Geologic Carbon Sequestration Opportunities in Kansas

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CAP CO2's focus is the use anthropogenic CO2 for enhanced oil recovery, with concurrent carbon storage.

IHR Improved Hydrocarbon Recovery LLC

CAP CO2

Outline – Growing Opportunities

1. Geologic sequestration
   - A key alternative
   - Costs
   - Kansas geology suitability and capacity
   - Kansas projects

2. Interim solution: Concurrent Enhanced Oil Recovery (EOR) and Carbon Capture and Storage (CCS)
   - "Green" oil with industrial CO2
   - Technical requirements
   - Kansas opportunities and economic impact

CO_2 Basics

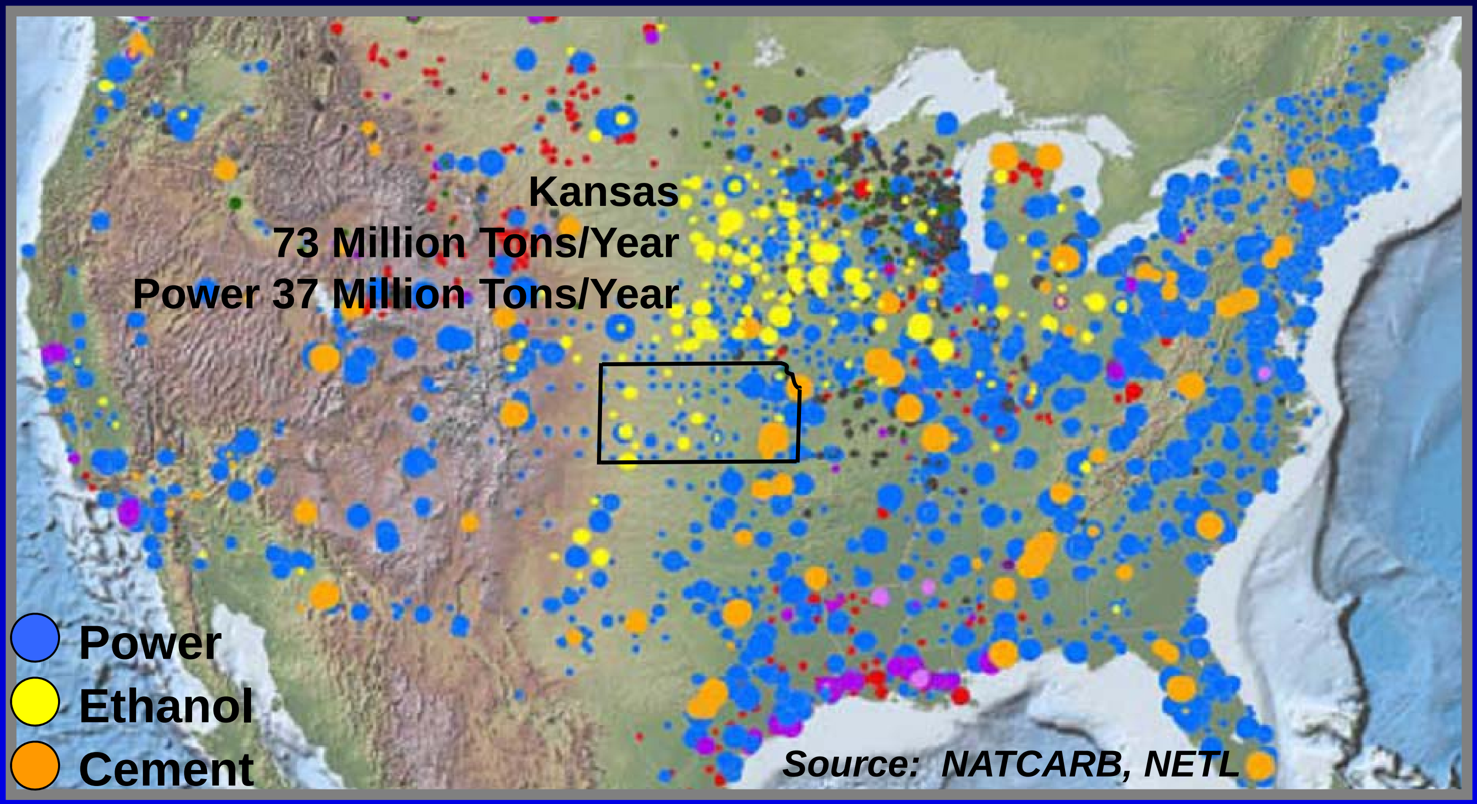
- 1 ton CO_2 = 17.2 mcf
- 1 metric ton = 19 mcf
- An average human exhales 6 mcf CO2/ yr
- Combustion of 1 barrel of oil yields 8 mcf CO2
- 7 mcf CO2 / BO (Net utilization: *Sequestered*)
- Ethanol (55mgy) – 8.3 mmcfd, 0.16 million tonnes/yr (1-2 mbopd)
- Coffeyville fertilizer plant – 40 mmcfd, 0.8 million tonnes/yr (6-8 mbopd)
- New Sunflower 895 MW plant deal – 6.7 million tons/yr

Kansas:

- Total 72.8 Million Metric Tons/Year
- Coal-fired Power 37.2 Million Metric Tons/Year

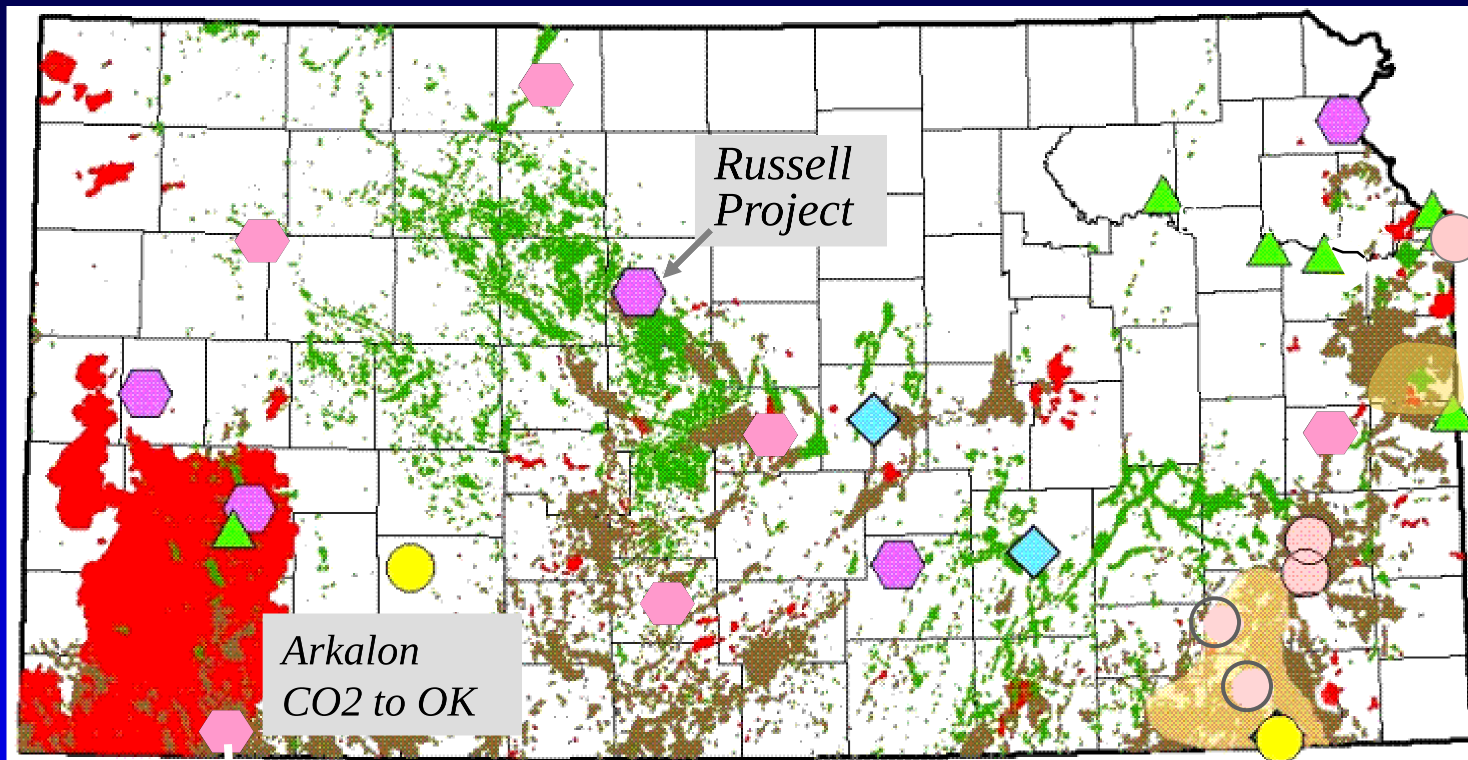
Handy CO2 properties calculator:
http://abyss.kgs.ku.edu/pls/abyss/natcarb.co2_calc.co2_prop

US Stationary CO2 Sources



Carbon legislation
+ Carbon capture
+ Need for geologic storage
+ CO2 pipeline infrastructure
= Opportunity for CCS and CO2 EOR in Kansas

Kansas CO_2 Sources and Oil Resource



Fields

- Oil
- Oil & Gas
- Gas
- CBM

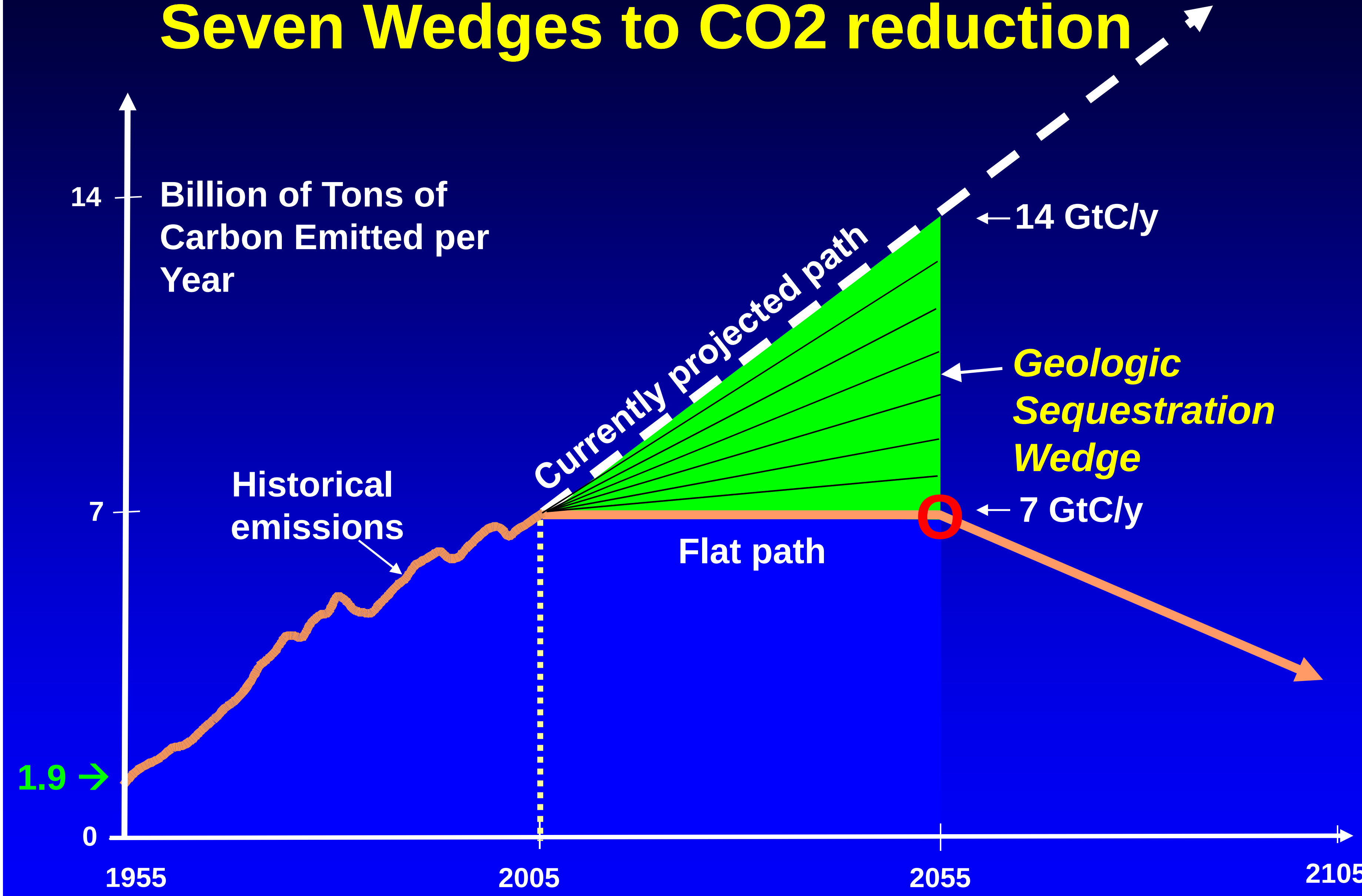
Industry	CO2 Purity
Cement	20%
Power	8-12%
Ethanol	99%
Ammonia	99%
Refinery	65%*

Cumulative Oil

Zone	Billion BO
Arbuckle	2.3 (37%)
L-KC	1.3 (20%)
Miss.	1.0 (17%\
Other	1.7 (27%)

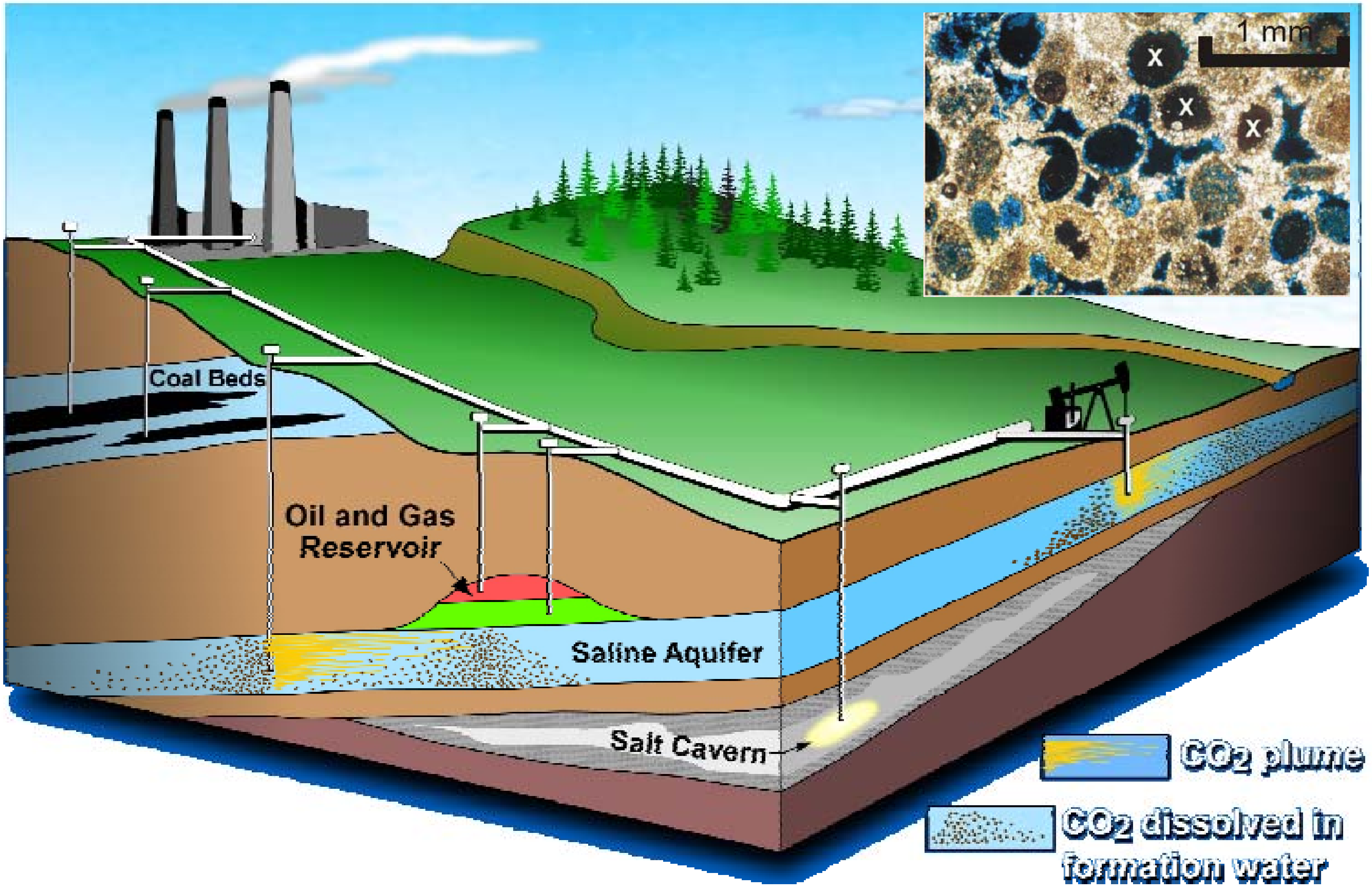
** gasification for desulphurization*

Seven Wedges to CO2 reduction

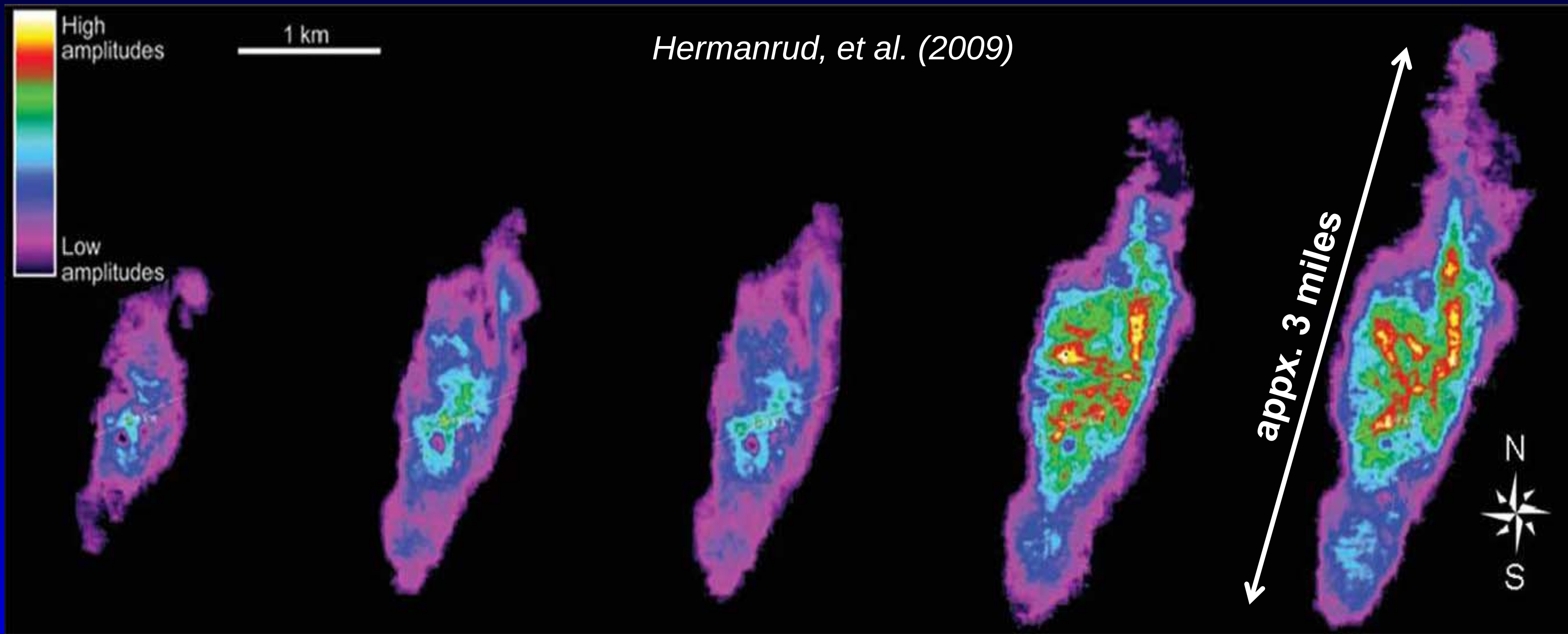


Graphic: Socolow & Pacala

CO_2 Geologic Sequestration



Compare scale of Arbuckle with Sleipner

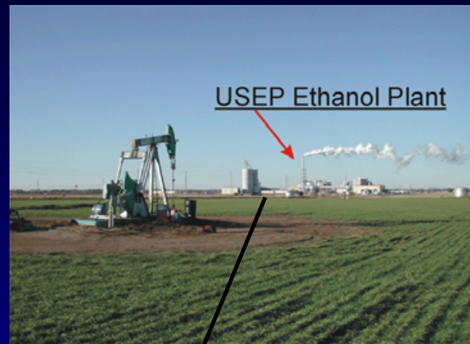


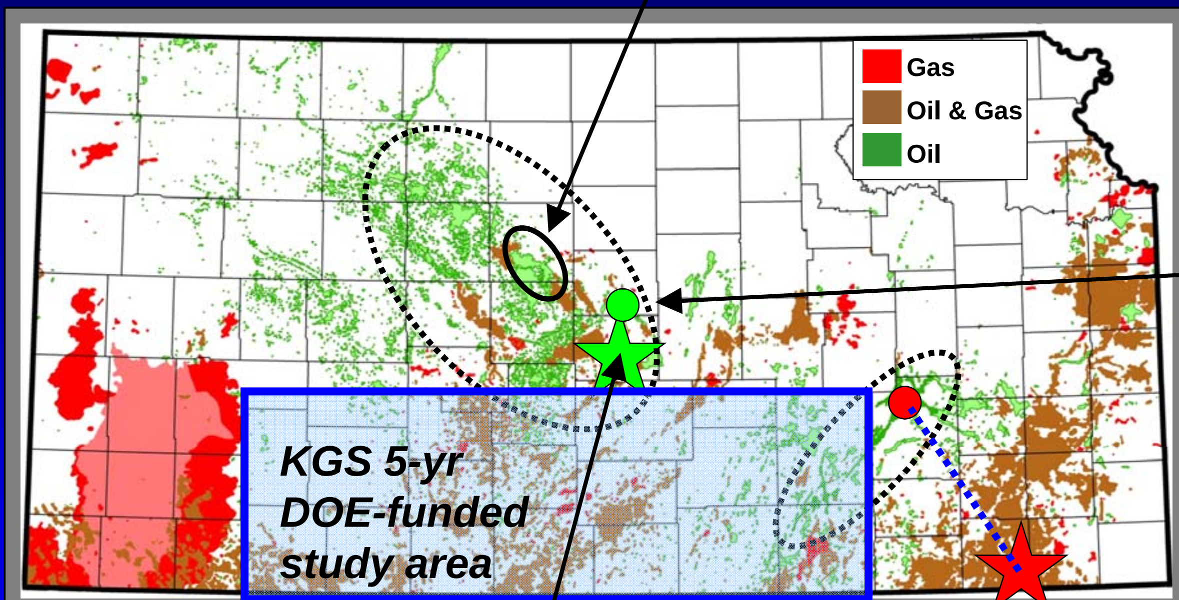
1999 2001 2002 2004 2006

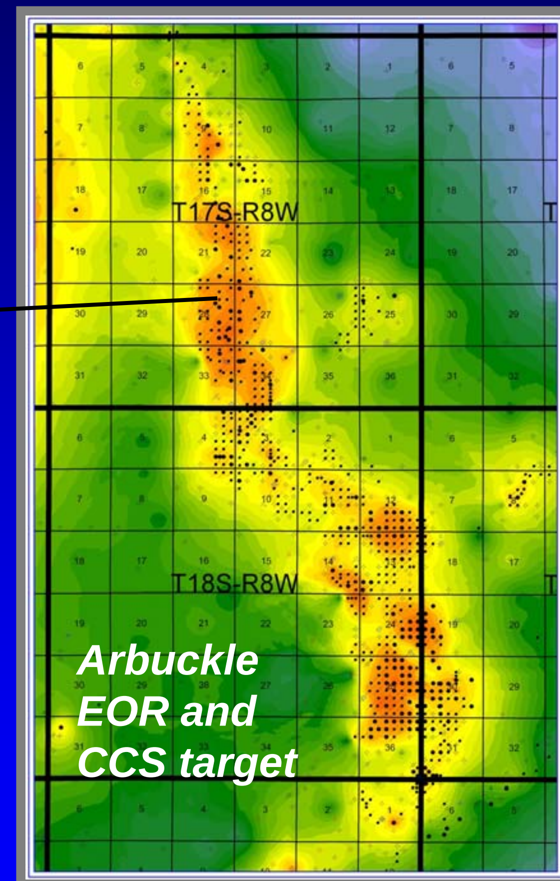
- Accumulated total reflection amplitude from all nine layers of the Sleipner CO2 plume.
- I am not sure how much had been injected in 2006, but as of 2008 ~10 M tons had been injected.
- Sleipner project is about the size of some Arbuckle "domes" on the CKU.

Kansas CO2 EOR and CCS studies and proposed projects

KGS and TORP (KU) - successful Russell CO2 pilot project (99-09)







Geneseo-Edwards field could store >8.5 million tons CO2

CAP CO2, Blue Source etal – Phase I DOE study. Two sources, multiple sinks

Arbuckle injection rates and sequestration

Injectivity Documented

- 2000 SWDW in Arbuckle in Kansas
- 3-5,000 BWPD common; some >10,000 BWPD, on a vacuum.
- 100 - 350 metric tons/day, (37 - 130 k metric tons/yr)
- 50 -175 injection wells for the planned 850MW Sunflower plant
- 1-3 wells for a 55mgy ethanol plant

(CO2 properties at 110F and 1100psi – supercritical, 13.8 lbs/ft^3, and 0.22 gm/cc)

Storage space available

A Single Example: Ellsworth anticline (saline aquifer)

- 126 square miles (6X21 mi)
- 100 ft of closure
- 15% porosity
- Sw = 100%
- Store 278 million metric tons supercritical displacement
- 66 million metric tons as dissolved gas

(Assumed 100F, 1200psi, TDS = 30,000 ppm)
Carr, et al. (2005)

Volumetric estimates for storing CO2 in Arbuckle domes on CKU

FIELD	DISC YR	CUM. OIL (mmbo)	CO2 REPLACE OIL	CO2 TO SPILL (~2.5X*)
TRAPP	1929	308	11.9	29.8
CHASE-SILICA	1929	280	10.8	27.0
BEMIS-SHUTTS	1928	261	10.1	25.3
HALL-GURNEY	1931	160	6.2	15.5
KRAFT-PRUSA	1937	137	5.3	13.3
GORHAM	1926	98	3.8	9.5
GENESEO-EDWARDS	1934	89	3.4	8.5
		1,333	**51.5**	**128.8**

Million Metric Tons

Kansas:

- Total 72.8 Million Metric Tons/Year
- Electric Power 37.2 Million Metric Tons/Year
- New Sunflower 895 MW plant deal – 6.7 million tons/yr (metric tons?)

* Assumptions: Cumulative oil is ~40% OOIP and 28% of pore volume, FVF = 1.1, Swi = 30%, final S_{CO_2} = 70% and reservoir is filled to spill point. CO2 properties at 110F and 1100psi – supercritical, 13.8 lbs/ft^3, and 0.22 gm/cc.

Theoretical CO_2 storage volume in "depleted" Kansas oil and gas reservoirs

Filling only the space vacated by the hydrocarbon

OIL

Cumulative Production	6.3 Billion BO	
Reservoir Volume	6.93 Billion bbls	*(FVF=1.1)*
Reservoir Volume	38.9 BCF	
Tonnes CO2*	**243 million tonnes**	

GAS

Cumulative Production	38.4 TCF	
Reservoir Volume	1.12 TCF	*(Bg = 34.3)*
Tonnes CO2**	**2,232 million tonnes**	

* *Assumes 110F and 1100 psi for average oil reservoir - CKU*
13.8 lbs CO2 / ft^3

** *Assumes 100F and 500 psi for avarage gas reservoir - Hugoton*
4.4 lbs CO2 / ft^3

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Arbuckle as saline aquifer storage

Positives

+ Proven seal
+ Proven injection zone
+ Vast storage capacity
+ Fluid gradients working in our favor (Carr, et al.,2005)
+ Fluid velocities in aquifer are very slow (Jorgensen et al., 1993)

Negatives

– Much is below supercritical
– Existing wellbores may be problematic
– Best structures are still oil productive *

*** But….what about concurrent EOR and CCS?**

Reality of costs

Cost per Ton CO2 ($)		
Capture	0 - 50	(pure vs. coal-power)
Compression	15 - 20	
Transportation	0 - 20	(on site vs. distant)
Injection & monitor	5 - 10	
	$20 - $100 per ton	

Present financial incentive to capture and store: $0 - $20*/ton

** $20 tax credit for sequestration for large CO2 sources*

Interim solution: "Green Oil"

2.8 Barrels of oil recovered ($200 gross value)

One ton CO2 <u>permanently</u> stored

Combust 2.8 Barrels of oil yields 1.1 tons CO2

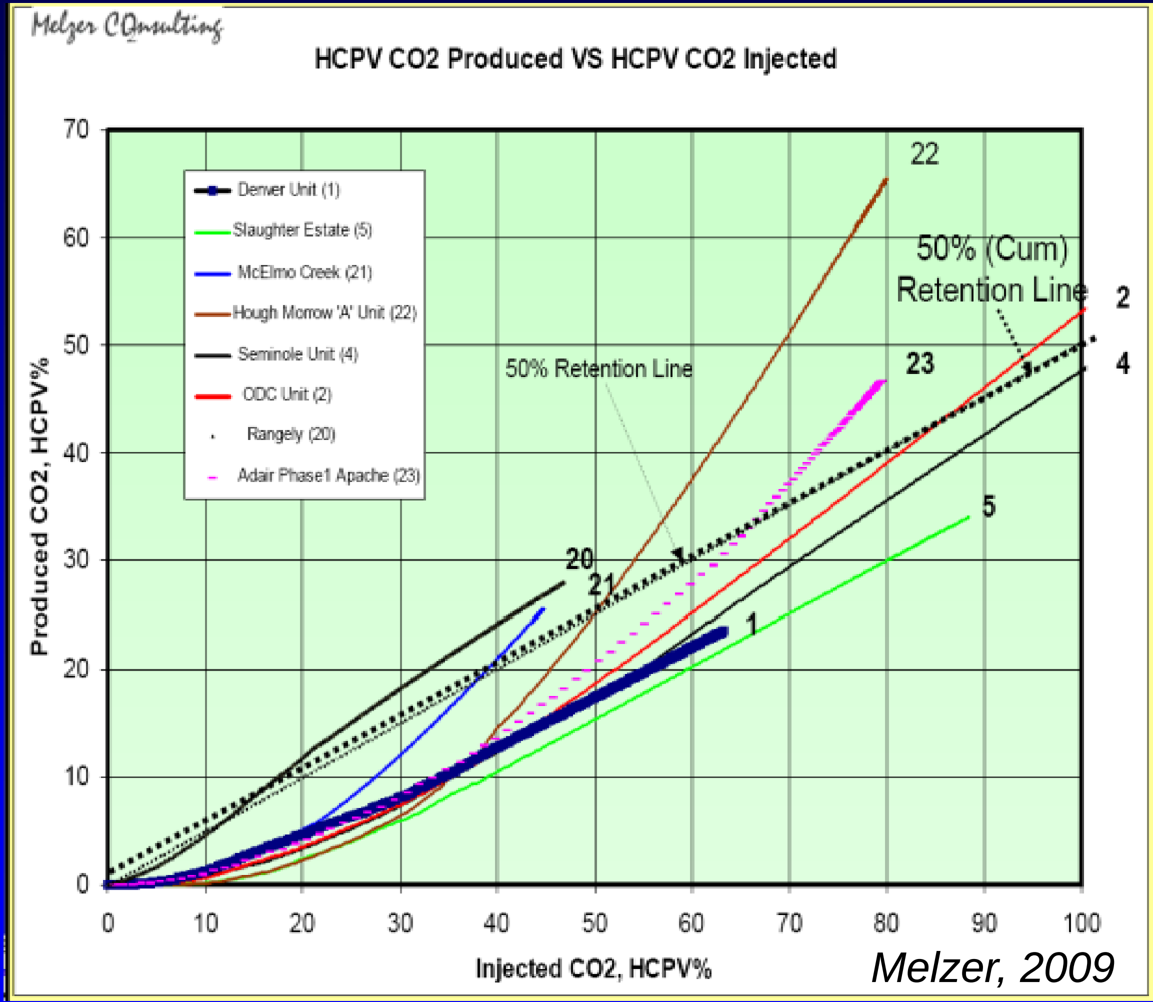
CO2 Retention in EOR

- Historically 50% of CO_2 is retained in the reservoir
- The other 50% is captured, recycled and re-injected
- Eventually nearly all is stored, permanently (<5% loss over time)

Anthro-CO_2 oil is nearly carbon neutral*

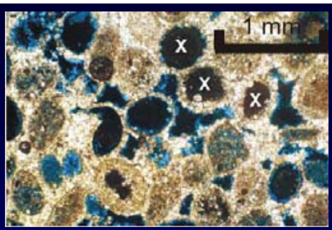
- ✓ 7 mcf CO_2 sequestered
- ✓ 8 mcf /barrel oil oxidized

* Excludes, refining, transportation CO_2 costs



Long-lived CO_2 EOR projects, mainly Permian basin

CO2 storage capacity and mode

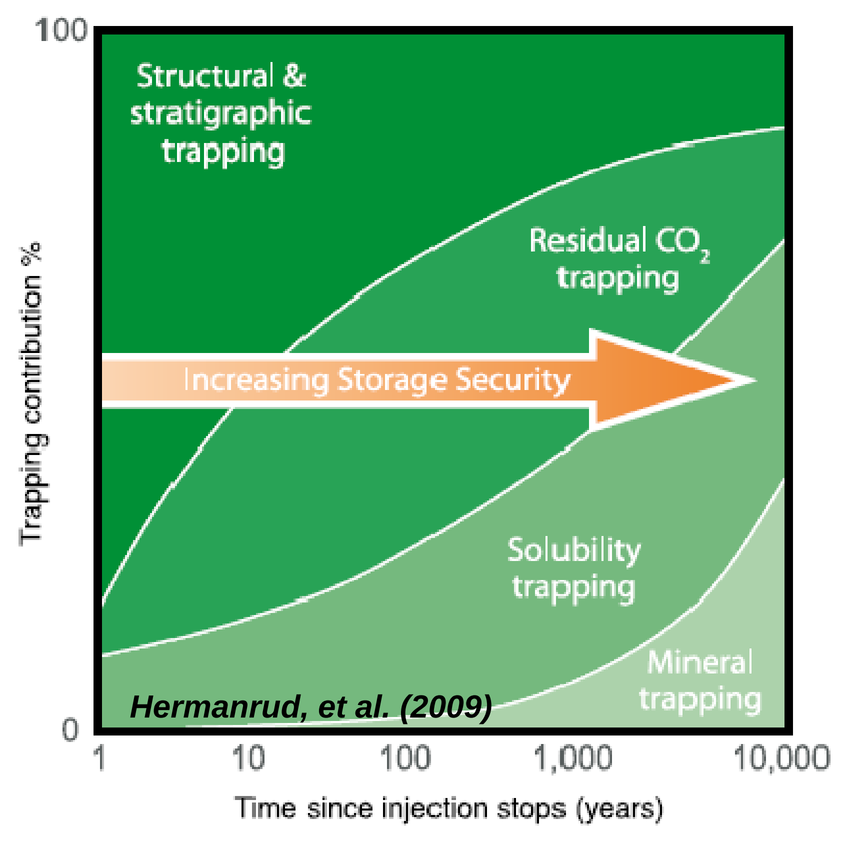


Amount of CO2 sequestered

depends on temperature, pressure, brine chemistry, hydrocarbon properties, rock chemistry, and pore throat diameters (capillary pressures)

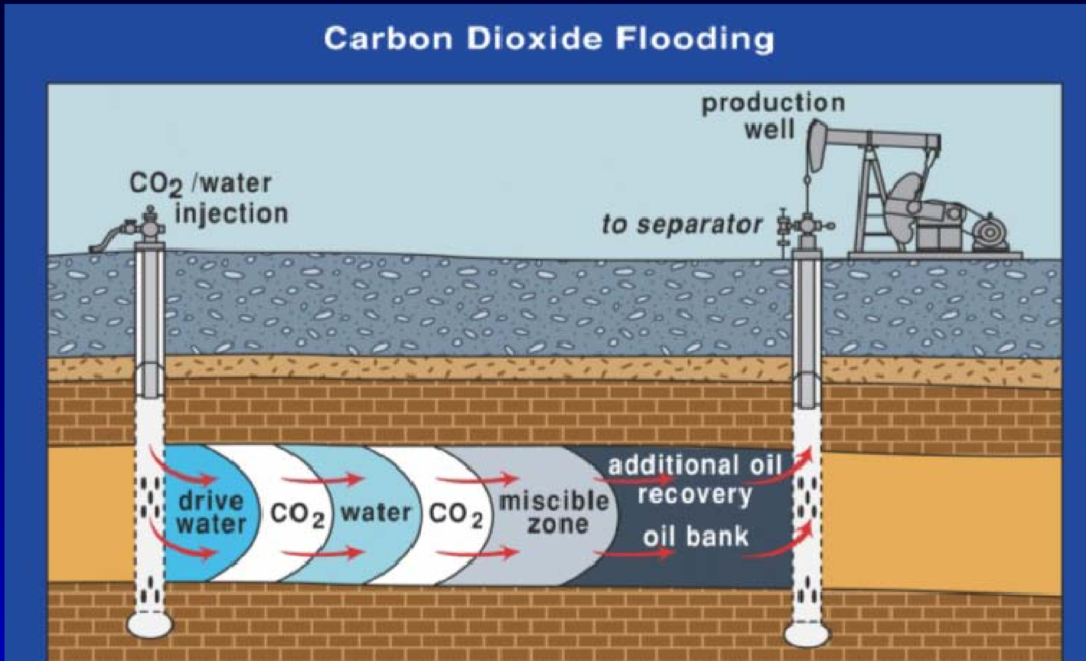
Modes of storage

1. Displacement – *f*(density) = *f*(P,T)
2. Residual saturation – *f*(pores)
3. Solubility trapping* – *f*(salinity, P, T)
4. Mineralization – f(mineralogy, T, brine)

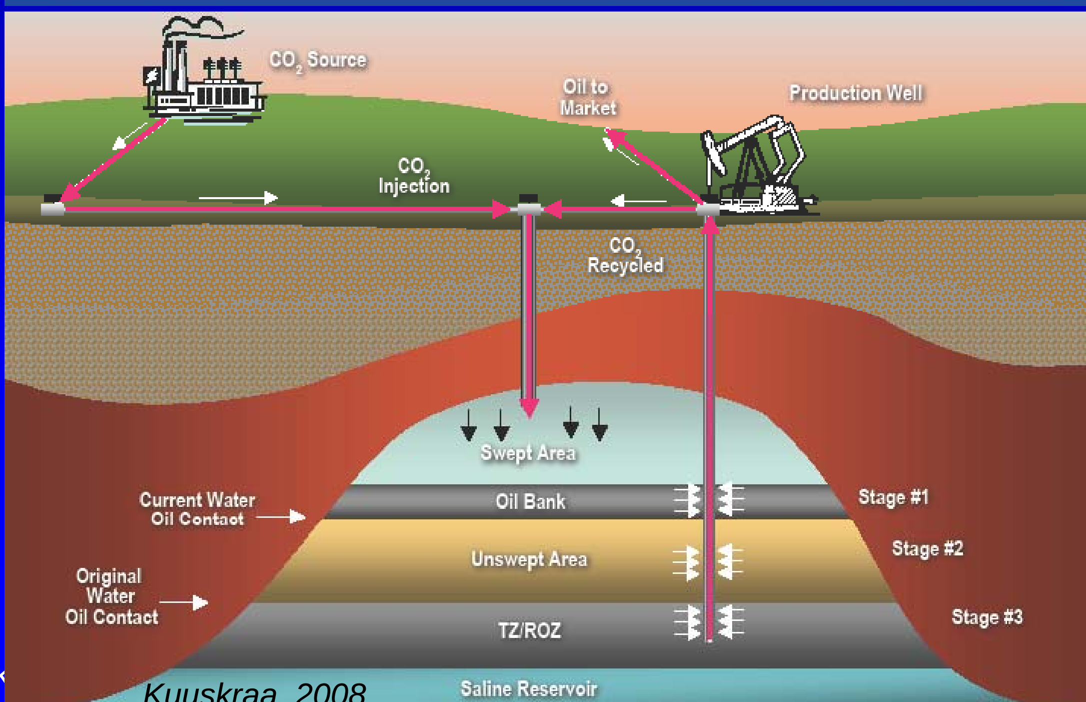


State of CO2 stored is function of time

Noteworthy: Solubility of CO2 in oil is > than in Sw



Kinder Morgan website

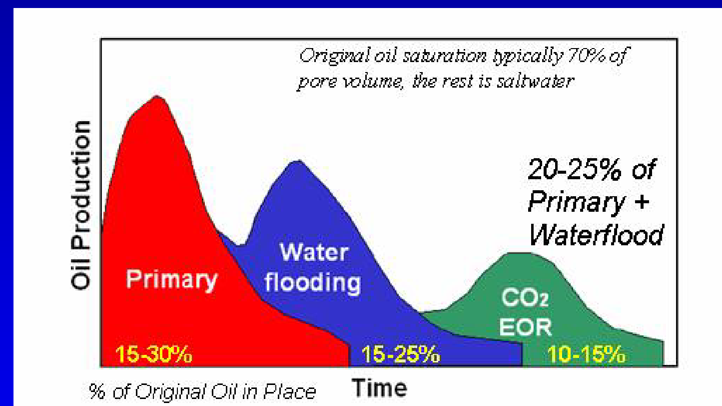


Kuuskraa, 2008

CO2 Processing Styles

Horizontal (piston) flood

- Application: Follow waterfloods
- KS targets: L-KC, Bartlesville, Morrow, Chester
- Well documented



Gravity-stable flood

- Application: bottom-water drive reservoirs
- KS targets: Arbuckle, Simpson, Viola
- Fewer analogues

Technical Requirements

Miscible – piston displacement

1. Inject pressure > **CO2 in supercritical state** (>1073)
2. Inject pressure **< frac pressure**
3. Reservoir **operating pressure > MMP** (1200-2000 psi)
4. Adequate working pressure range (Frac pressure – MMP)
5. Adequate Remaining OIP
6. Reservoir conditions allowing contact throughout the reservoir (good waterflood)

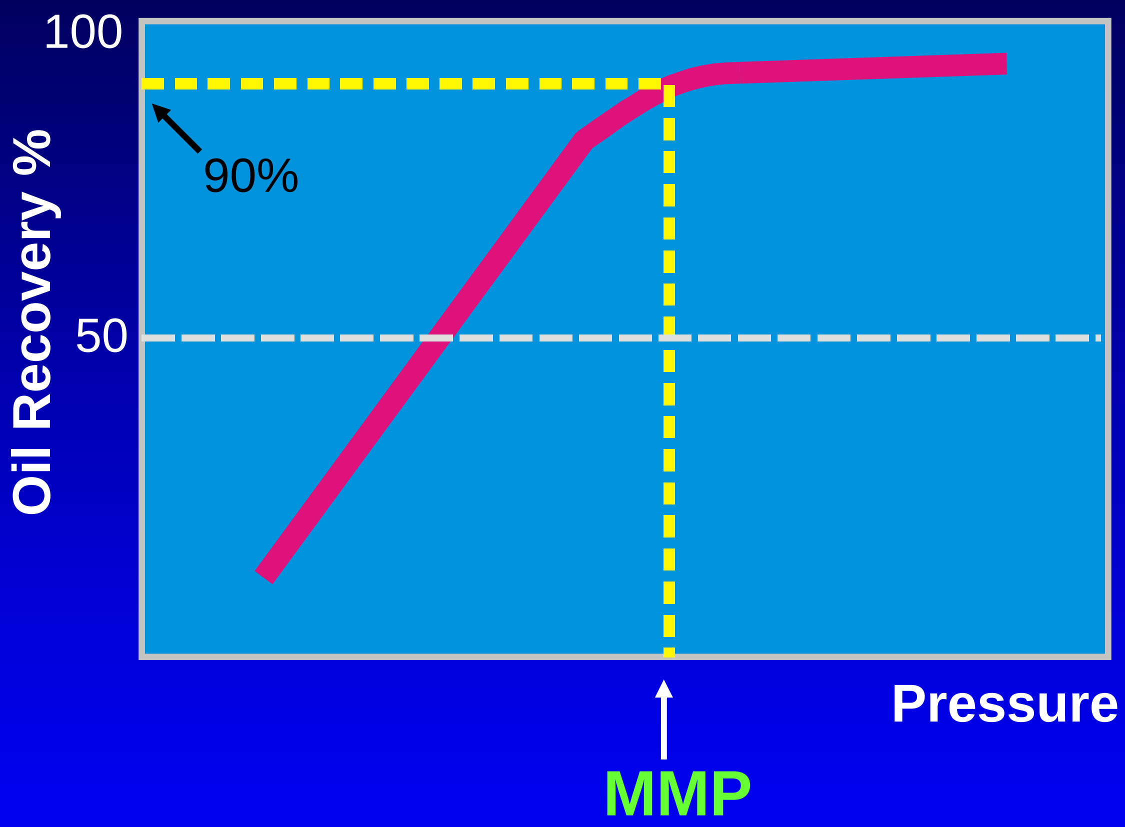
Miscible or near-miscible gravity-stable displacement

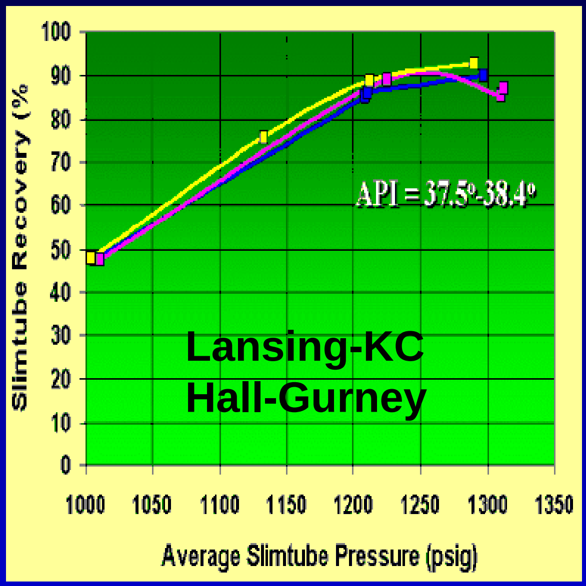
Same constraints………

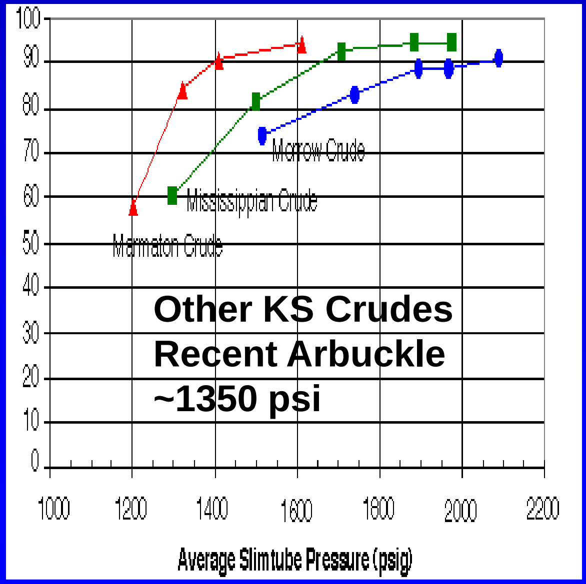
- Reservoir BHP above MMP for miscible (for bottom-water drive reservoirs)
- Reservoir conditions & wellbore configuration to build uniformly expanding CO2 gas cap

Minimum Miscibility Pressure

MMP's performed by TORP, KU

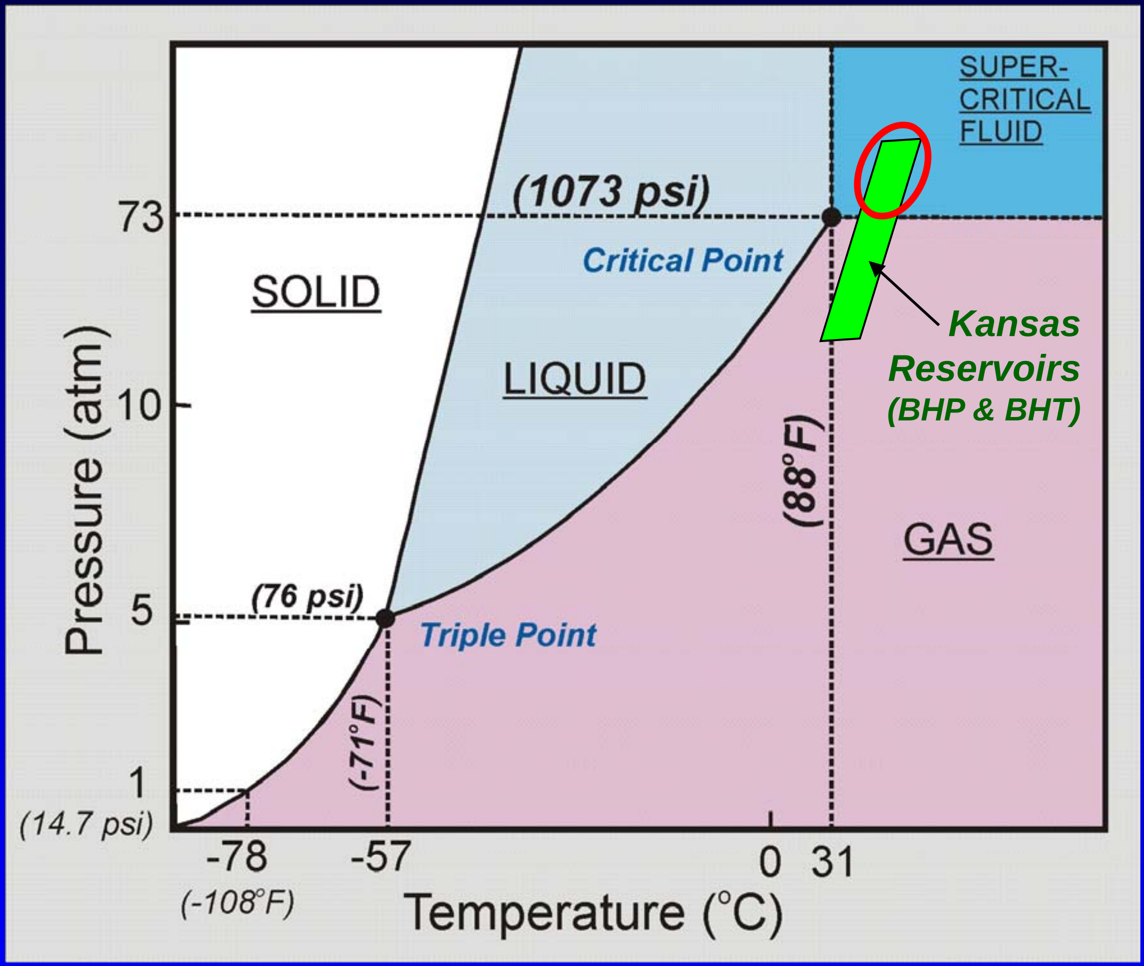






MMP = system pressure at which 90% of lease crude oil in sand-packed slim tube is recovered

CO2 Phase Diagram



Modified after Condren
www.cbu.edu/~mcondren/CO2_phase_diagram.jpg

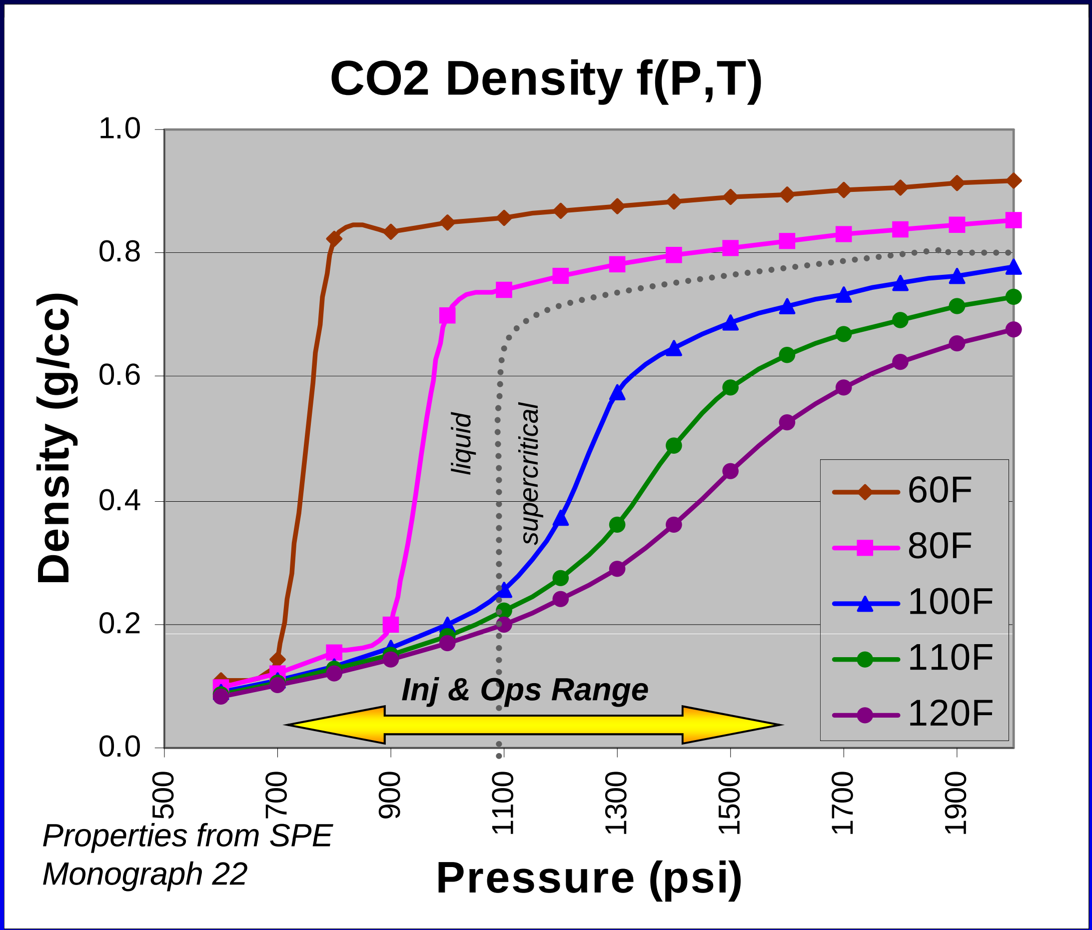
Miscible floods operate at

- > supercritical (1073 psi)
- above MMP MMP (>1200 psi)

Kansas reservoir properties range:

- 400 psi, 85F at 1000 ft
- 1600 psi, 125 F at 6000 ft

CO2's operating requirements and reservoir constraints

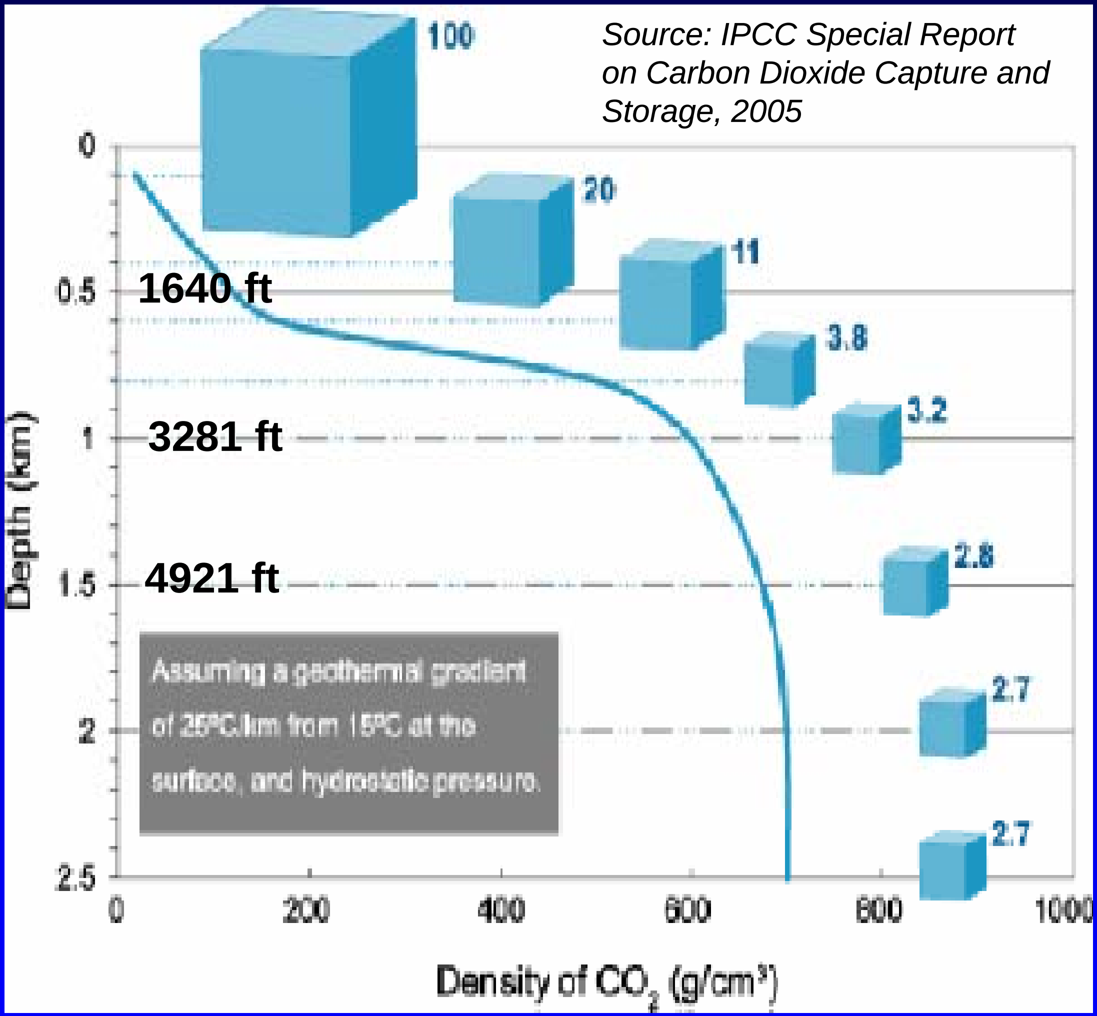


Target screen dimensions determined by pressure constraints (miscible)

- ✓ CO_2 supercritical at >1073 psi
- ✓ MMP variable, >1200 psi and increases with BHT (depth)
- ✓ Frac pressure is upper limit to injection pressure
- ✓ High absolute maximum operating pressure range is desirable (Delta P = frac P – MMP)

Density and viscosity varies significantly from light liquid to heavy super-critical within the range of P & T for surface to BH

CO2 volume with depth (P and T)



Relative volume for CO2 under "normal" pressure and temperature conditions. Kansas is under-pressured

Defining Kansas Resource Targets

Pressure constraints (Miscible, Delta P could vary, but generally >300 psi)

- ✓ Shallowest ~2000 ft (BHP 800 psi)

  Can work at shallow depths: low BHT lowers MMP and improved frac P with pressured reservoir.

- ✓ Ideal miscible >4000 ft (BHP 1300 psi)

Process rate and uniformity

- ✓ Higher Delta P for higher process rate
- ✓ Low vertical heterogeneity and good later communication (good sweep efficiency demonstrated by good waterflood)

Large remaining oil in place

- ✓ "Critical mass" is required to justify non-oil field capital requirements
- ✓ High ROIP per-acre required to justify oil-field capital requirements
- ✓ Maximize return on capital

Gravity-stable targets

- ✓ High BHP preferred
- ✓ High gravity, lower MMP preferred
- ✓ Vertical permeability, layering, coning are complicating factors

CO_2 EOR impact in Kansas will be significant…. just how significant will be determined by future events.

- ✓ Carbon management legislation and laws (Cap & Trade)
- ✓ Geologic storage regulations (Federal and State)
- ✓ Kansas oil industry response

Plus the usual underlying fundamentals

- EOR resource base
- Oil price
- Favorable / unfavorable tax environment

Convergence

The CO2 landscape has changed dramatically over the past seven years at the state, regional, and federal level.

1. CO2 emissions is publicly accepted as a significant issue to be dealt with
2. Looming carbon management legislation and laws (Cap & Trade) would be a game-changer
3. Geologic storage regulations are moving forward (Federal and State)
4. Pure CO2 sources increased 4X in Kansas (3 ethanol plants, 1 ammonia plant and 30 mmcfd to 10 ethanol plants, 2 ammonia plants 120 mmcfd)
5. Technical advancements in CO2 EOR expand targets (gravity-stable, shallower depths, drilling and completion)

Potential CO_2 EOR in Kansas

Kansas Cumulative to date:	6.3 Billion Barrels
20% of P&S:	1.2 Billion
KGS upper end technically feasible	600 Million
Technically feasible (*ARI):	570 Million
More conservative view:	200 Million
Half of that:	100 Million (2.5x annual)

* Kusskraa (ARI), 2006

(even most conservative view is significant)

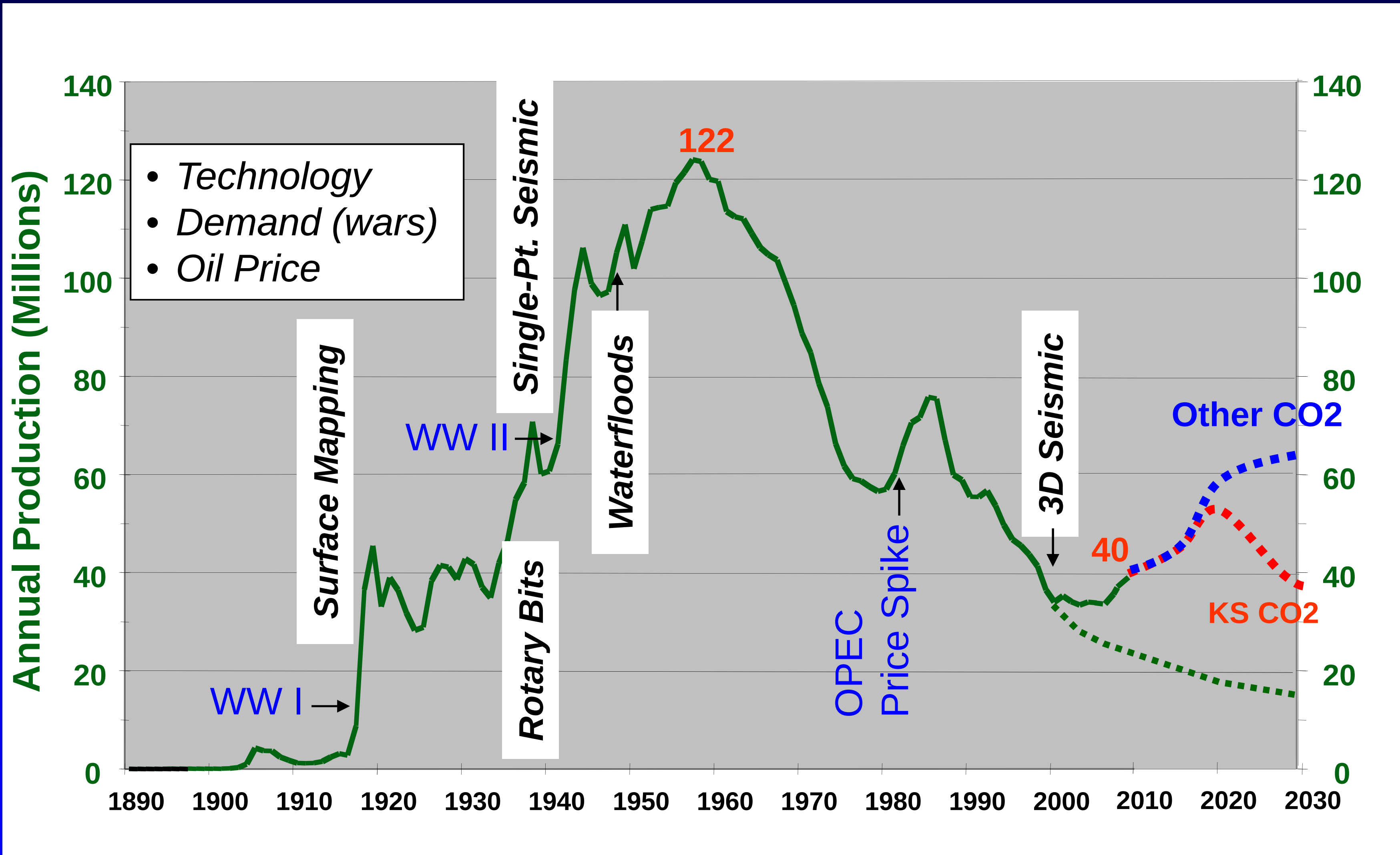
Costs for 100 million barrels CO_2 EOR oil

Capital costs in field	$1 Billion	$30/BO
CO_2 costs**	$1 Billion	
Operating costs	$1 Billion	
Cost of Capital	$x Billion	

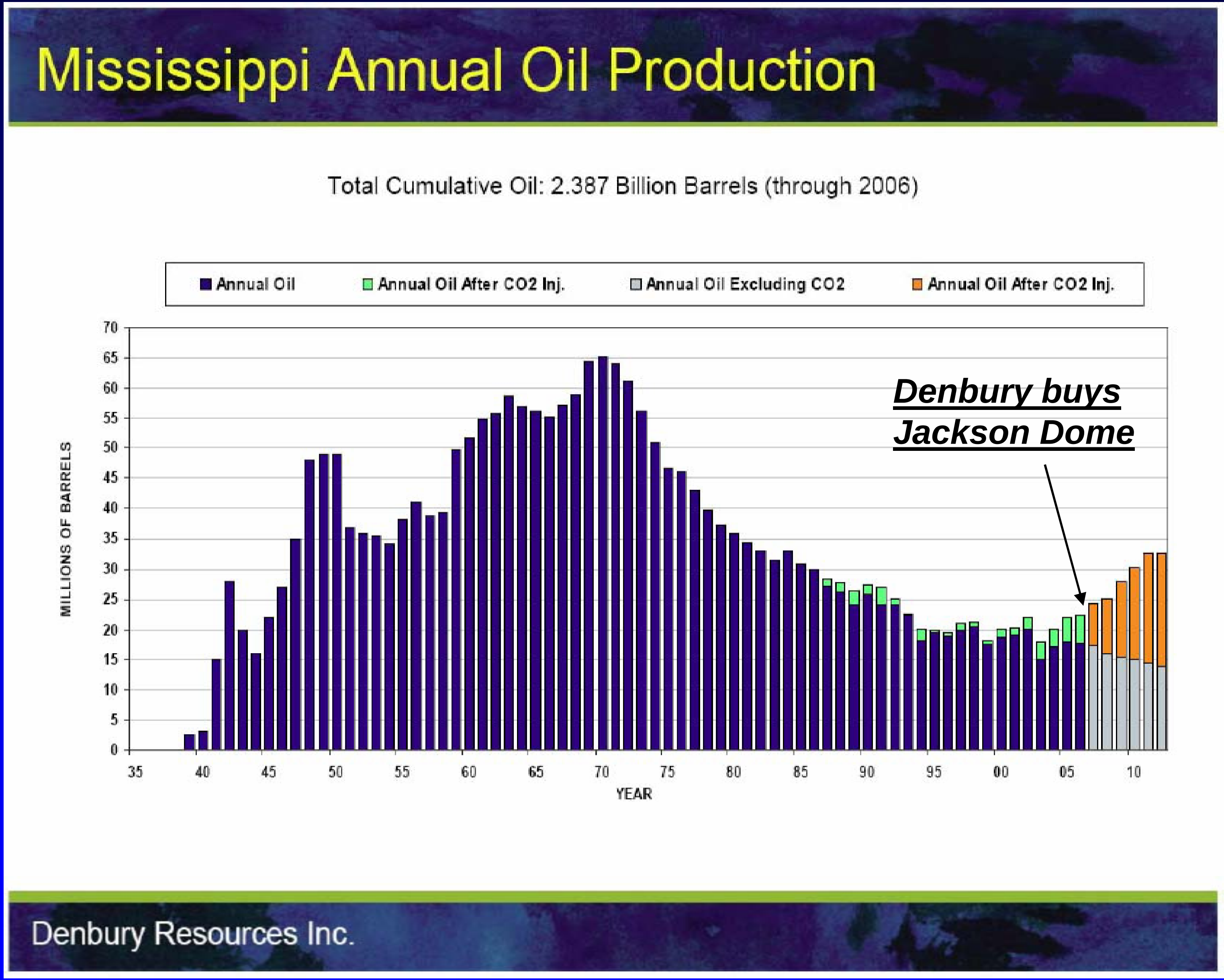
** $1.5/mcf + $0.50/mcf recycle. N/G = 5/10.

Costs could vary significantly. Numbers are intended only for illustrating that significant investment is required.

Impact of Technology on Kansas Oil Production



Why not Kansas?



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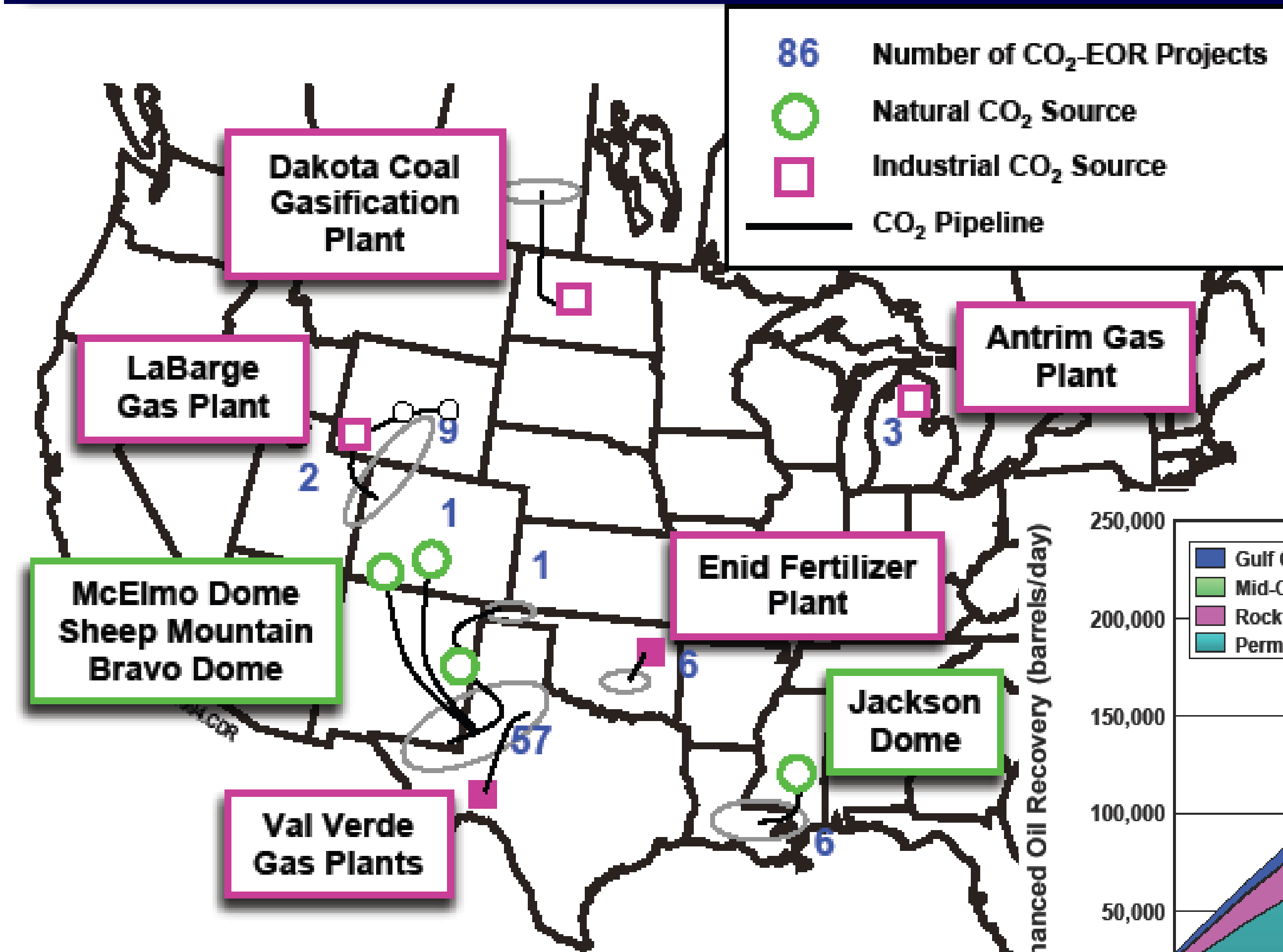
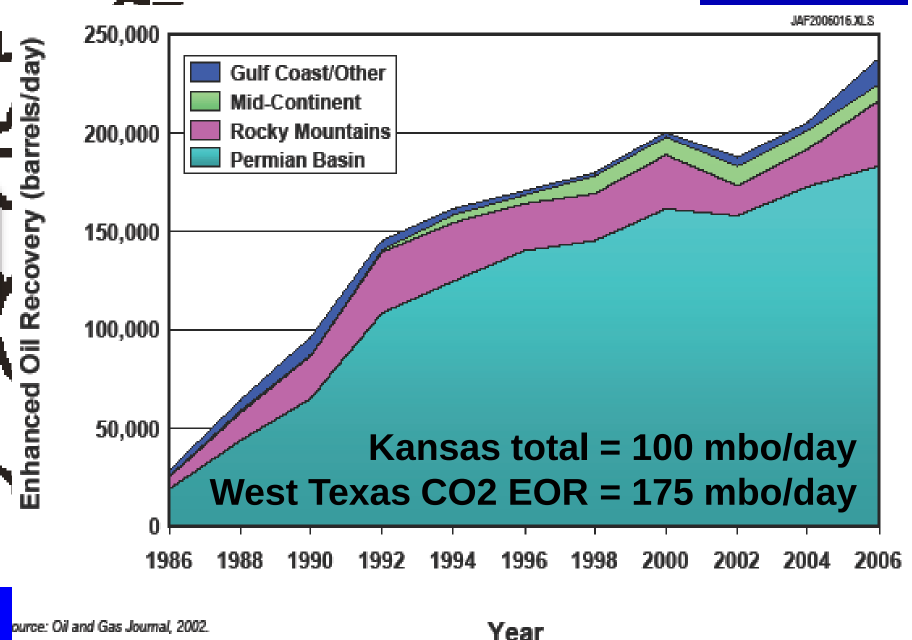


- 86 projects
- 237 mbo/d



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Laws of physics also apply in Kansas

Current CO2 Used for EOR

State/ Province (storage location)	Source Type (location)	CO2 Supply MMcfd**	
		Natural	Anthropogenic
Texas-Utah-New Mexico-Oklahoma	Geologic (Colorado-New Mexico) Gas Processing (Texas)	1,700	110
Colorado-Wyoming	Gas Processing (Wyoming)	-	340
Mississippi	Geologic (Mississippi)	400	-
Michigan	Ammonia Plant (Michigan)	-	15
Oklahoma	Fertilizer Plant (Oklahoma)	-	35
Saskatchewan	Coal Gasification (North Dakota)	-	145
TOTAL		**2,100**	**645**

* Source: 12th Annual CO2 Flooding Conference, Dec. 2006

** MMcfd of CO2 can be converted to million metric tons per year by first multiplying by 365 (days per year) and then dividing by 18.9 * 10^3 (Mcf per metric ton).

Kuuskraa, ARI - 2008

Kansas currently vents **120 mmcfd** of high purity CO2 from Ethanol and Fertilizer plants *(EOR potential12-25 mbo/d)*

Kansas Strengths and Challenges for CO_2 EOR CCS Development

Kansas strengths

- Significant oil resource base
- Well-defined, large sequestration targets
- CO_2 sources: Local and regional
- Head start on regulatory framework
- Favorable relationships with research groups (TORP and KGS)
- Strong industry and professional groups (KIOGA, KGS (all of them), SPE)
- Long-standing intercompany relationships
- Skilled workforce

Challenges - Kansas

- Resource base – needs to be validated
- High % of wells are plugged and many pose a risk to containment
- Resources are unconsolidated
- Missing CO_2 EOR skill sets
- Capital
- Tendency to be late adopters

Challenges - Federal and State

- Philosophical and Regulatory hurdles (CCS vs. EOR)
- Regulatory framework still in developmental stage

Kansas Oil's next generation?

1. Recognize opportunity
2. Understand the challenges
3. Proactive in molding public acceptance and regulatory framework
4. Take the long view, *but* be early adopters
5. Willingness to collaborate and cooperate

END