage stakeholders to develop, support and underwrite strategic initiative**
  - Administrate (Dept. of Commerce?) and develop components of a Kansas CO_2 initiative/Kansas Model for CO_2 Utilization and Storage
    - Secure advisory group of operators, gas suppliers, officials with Department of Commerce and KU, lawmakers and regulators
    - Define needs to address uncertainties and concerns, weigh challenges and concerns against benefits to affect public perception, sequestration defined, state of readiness, engaging community, leveraging what has been learned, priorities, and opportunities via **Governor's Conference**
    - Timetable and costs for planning and development
    - Establish state of the technology in Kansas via research and workshop workshops and share resources and scoping models

CO2 EOR & Geologic Storage



DOE project team -- DE-FE002056

Principal Investigators
Jason Rush -- Joint PI
W. Lynn Watney - Joint PI

UNIVERSITY OF KANSAS

Kansas Geological Survey

Co-Principal Investigators
Kerry D. Newell -- stratigraphy, geochemistry
Jason Rush -- Petrel geomodeling and data integration
Richard Miller -- geophysics
John Doveton-- log petrophysics and core-log modeling
Jianghai Xia -- gravity-magnetics modeling & interpretation
Marios Sophocleous --geohydrology

Key Personnel
John Victorine -- Java web app development
David Laflen -- manage core & curation
Mike Killion -- modify ESRI map service for project
Jennifer Raney -- asst. project manager
Debra Stewart, Dan Suchy -- data management
Yevhen 'Eugene' Holubnyak, Petroleum Engineer
Fatemeh "Mina" FazelAlavi, Engineering Research Assistant

KU Department of Geology

Co-Principal Investigators
Evan Franseen --sedimentology, stratigraphy
Robert Goldstein -- diagenesis, fluid inclusion
David Fowle -- reactive pathways, microbial catalysis
Jennifer Roberts -- reactive pathways, microbial catalysis
George Tsoflias -- geophysics

Grad Research Assistants
Aimee Scheffer (graduated) -- biogeology & geochemistry
Breanna Huff -- biogeology
Christa Jackson -- biogeology and geochemistry
Ayrat Sirazhiev (graduated) -- geophysics
Yousuf Fadolalkarem -- geophysics
Brad King -- diagenesis

SUBCONTRACTS

Berexco, Beredco Drilling -- *Wichita, KS*

Wellington Field access; drilling, coring, completion and testing; modeling and simulation

Key Personnel
Dana Wreath - manager, reservoir and production engineer
Randy Koudele - reservoir engineer
Bill Lamb - reservoir engineer

Bittersweet Energy, Inc., *Wichita, KS*

Tom Hansen, Principal, Wichita, Geological Supervision - regional data, Arbuckle hydrogeology
Paul Gerlach -- regional data acquisition, 2 yrs.
Larry Nicholson -- regional data acquisition, 2 yrs.
Anna Smith -- regional data acquisition, 2 yrs.
Ken Cooper, Petrotek Engineering, Littleton, CO- engineer, well injection, hydrogeology
John Lorenz, Scott Cooper, FractureStudies, Edgewood, NM -- core fracture study

Kansas State University

Seismic and Geochemical Services

Co-Principal Investigators
Saugata Datta -- reactive pathways and reaction constants
Abdelmoneam Raef -- seismic analysis and modeling

Grad Research Assistants
Robin Barker (graduated)
Derek Ohl - seismic analysis and modeling
Randi Isham -- seismic
Brent Campbell - aqueous geochemistry

Services

LOGDIGI, LLC, *Katy, TX* - wireline log digitizing
David G. KOGER, *Dallas, TX* - remote sensing data and analysis
Weatherford Laboratories, *Houston, TX* -- core analyses
CMG - Simulation Services, *Calgary, Alberta* --greenhouse gas simulation and software
Halliburton, *Liberal, KS* -- wireline logging services
Hedke-Saenger Geoscience, LTD., *Wichita, KS* - geophysical acquistion, interpret & design
Susan E. Nissen, *McLouth, KS* -- Geophysical Consultant, volumetic curvature
Lockhart Geophysical, *Denver, CO* -- acquis & interpret 2D shear wave, gravity & mag
Fairfield Industries, Inc., *Denver, CO* -- 2D, 3D multicomponent seismic processing
Paragon Geophysical Services, *Wichita, KS* -- 3D seismic acquisition
Echo Geophysical, *Denver, CO* -- 3D seismic processing
Converging Point - QC seismic acquisition
Noble Energy, *Houston, TX; Denver, CO* -- collaborating co., fields adjoining Wellington

Southwest Kansas CO2 EOR Initiative - Chester Morrow

Martin Dubois, IHR, LLC -- team lead, geomodeling
John Youle, Sunflower Energy -- core and depositional models
Ray Sorenson, consultant -- data acquisition and advising
Eugene Williams, Williams Engineering -- reservoir modeling

Acknowledgements & Disclaimer

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