United States Environmental Protection Agency

Geological Sequestration of CO_2

A Brief Overview and Potential for Application for Oklahoma

Presented to Oklahoma Clean Lakes and Watersheds Association
Quartz Mountain Resort
April 1, 2009

Dominic DiGiulio, Ph.D.

Office of Research and Development
National Risk Management Research Laboratory,
Ground Water and Ecosystem Restoration Division, Ada, OK

United States Environmental Protection Agency

Outline of Presentation

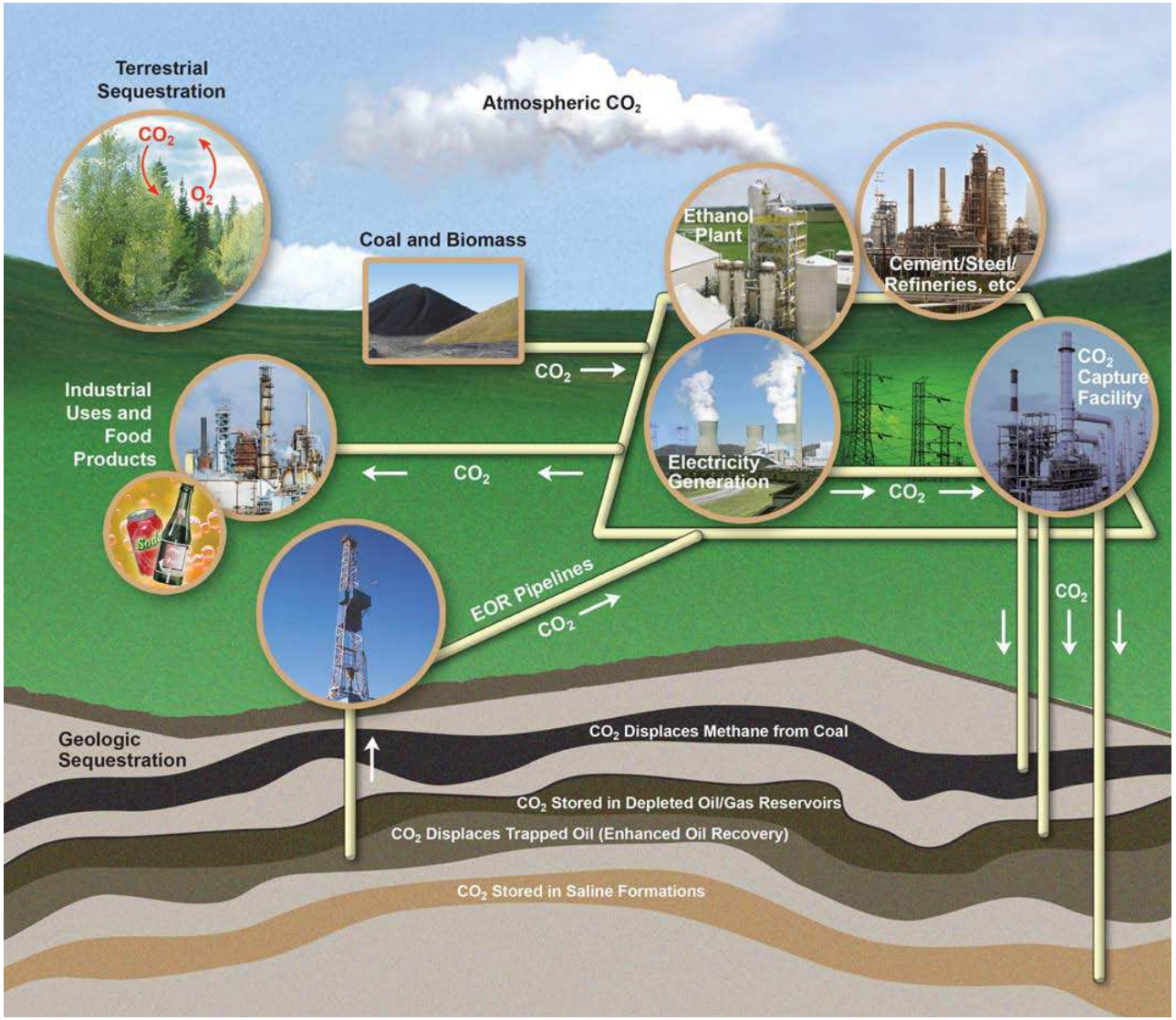
- Brief Overview of Geological Sequestration
- Potential for CO2-EOR in Oklahoma
- Research at R.S. Kerr Research Center, Ada, OK

Disclaimer:

This presentation does not necessarily reflect EPA policy.

United States Environmental Protection Agency

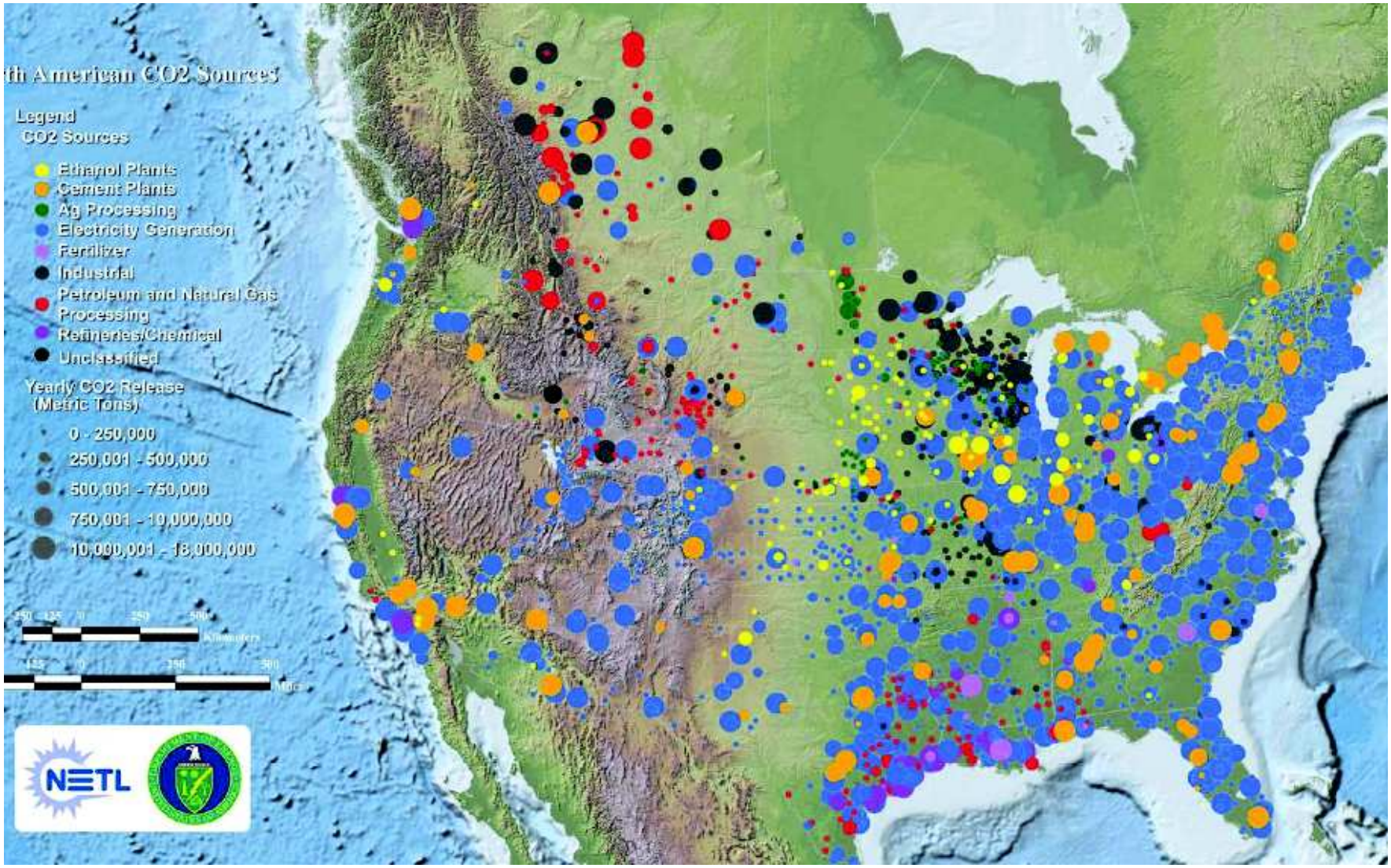
Carbon Capture and Storage (CCS) and Geological Sequestration (GS)



From DOE, 2008

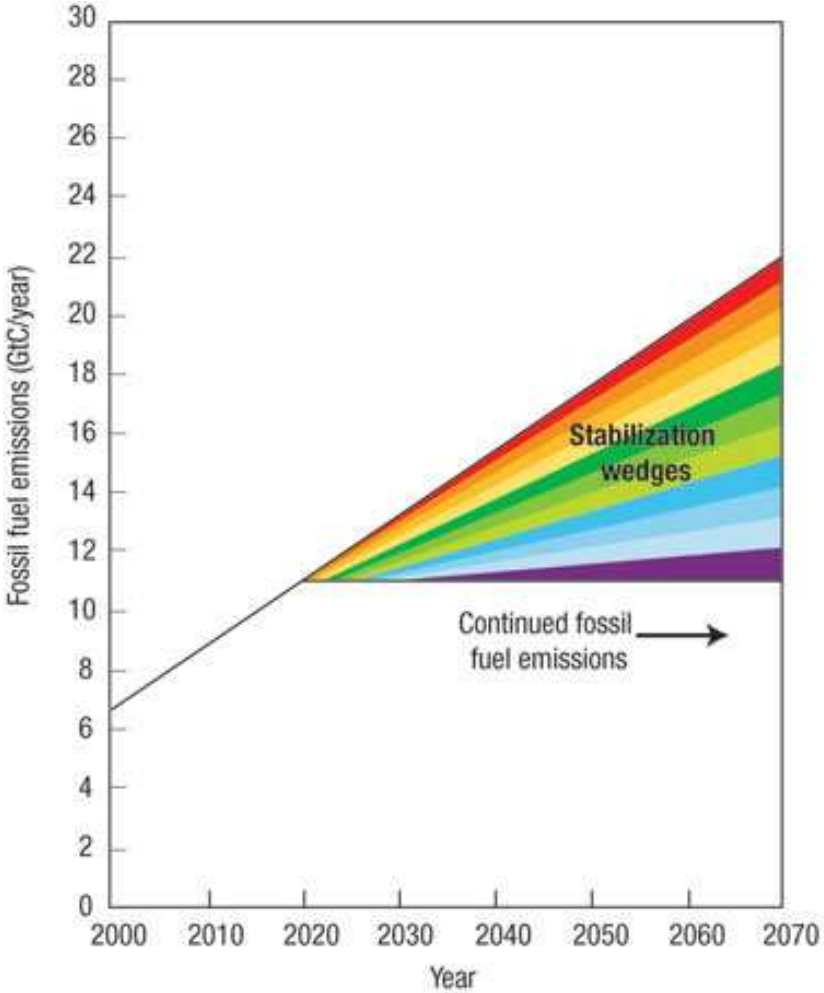
United States Environmental Protection Agency

Stationary Sources of CO_2



United States Environmental Protection Agency

CCS as Part of the Big Picture



- Coal: 800 gigawatt-sized plants with all the carbon captured and permanently sequestered
- Nuclear: 700 new gigawatt-sized plants (plus replacement plants)
- Concentrated solar thermal electric: 1,600 gigawatts peak power
- Solar photovoltaics: 3,000 gigawatts peak power
- Efficient buildings: savings totalling 5 million gigawatt-hours
- Efficient industry: savings totalling 5 million gigawatt-hours, including co-generation and heat recovery
- Wind power: 1 million large wind turbines (2 megawatts peak power)
- Vehicle efficiency: all cars 60 miles per US gallon
- Wind for vehicles: 2,000 gigawatts wind, with most cars plug-in hybrid electric vehicles or pure electric vehicles
- Cellulosic biofuels: using up to one-sixth of the world's cropland
- Forestry: end all tropical deforestation

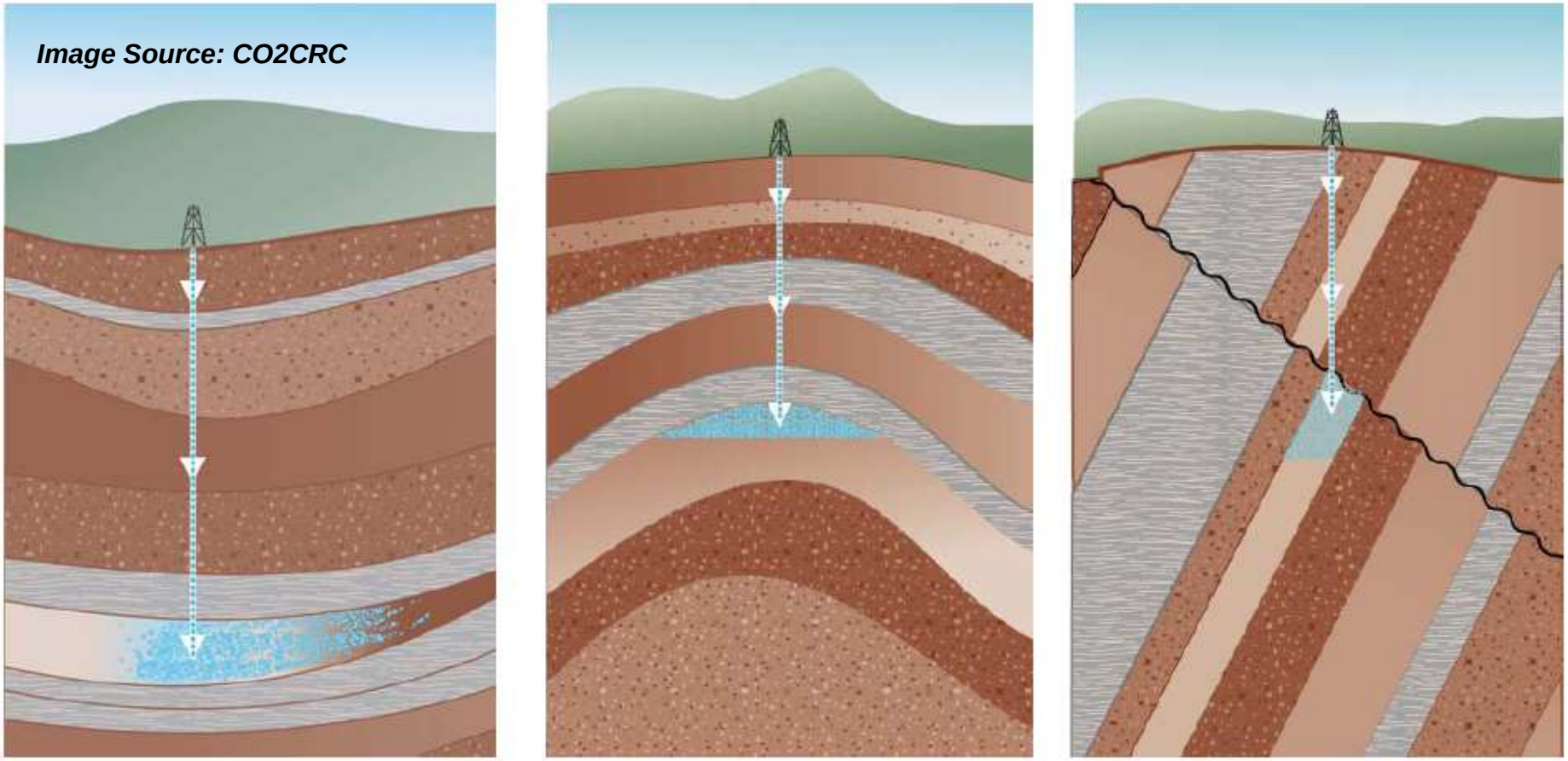
From Romm, 2008

United States Environmental Protection Agency

Trapping Mechanisms

Stratigraphic and Structural Trapping

The buoyancy of supercritical CO_2 necessitates that the injection zone must be overlain by a primary confining system of sufficient regional thickness and lateral extent to contain the entire CO_2 plume and associated pressure front. This will initially be the primary mechanism of containment.

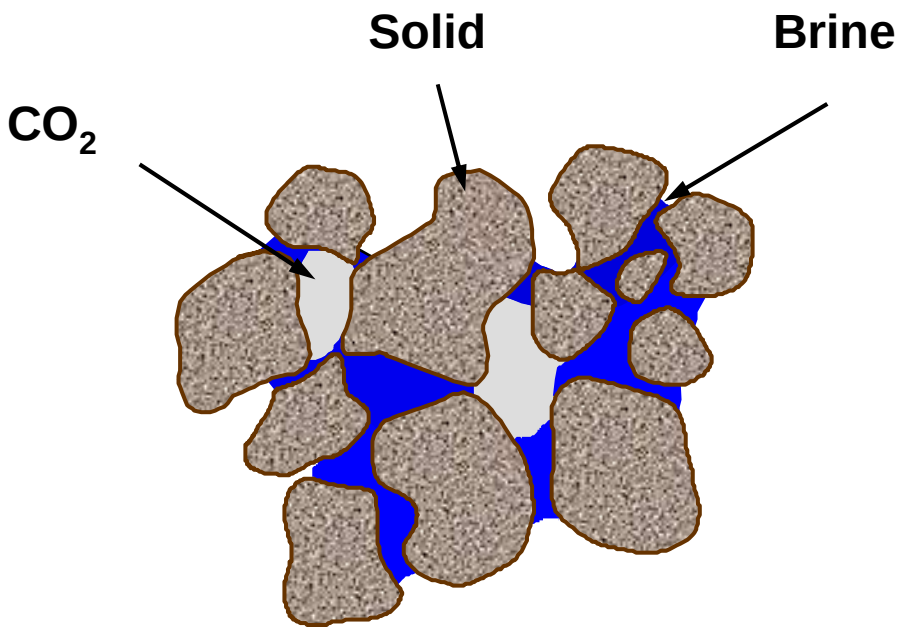


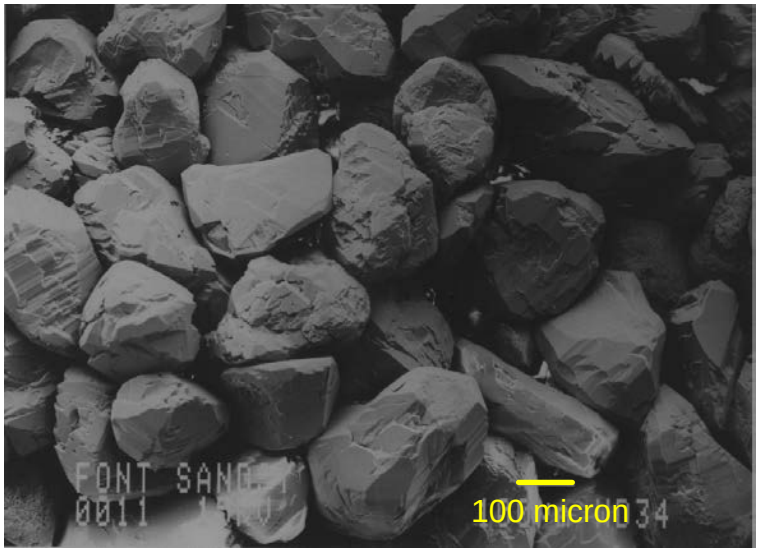
In stratigraphic trapping (left), CO_2 is trapped by an overlying layer of cap rock coupled with impermeable rock within a narrowing of the storage formation.

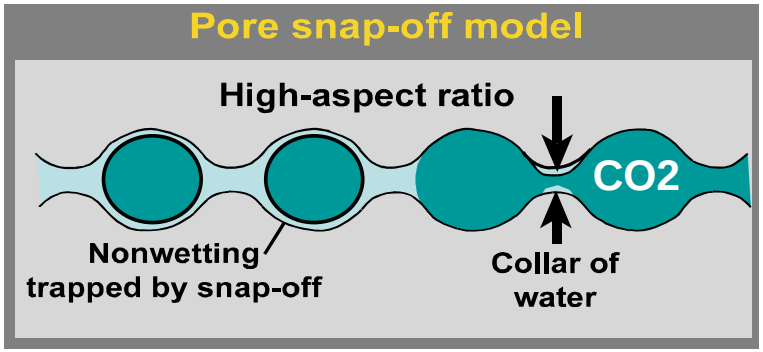
In structural trapping, CO_2 is trapped by a fold in the rock formations (middle) or by impermeable rock layers shifted along a sealing fault (right) to contain the CO_2.

United States Environmental Protection Agency

Capillary Trapping





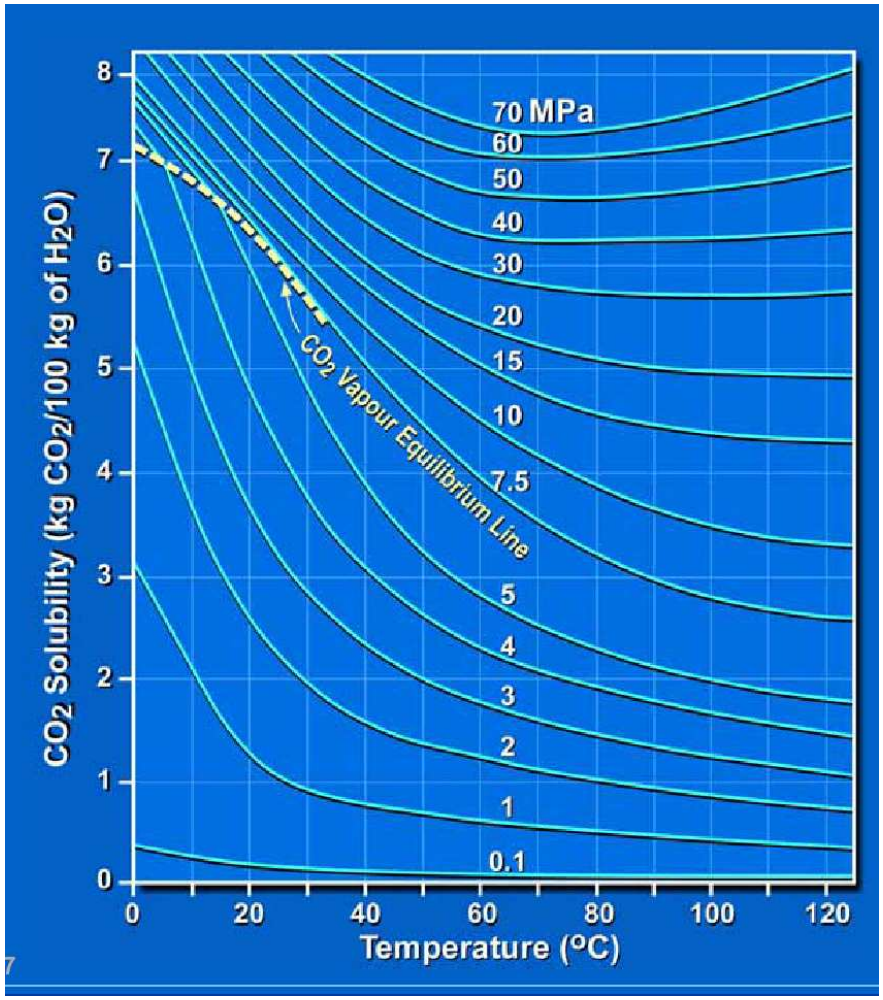


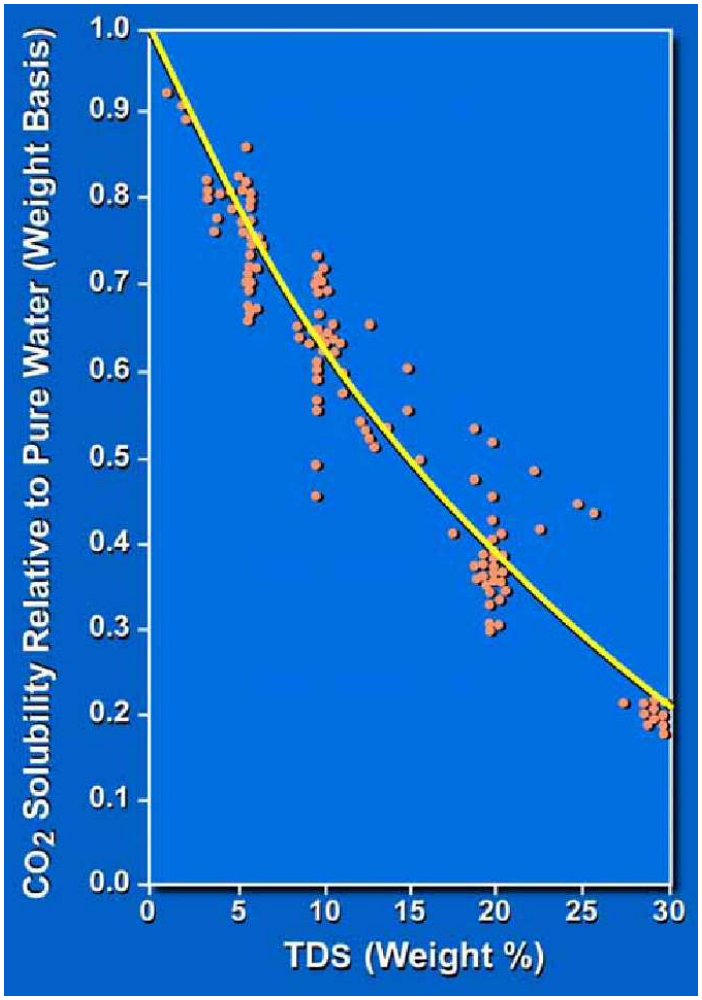
From Bryant, 2005

United States Environmental Protection Agency

Dissolution/Ionic Trapping

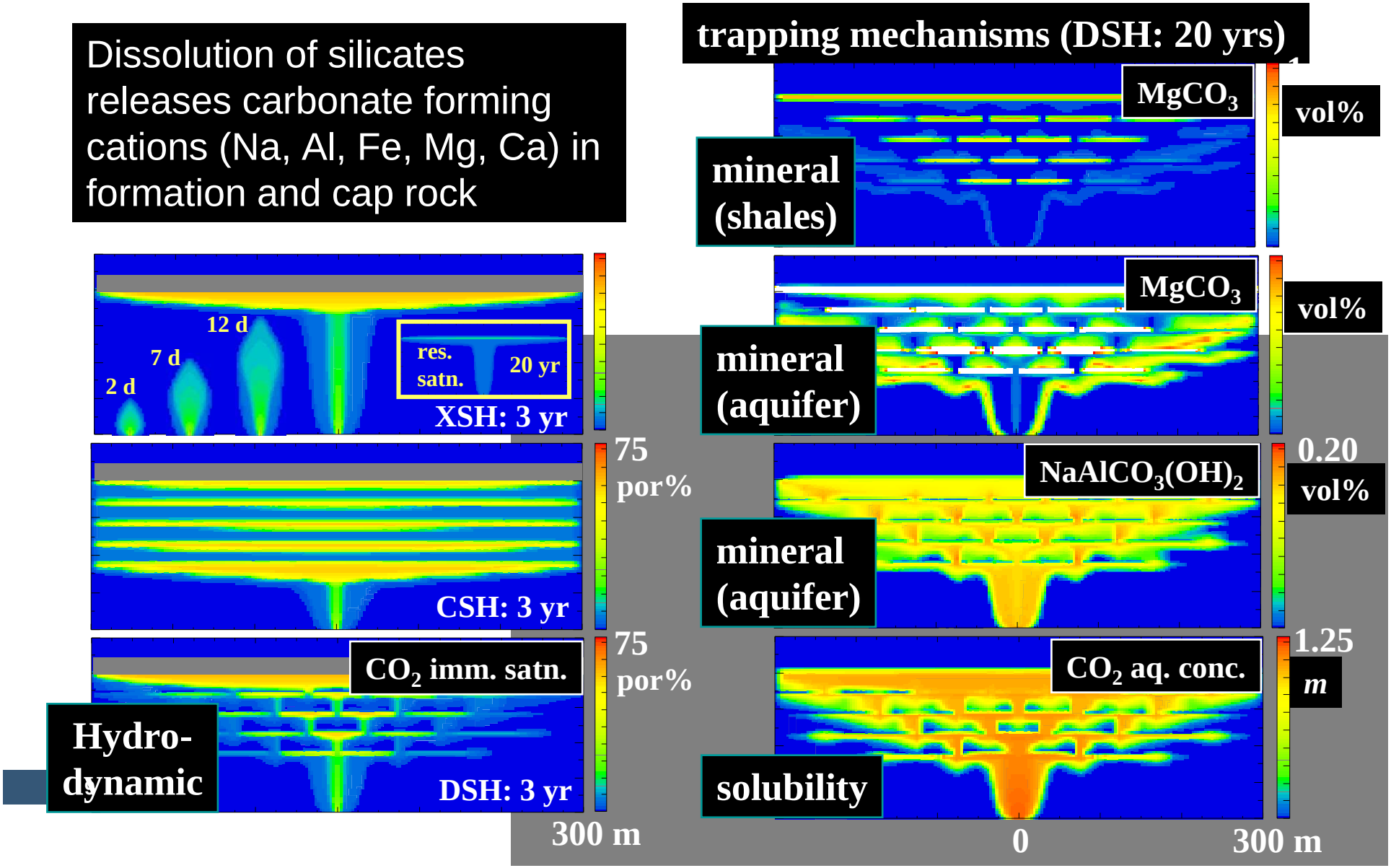
$$CO_2(g) + H_2O \leftrightarrow H_2CO_3 \leftrightarrow HCO_3^- + H^+ \leftrightarrow CO_3^{2-} + 2H^+$$





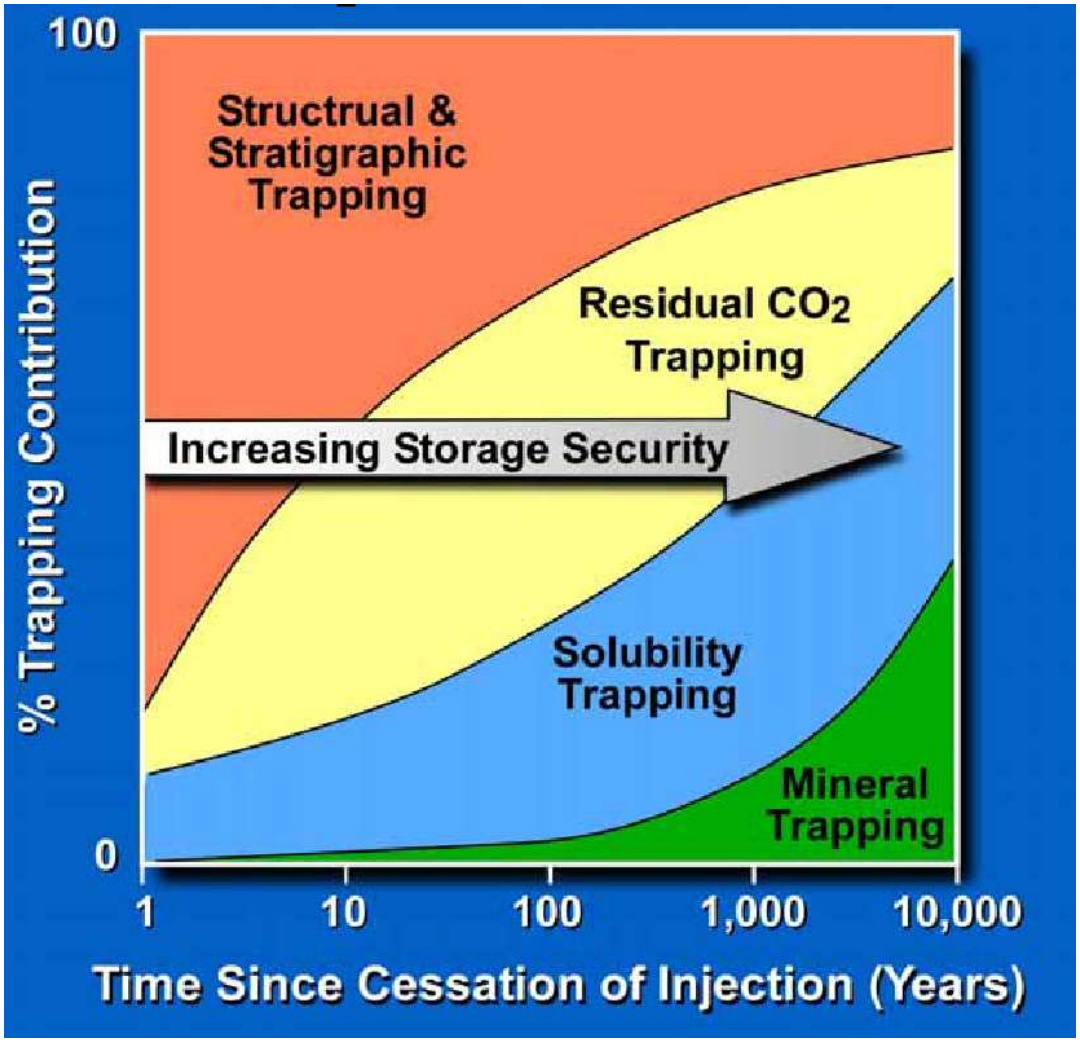
EPA United States Environmental Protection Agency

Dissolution of silicates releases carbonate forming cations (Na, Al, Fe, Mg, Ca) in formation and cap rock



United States Environmental Protection Agency

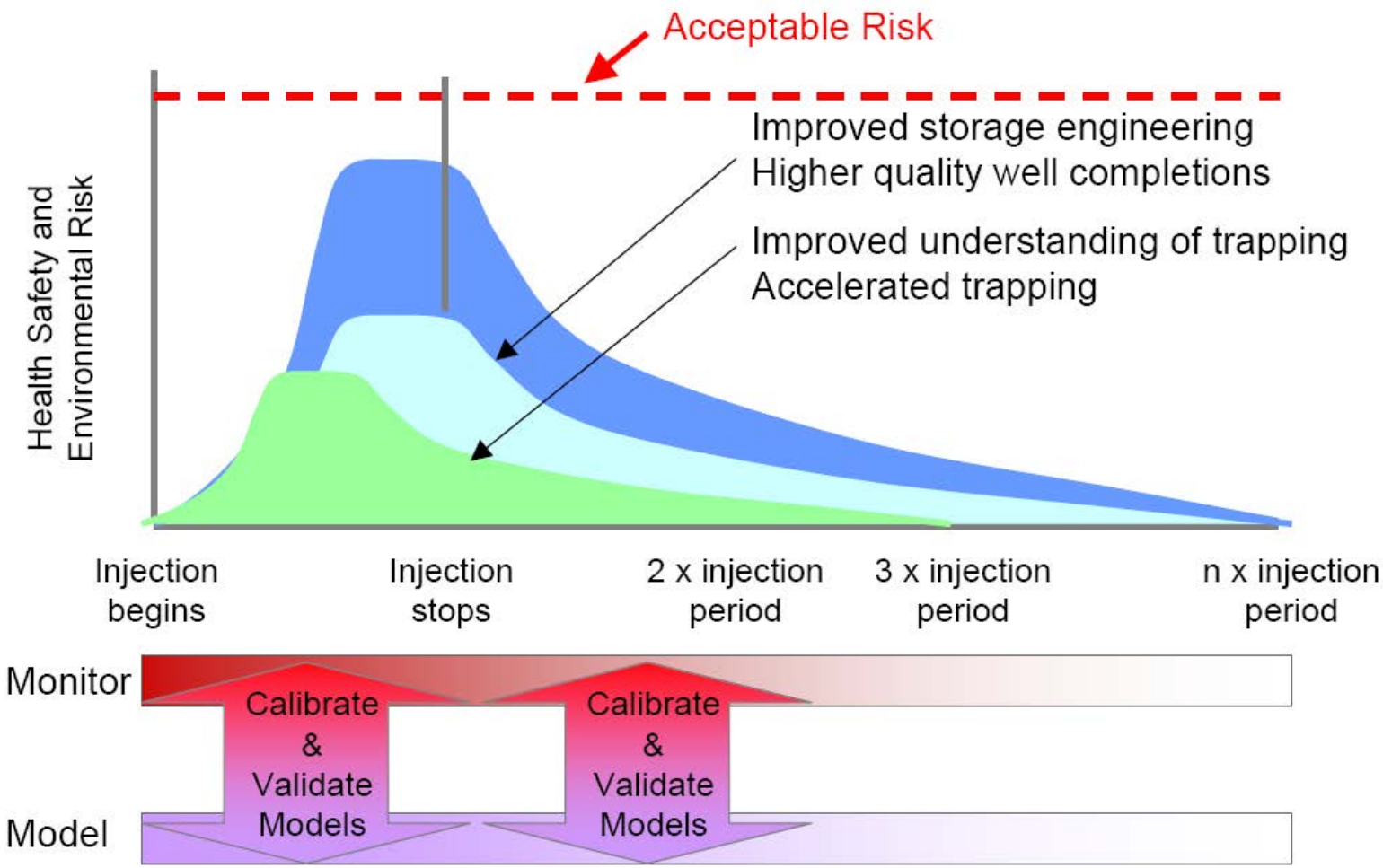
Primary Mechanisms of CO_2 Storage (not including adsorption to coal and shale)



From *IPCC Special Report on Carbon dioxide Capture and Storage*

United States Environmental Protection Agency

Improved Design = Less Liability



From Benson, 2008

United States Environmental Protection Agency

Storage Formations

United States Environmental Protection Agency

Deep Saline Aquifers

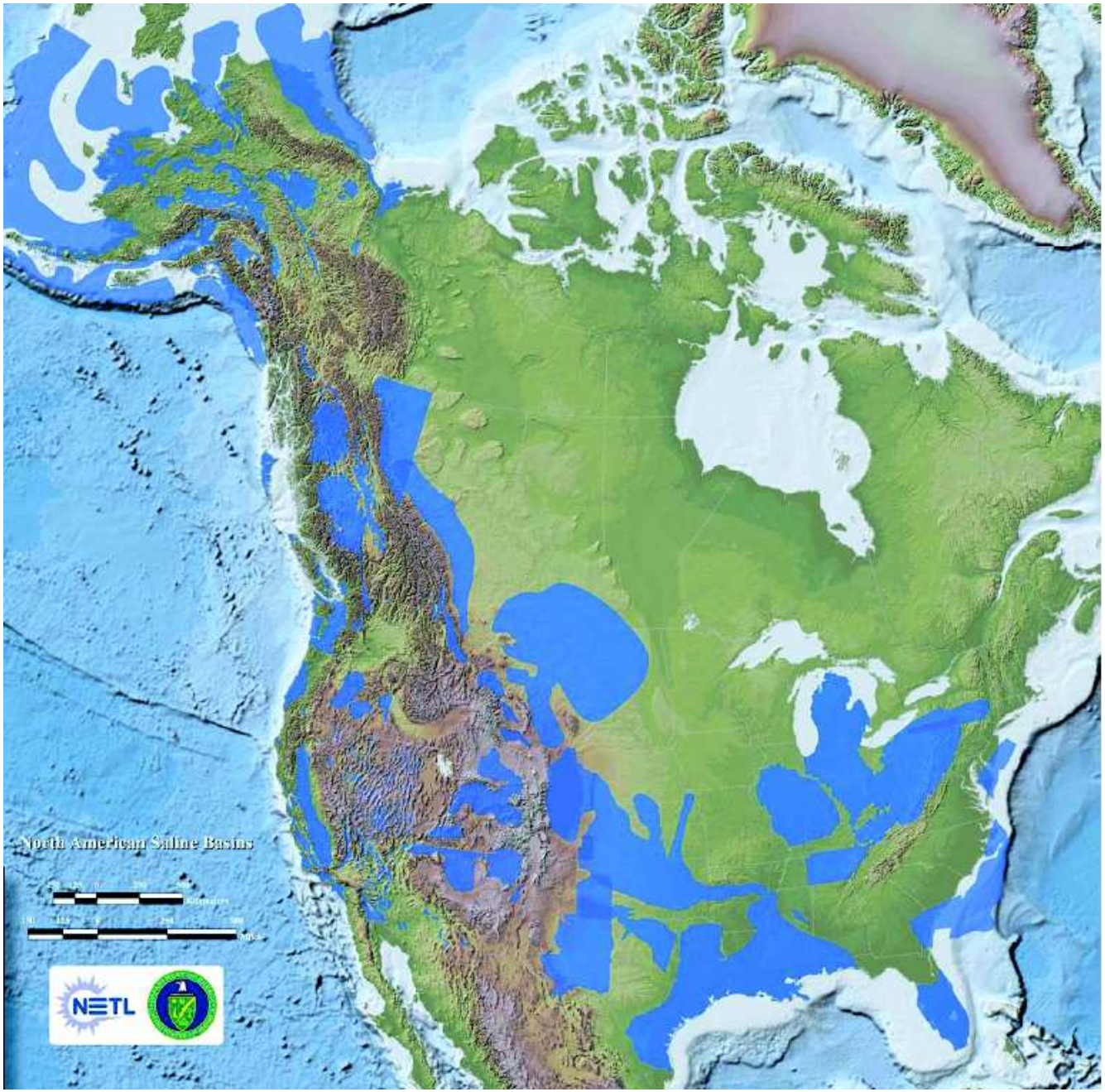


Figure DOE, 2007

United States Environmental Protection Agency

"Unmineable Coal Seams

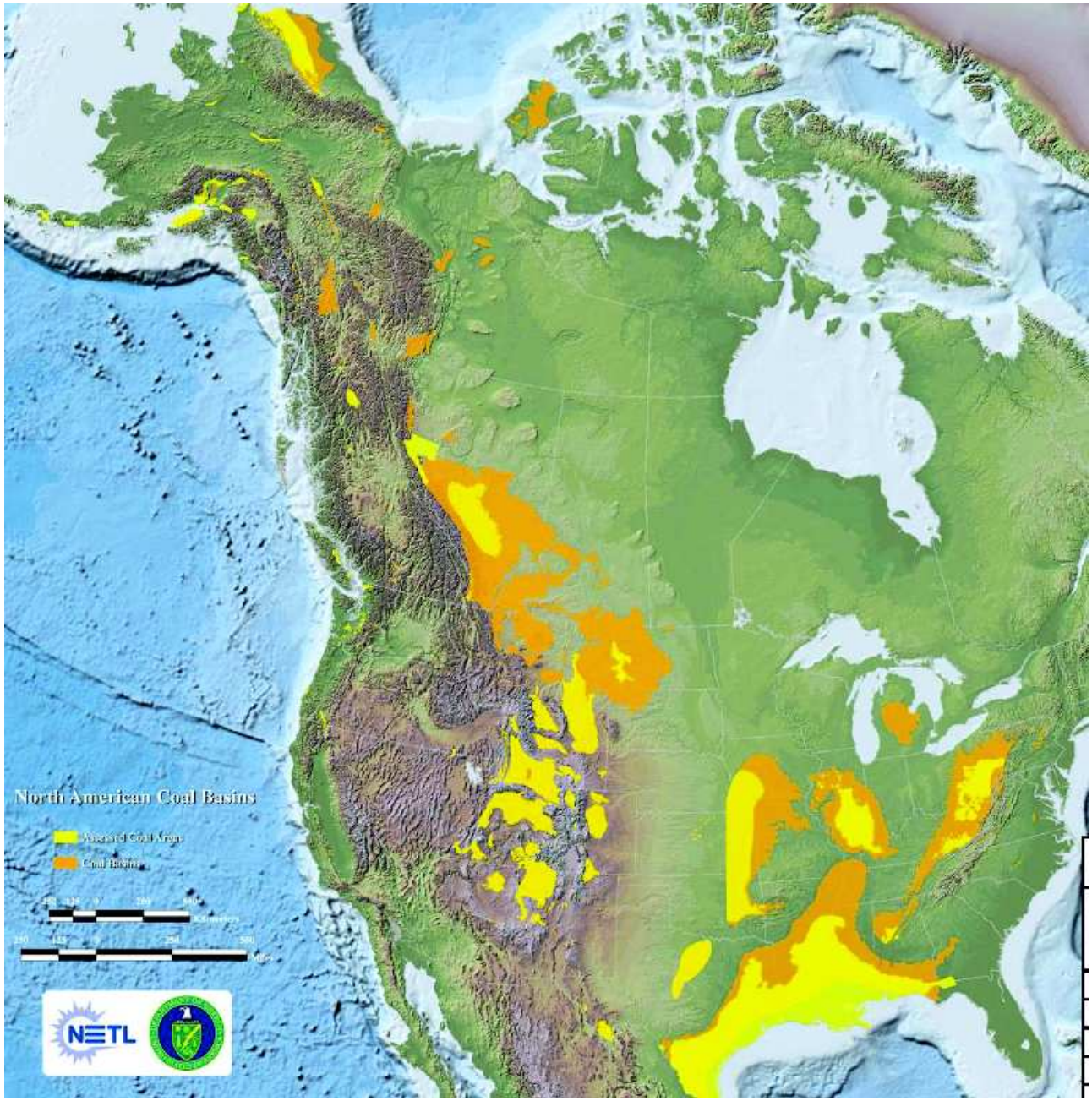
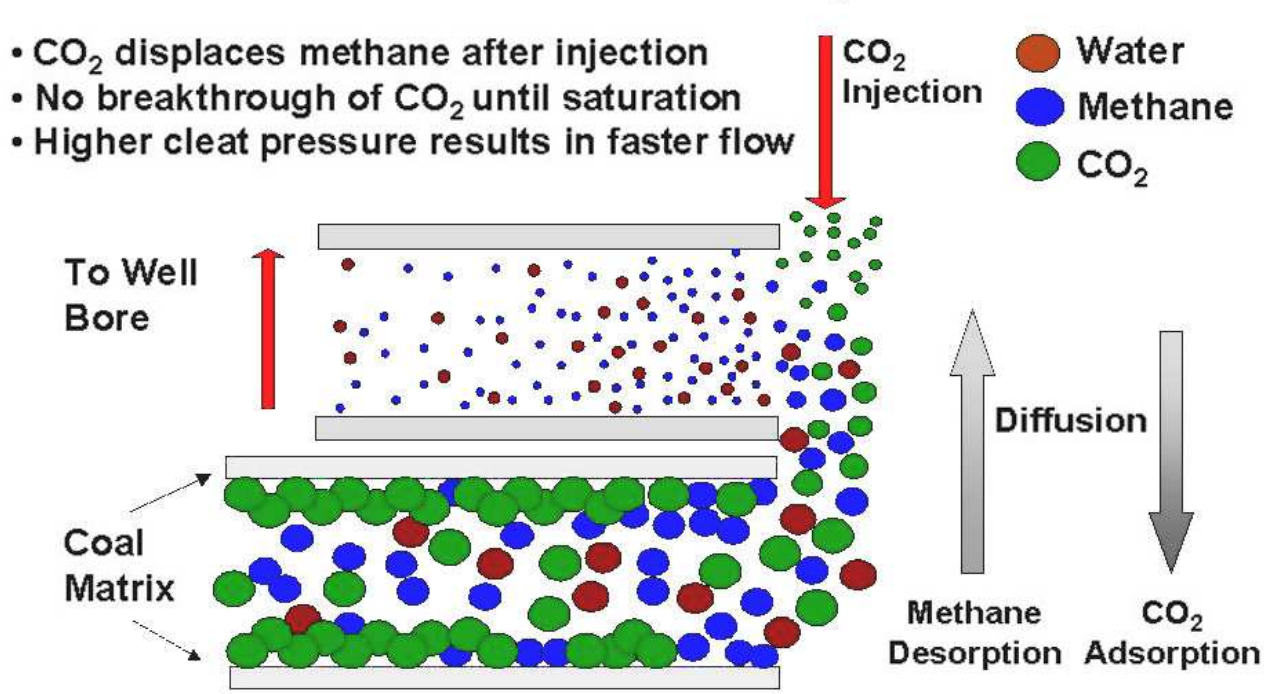


Figure from DOE, 2007

United States Environmental Protection Agency

Enhanced Coal Bed Methane (ECBM) Recovery



- Value added incentive.
- Access to “unmineable” coal deposits.
- Potential 1.5% storage capacity in U.S.

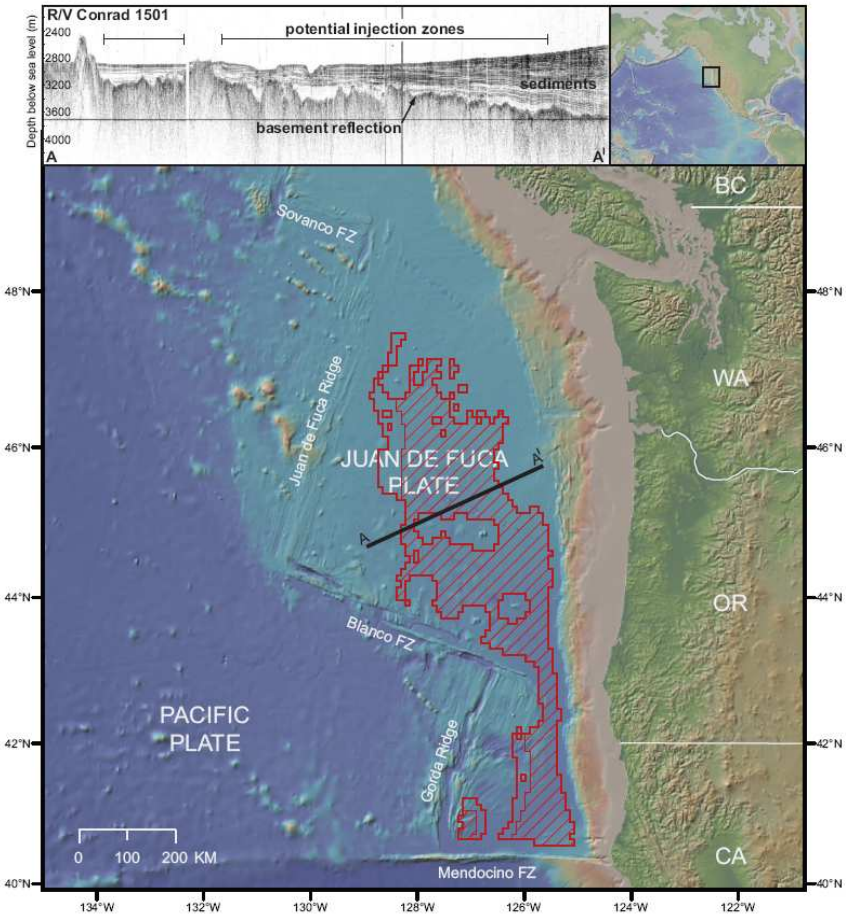
Figure from DOE, 2006

- Swelling - reduction of permeability.
- Brine disposal.
- Close to or part of USDWs
- Many coal seams too shallow for storage as supercritical fluid.

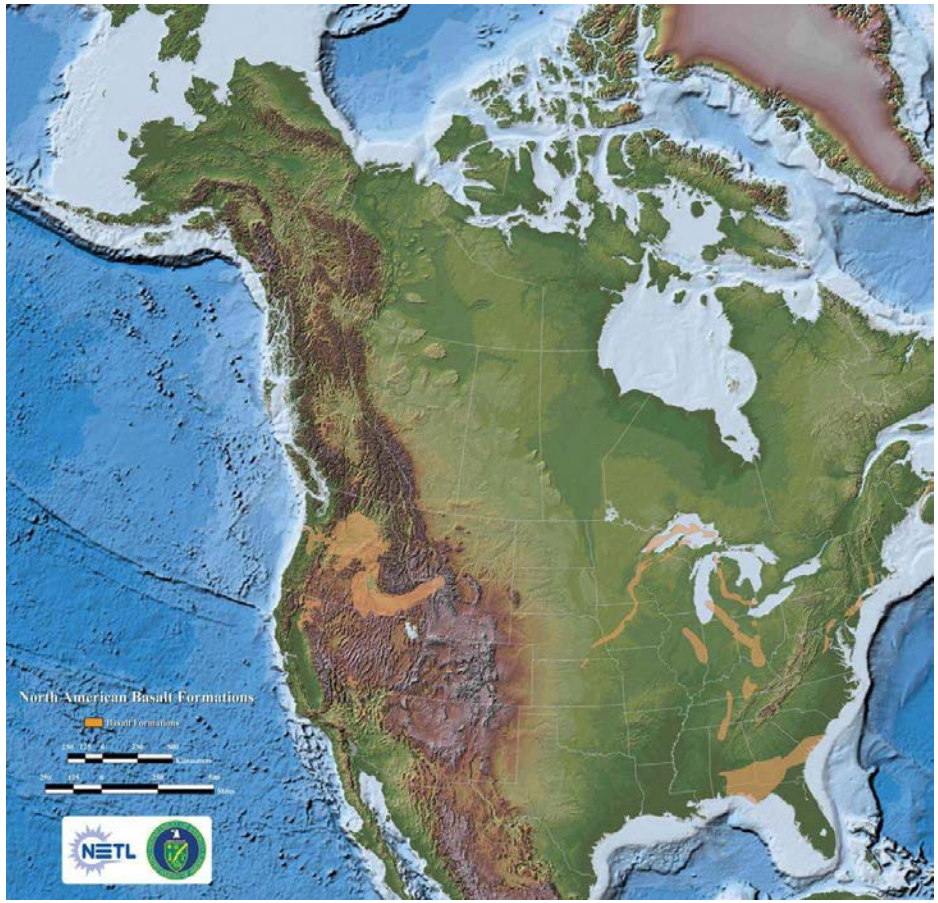
United States Environmental Protection Agency

Potential Storage in Basalt

The release of Ca^{2+} and Mg^{2+} ions from silicate minerals in basalt could result in rapid precipitation of carbonate minerals.



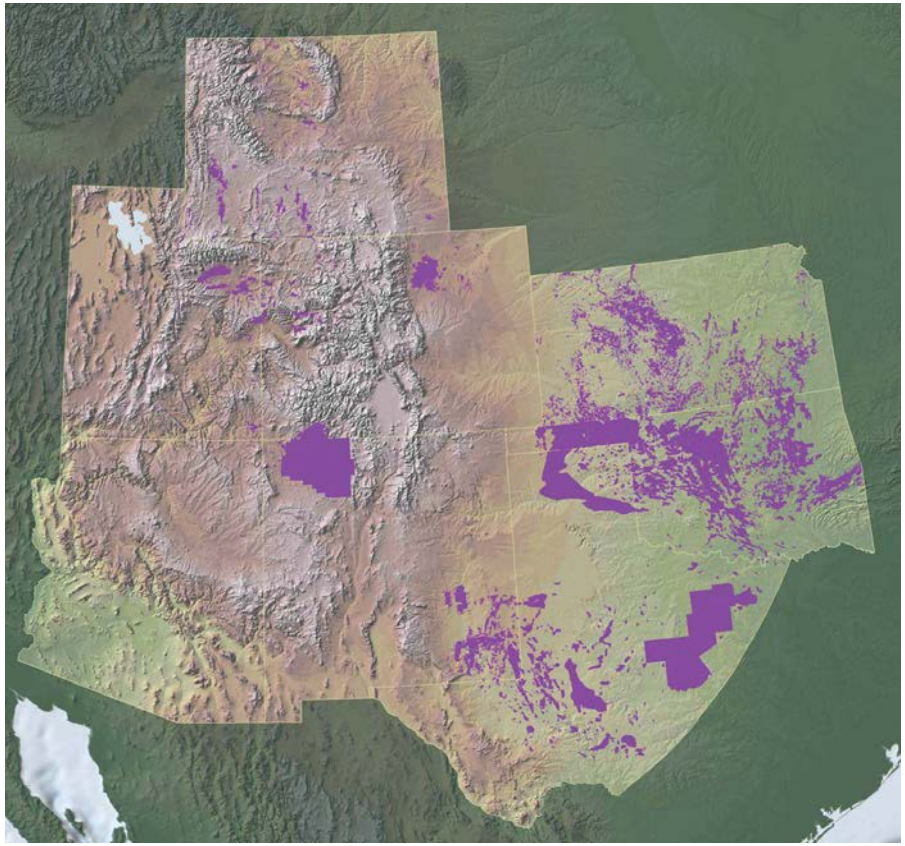
From Goldberg et al. 2008

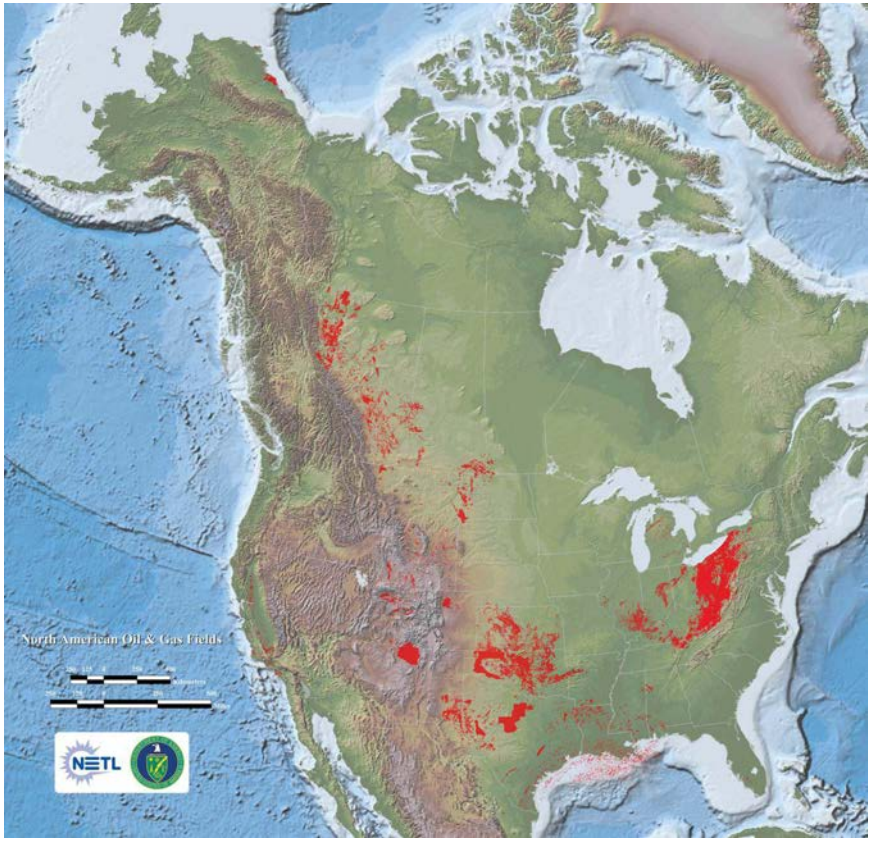


From DOE, 2007

United States Environmental Protection Agency

Storage Capacity in Petroleum and Gas Reservoirs



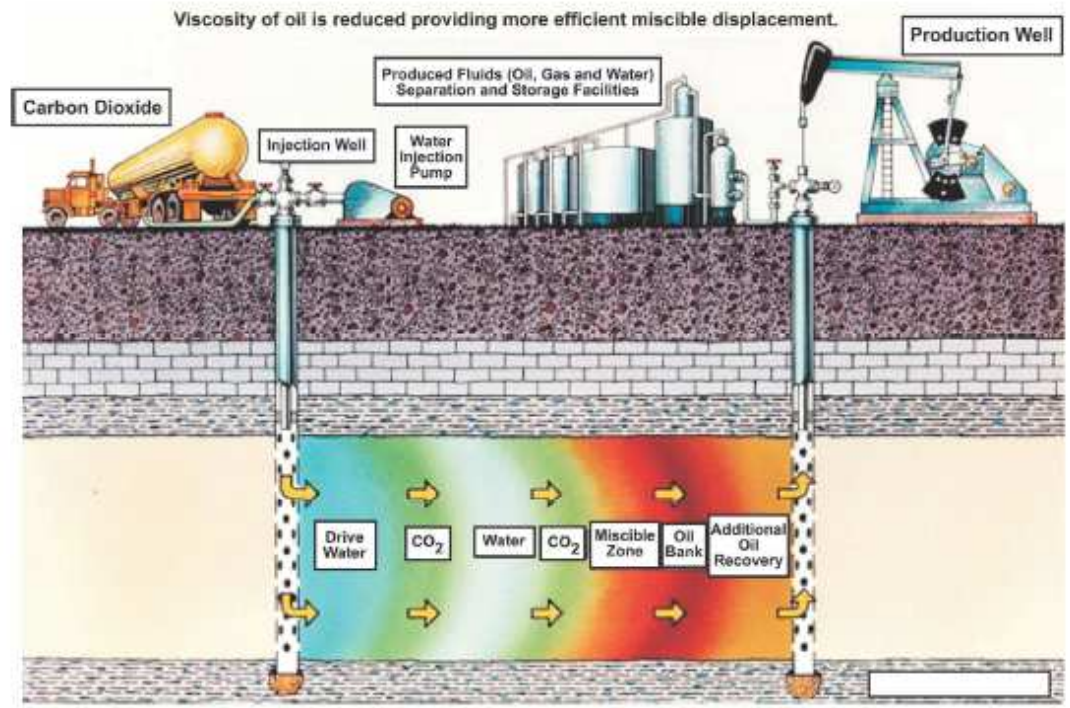


Most of the storage capacity in Oklahoma associated with oil and gas reservoirs.

Figures and table from DOE, 2007

EPA United States Environmental Protection Agency

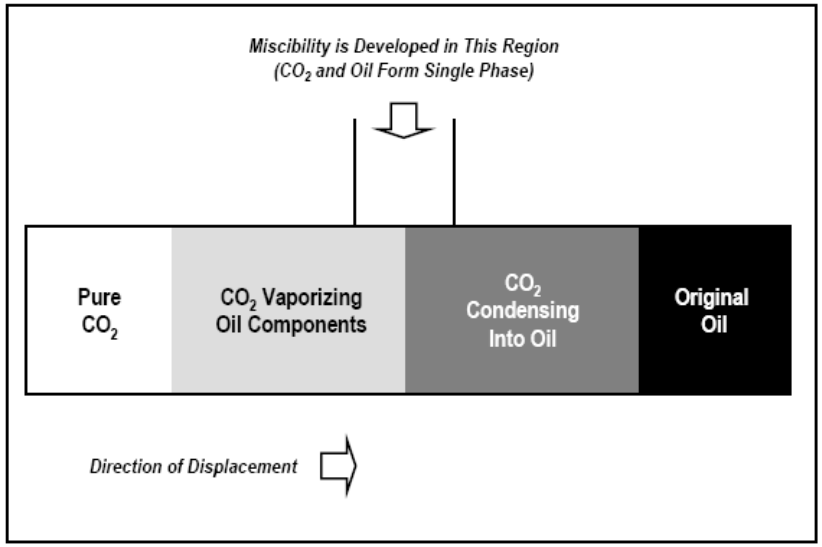
Enhanced Oil Recovery (EOR)



Schematic of CO_2 EOR

Figure from DOE, 2007

During miscible displacement, CO_2 lowers the viscosity and interfacial tension of oil. Deep "light" oil.



Figures from Basin Oriented Strategies for CO_2 Enhanced Oil Recovery: Oklahoma, DOE, NETL, March 2005

United States Environmental Protection Agency

CO_2-EOR

United States Environmental Protection Agency

Benefits of CO_2-EOR

- **Value Added Incentive**. Revenue for petroleum corporations from additional production of petroleum and carbon credits. Revenue for corporations or utilities selling CO_2 to meet cap and trade requirements.
- **Tax Revenue**. Substantial increase in tax revenue for States.
- **Trade Imbalance**. Reduce trade imbalance for imported petroleum with decreased reliance on countries hostile to U.S.
- **Infrastructure**. Some existing infrastructure already present. Widespread application will create additional infrastructure such as pipelines for eventual injection into saline aquifers.
- **Mineral Rights**. Mineral rights at petroleum reservoirs are already established.
- **Site Characterization**. Unlike saline aquifers, petroleum reservoirs are already well characterized.
- **Carbon Neutrality**. CO_2-EOR is 70% carbon neutral. Improve design to achieve 100% carbon neutrality (Corn-based ethanol only 10-15% carbon neutral and a net contributor to CO_2 emissions when coal used as a process fuel).

Taken from: Storing CO2 with Enhanced Oil Recovery, DOE/NETL-402/1312/02-07-08

United States Environmental Protection Agency

Nationwide CO2-EOR application would add about 85 billion barrels of incremental domestic oil supply ~ (4X current proved reserves).

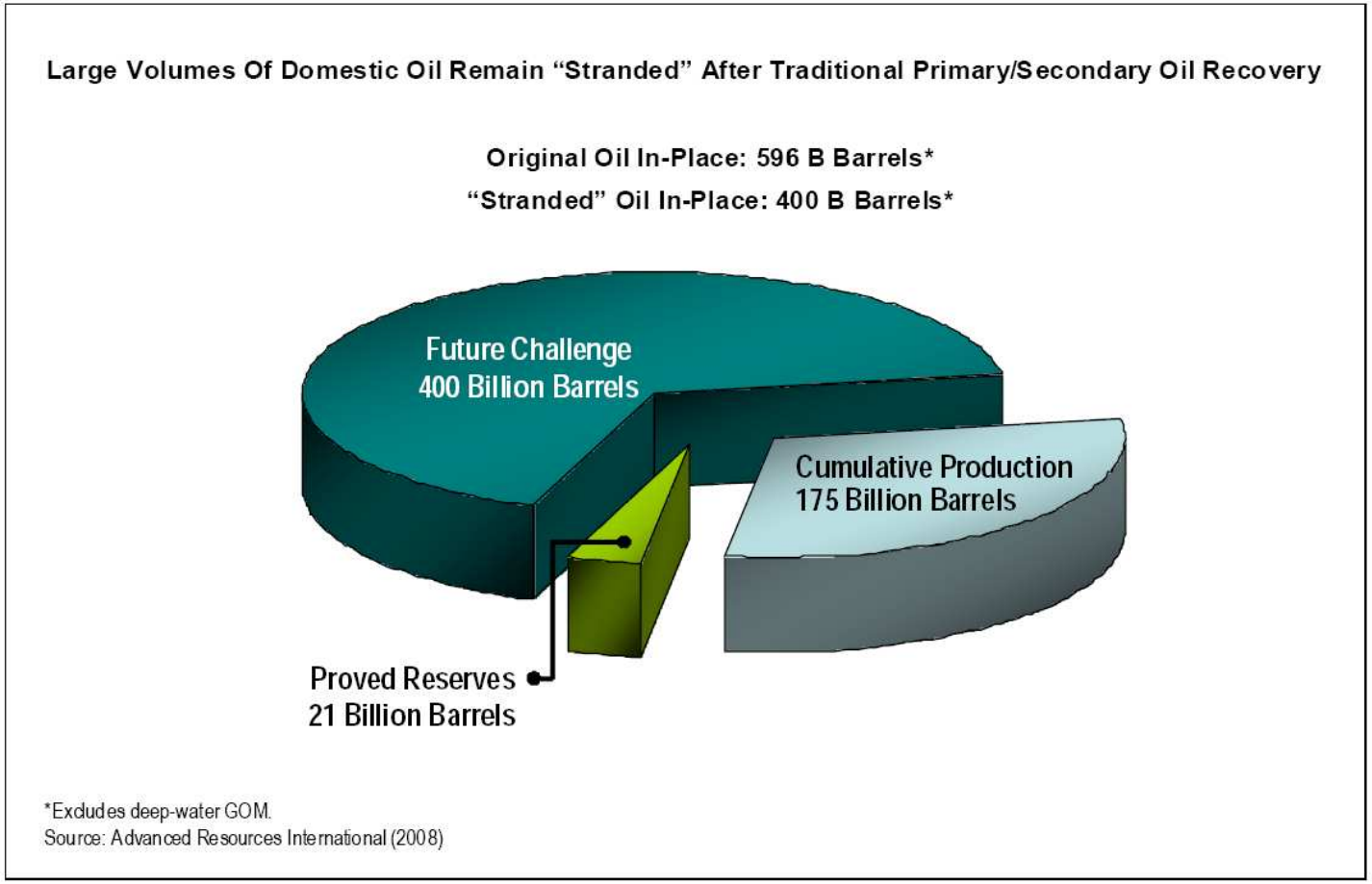
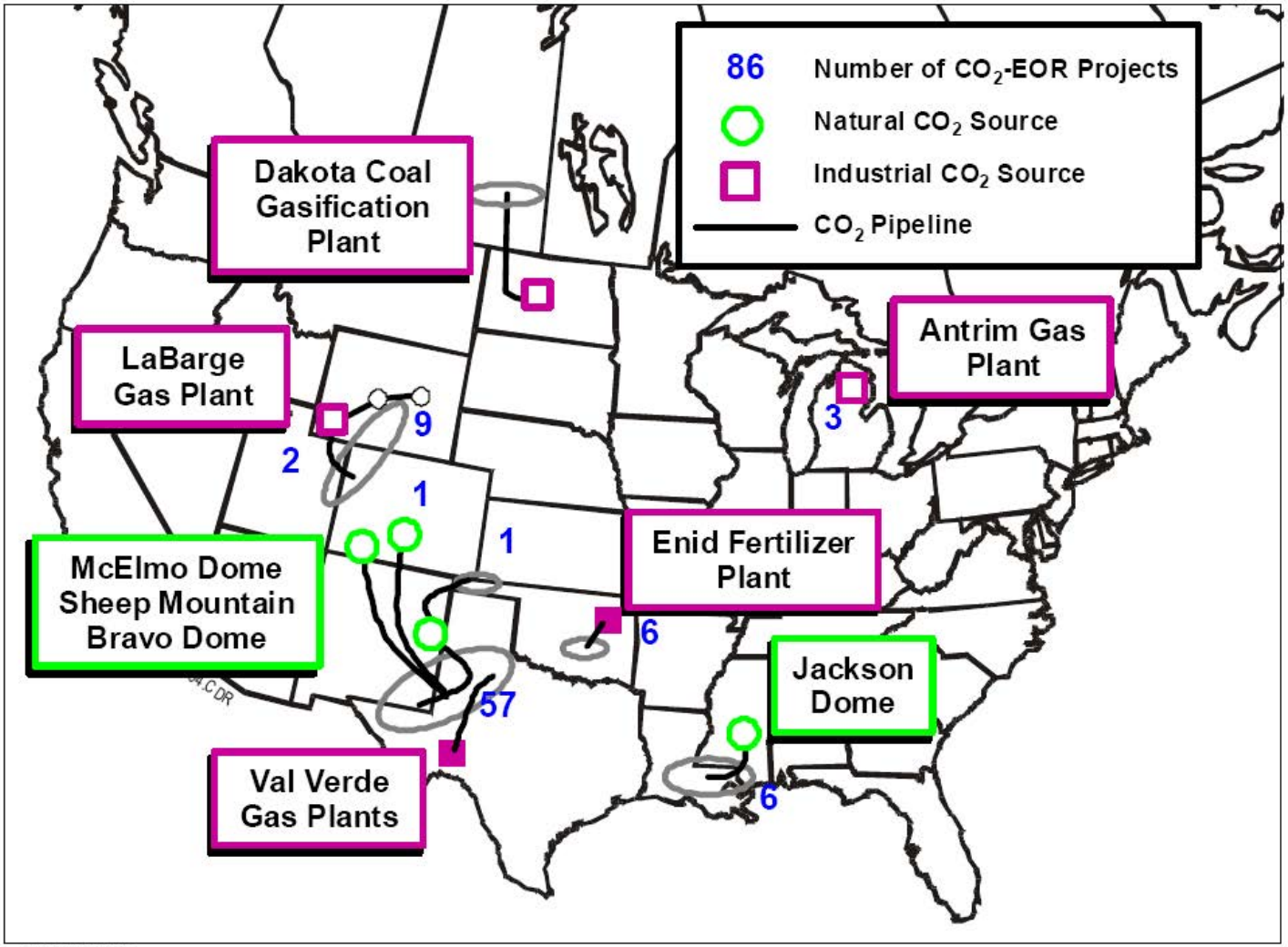


Figure from: Storing CO2 with Enhanced Oil Recovery, DOE/NETL-402/1312/02-07-08

United States Environmental Protection Agency

As of 2006, there were 86 CO2-EOR project in the U.S.



JAF02709.PPT

Figure from: Storing CO2 with Enhanced Oil Recovery, DOE/NETL-402/1312/02-07-08

EPA United States Environmental Protection Agency

Conceptual Pipeline System Connecting Fossil-Fuel Based CO_2 Sources with Major Petroleum Reservoirs

CO_2 could be provided by H_2 plants in Ponca City (11 MMcfd, Ardmore (26 MMcfd, and Wynnewood (9 MMcfd)

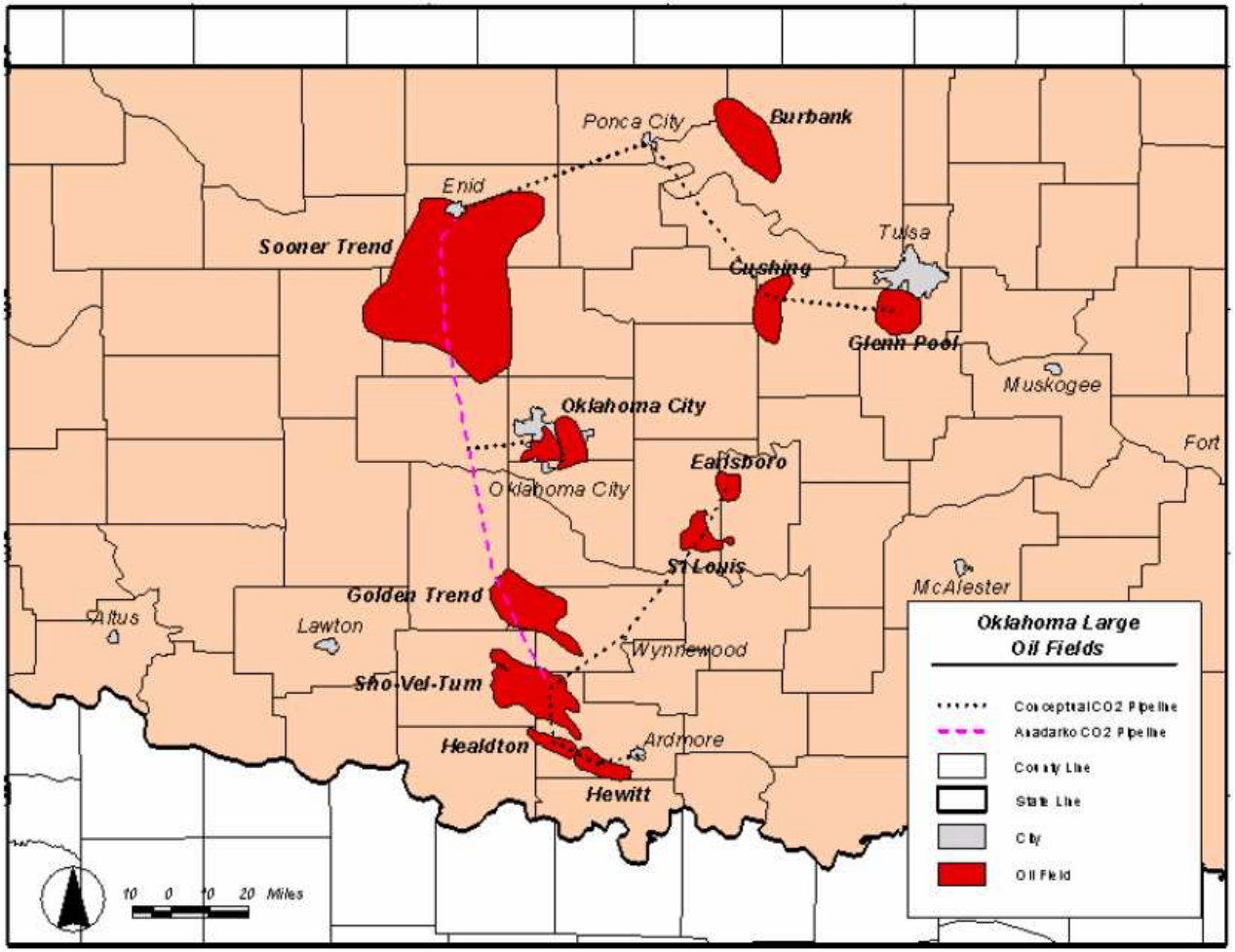


Figure from Basin Oriented Strategies for CO_2 Enhanced Oil Recovery: Oklahoma, DOE, March 2005

United States Environmental Protection Agency

History of Oklahoma Crude Oil Production, 1950-2002

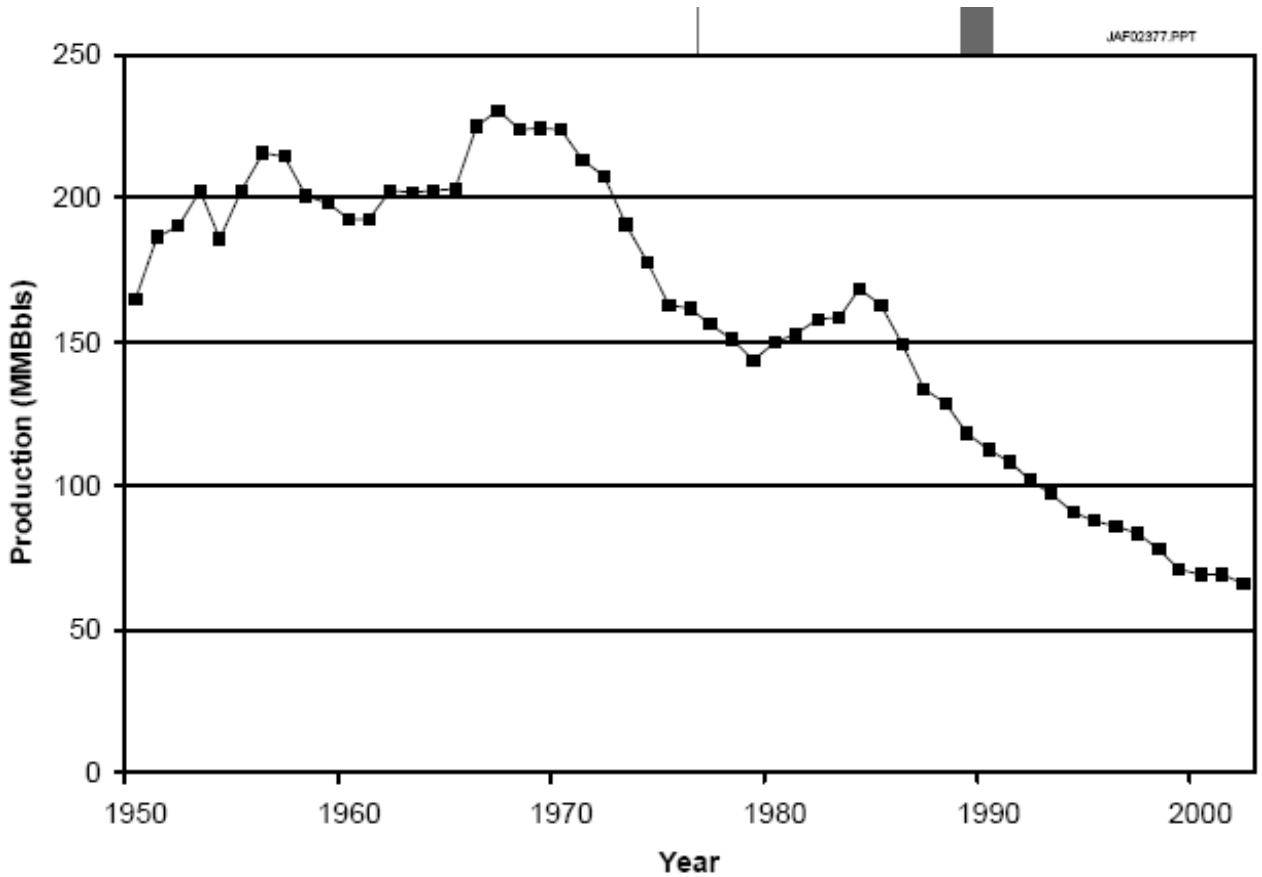


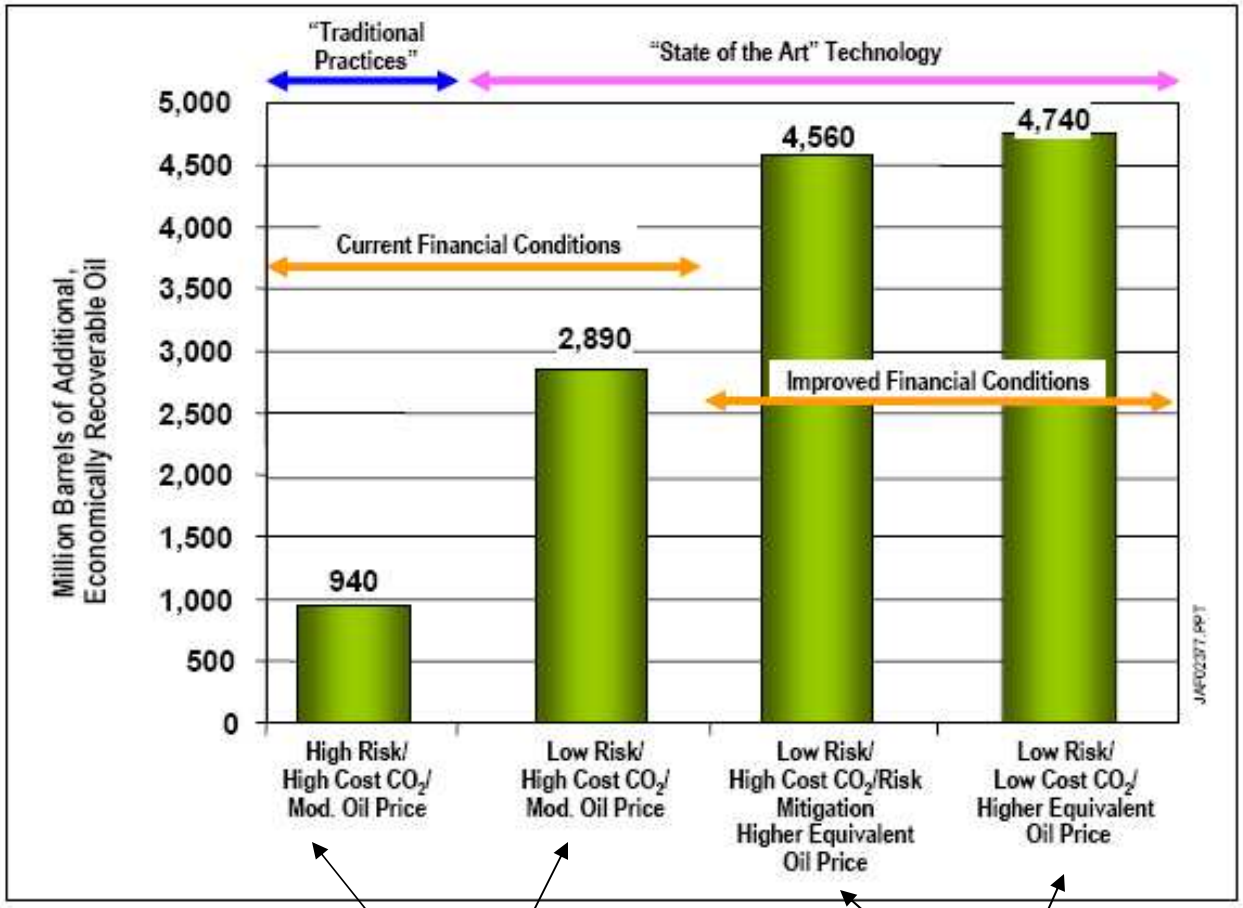
Figure from Basin Oriented Strategies for CO_2 Enhanced Oil Recovery: Oklahoma, March 2005

EPA United States Environmental Protection Agency

Technical recovery at 63 large reservoirs (60.5% of state) is about 5.4 billon barrels.

Technical recovery in entire state is about 9 billion barrels from 45 billion barrels remaining. OOIP was 60 billion barrels.

Figure 1. Impact of Advanced Technology and Improved Financial Conditions on Economically Recoverable Oil from Oklahoma's Major Reservoirs Using CO_2-EOR (Million Barrels).



$25/barrel **$35/barrel**

Figure from Basin Oriented Strategies for CO2 Enhanced Oil Recovery: Oklahoma, March 2005

United States Environmental Protection Agency

Federal Rule-Making

120 day comment period

Federal Register

Friday,
July 25, 2008

Part II

Environmental Protection Agency

40 CFR Parts 144 and 146

Federal Requirements Under the Underground Injection Control (UIC) Program for Carbon Dioxide (CO_2) Geologic Sequestration (GS) Wells; Proposed Rule

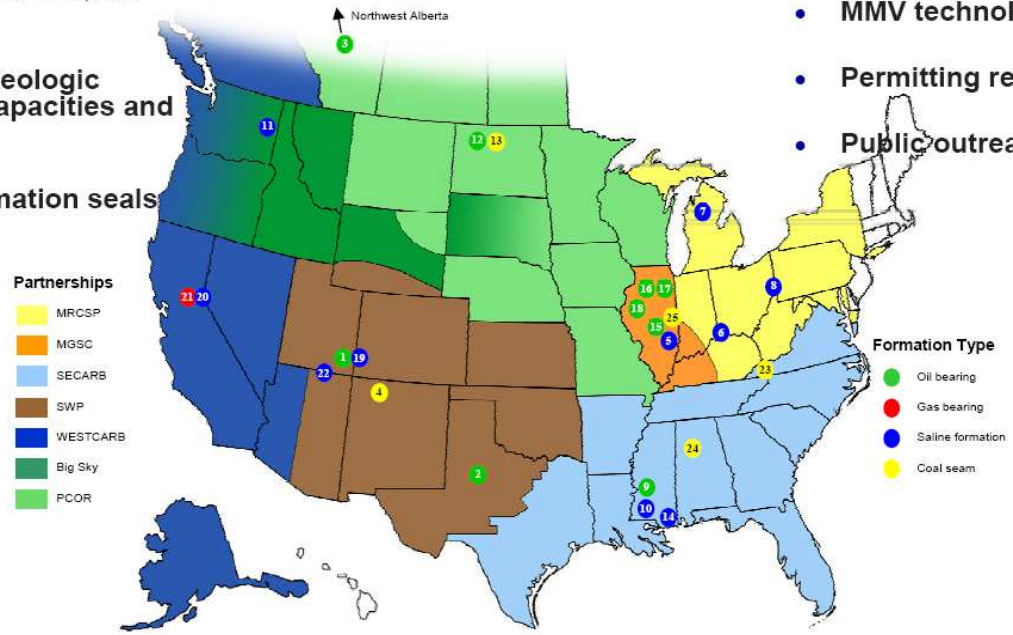
United States Environmental Protection Agency

DOE Research

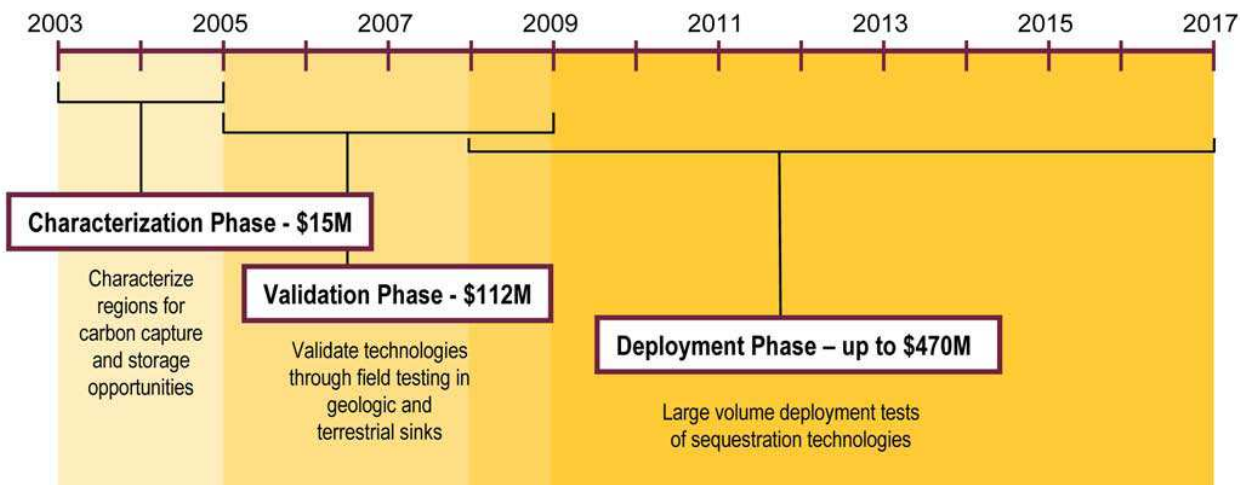
United States Environmental Protection Agency

Phase II Field Validation 25 Geologic Tests

- Injections 750-525,000 Tons CO_2
- Validating geologic formation capacities and injectivity
- Testing formation seals



- MMV technologies
- Permitting requirements
- Public outreach



United States Environmental Protection Agency

Summary of Potential Monitoring Tools

Onshore only | Offshore only | Onshore & Offshore | Primary use | Secondary use

				Deep	Shallow	Plume location/ migration	Fine scale processes	Leakage	Quantification
Seismic			3D/4D surface seismic	Primary	Secondary	Primary	Secondary	Secondary	Primary
			Time lapse 2D surface seismic	Primary		Primary	Secondary		
			Multicomponent seismic	Primary		Primary	Primary		
	Acoustic imaging		Boomer / Sparker		Primary	Secondary		Primary	
			High resolution acoustic imaging		Primary	Secondary		Primary	
			Microseismic monitoring			Secondary			
	Well based		4D cross-hole seismic	Primary		Secondary	Primary		Secondary
			4D VSP	Primary		Secondary	Primary		
Sonar Bathymetry			Sidescan sonar		Primary			Primary	
			Multi beam echo sounding		Primary			Primary	
Gravimetry			Time lapse surface gravimetry	Primary		Secondary			Secondary
			Time lapse well gravimetry	Primary			Secondary		
Electric / Electro - magnetic			Surface EM	Secondary	Primary	Secondary		Secondary	
			Seabottom EM	Primary	Primary	Secondary			
			Cross-hole EM	Primary			Secondary		
			Permanent borehole EM	Primary			Secondary		
			Cross-hole ERT	Primary			Secondary		
			ESP	Primary	Secondary	Primary		Secondary	
Geochemical	*Fluids*	Down - hole / Springs	Downhole fluid chemistry	Primary	Primary		Secondary	Primary	Secondary
			PH measurements	Primary	Primary		Secondary	Primary	Secondary
			Tracers	Primary	Primary		Secondary	Primary	Secondary
		Marine	Seawater chemistry		Primary			Primary	Secondary
	Gasses		Bubble stream chemistry		Primary			Primary	Secondary
		Atmos-phere	Short closed path (NDIRs & IR		Primary			Primary	Secondary
			Short open path (IR diode lasers)		Primary			Primary	Secondary
			Long open path (IR diode lasers)		Primary			Primary	Secondary
			Eddy covariance		Primary			Primary	Secondary
		Soil gas	Gas flux		Primary			Primary	Secondary
			Gas concentrations		Primary			Primary	Secondary
Ecosystems			Ecosystems studies		Primary			Primary	
Remote sensing			Airborne hyperspectral imaging		Primary			Primary	Secondary
			Satellite interferometry	Primary		Primary			
			Airborne EM		Primary			Primary	
Others			Geophysical logs	Primary			Primary		Secondary
			Pressure / temperature	Primary				Primary	Secondary
			Tiltmeters	Primary	Secondary	Secondary	Secondary		

From CO2STORE, 2007

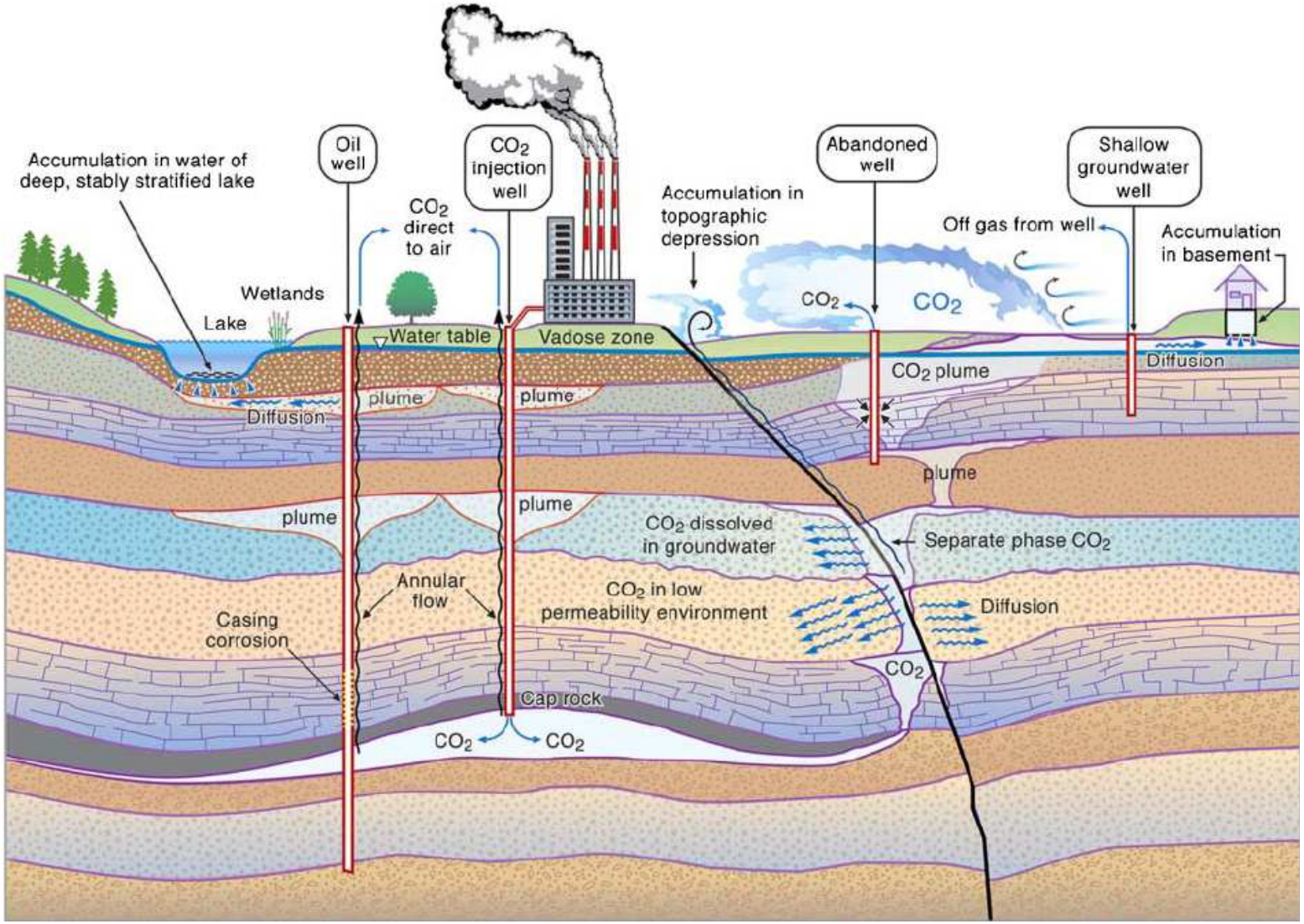
United States
Environmental Protection
Agency

Research at R.S. Kerr Research Center

Potential Leakage Pathways and Consequences

United States Environmental Protection Agency

From Benson and Hepple (2005)



Use Soil-Gas, Gas Flux, and Ground-Water Monitoring to Evaluate the Potential Leakage from Well Penetrations (NRMRL-Ada)

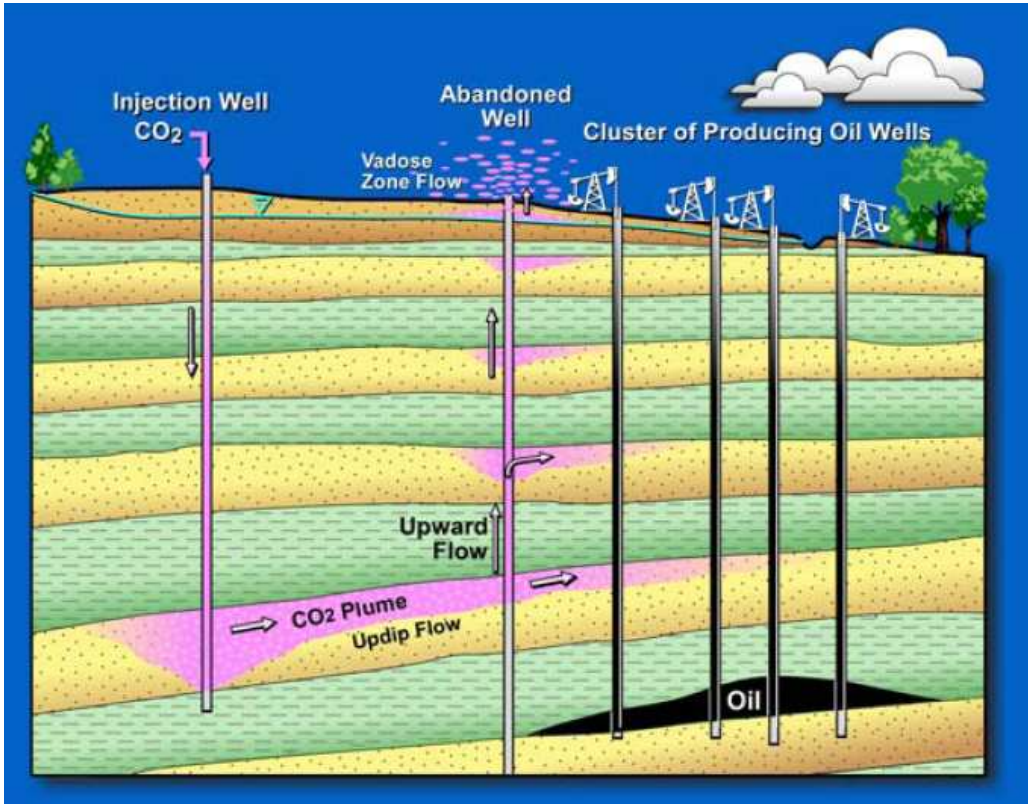


Figure from Celia et al. (2006)

Use soil-gas, gas flux, and ground-water monitoring of C1-C4 hydrocarbons, CO_2, δ13C, Δ14C, H_2, He, H_2S, ^{222}Rn, major ions, pH, and inorganics to evaluate the presence of existing migration pathways.

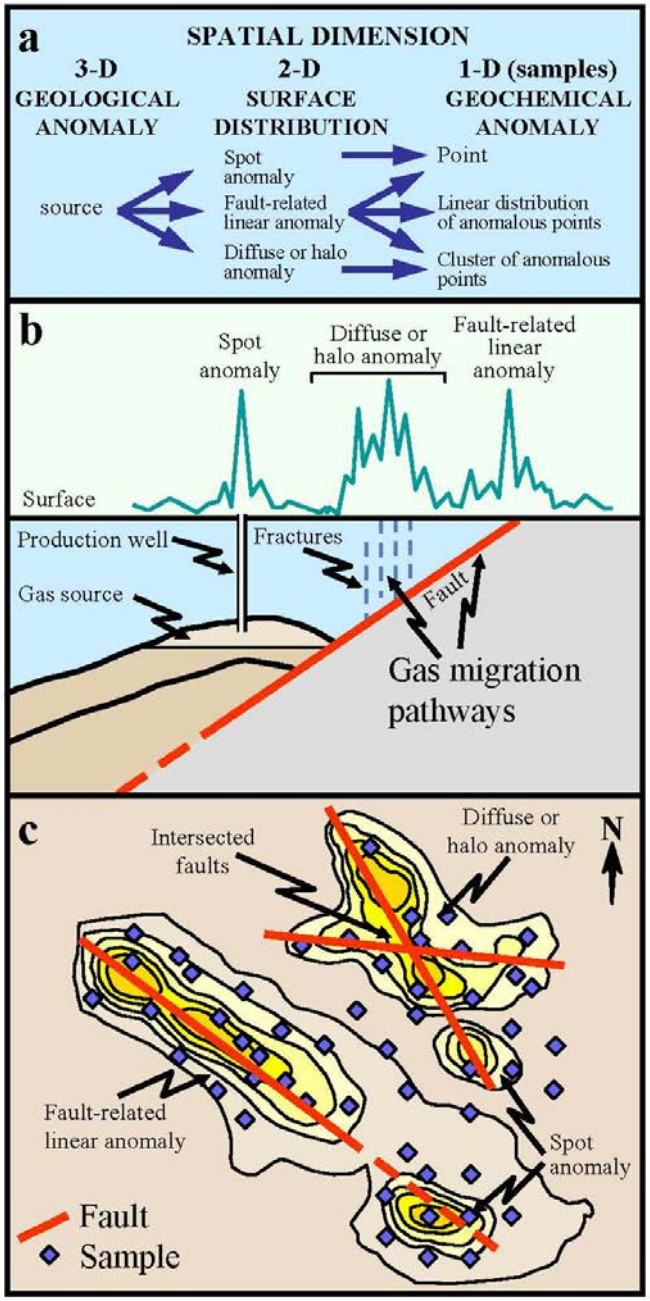


Figure modified from Ciotoli et al., (2004).

United States Environmental Protection Agency

Evaluate Impacts to USDWs due to Carbon Dioxide Release from Geologic Sequestration Projects: Modeling and Experimental Studies (NRMRL-Ada)

- Conduct column and batch-scale studies from formation (USDW) samples collected from test sites.
- Examine and simulate element partitioning and associated kinetics between the solid and aqueous phase over a range of CO_2 partial pressures.
- Where appropriate, modify geochemical databases with the most current thermochemical data.
- Use results to prepare sampling strategies for a controlled CO_2 injection field study.

United States Environmental Protection Agency

Use semi-analytical solutions to create a user-friendly, open-source software package to allow a rapid, inexpensive, first-order determination of the Area of Review

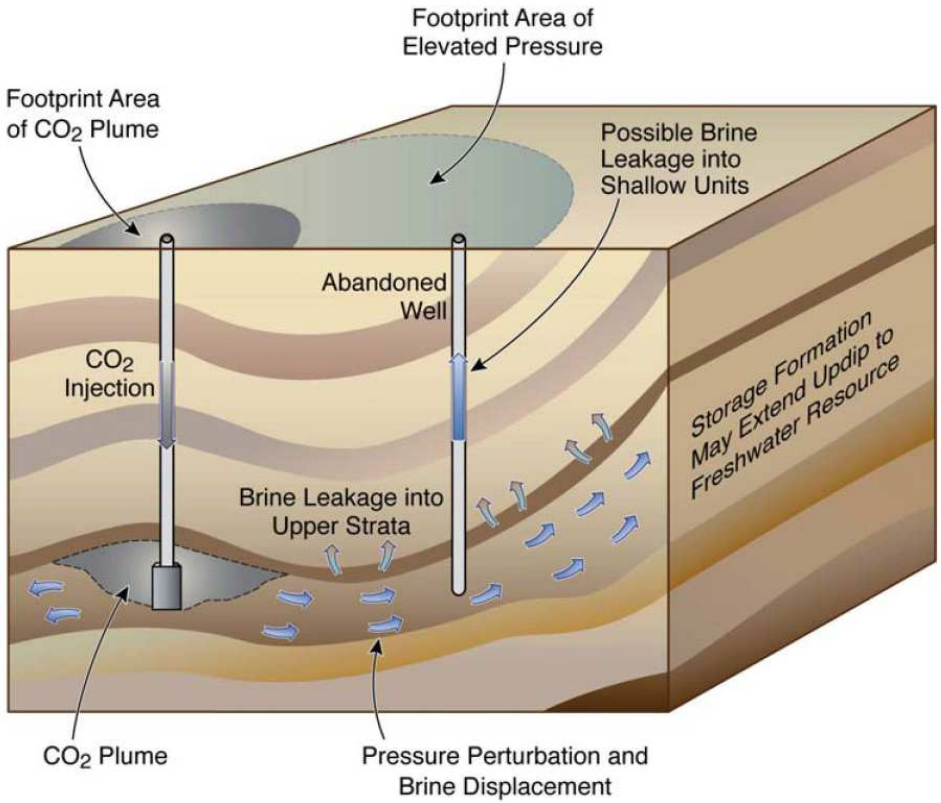
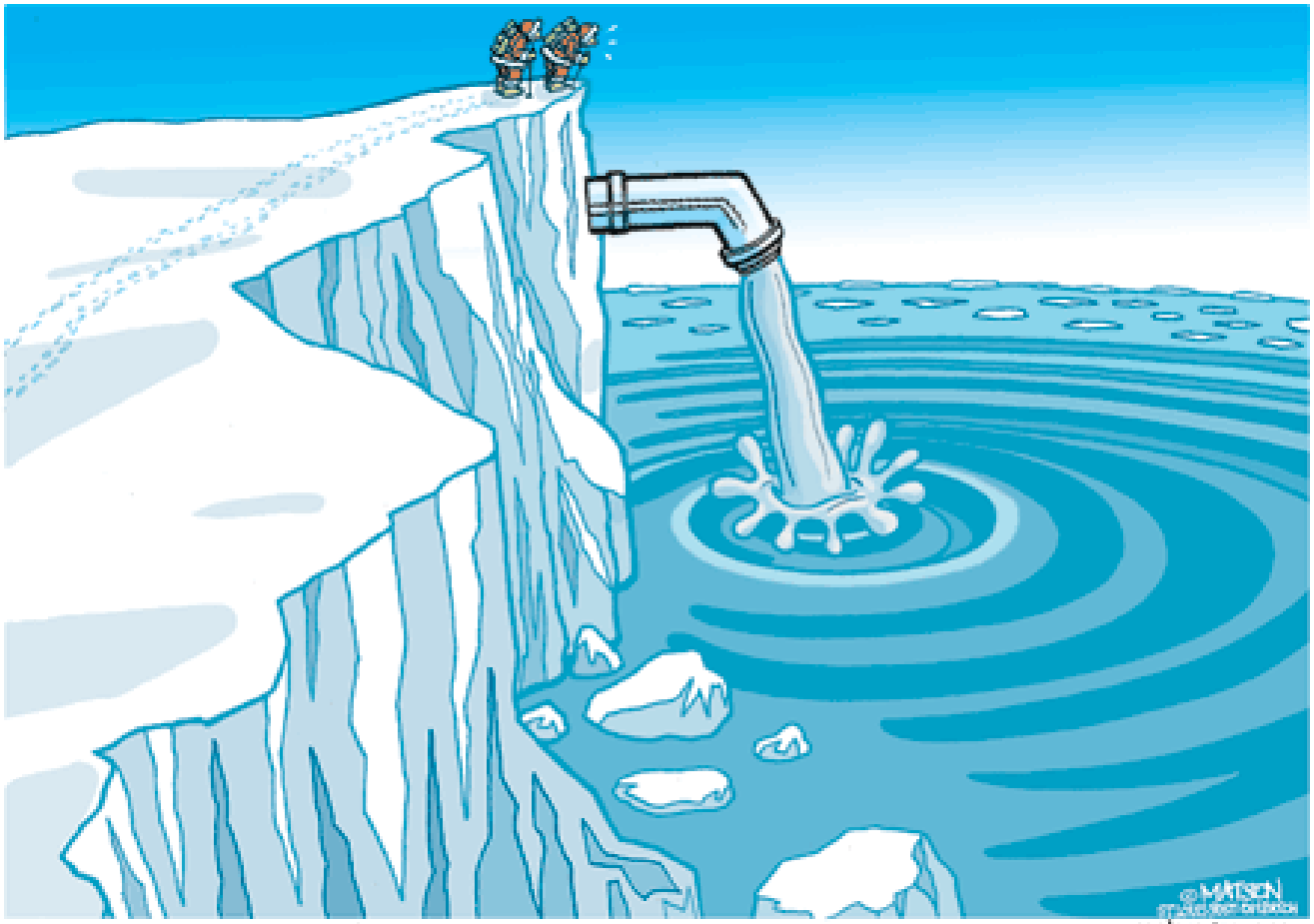


Figure from Birkholzer et al., 2008

- Solutions will complement not replace need for numerical analysis.
- Can be used for designing monitoring strategies (e.g., pressure perturbation in overlying permeable formation).
- Computationally more efficient for evaluating leakage through abandoned wells

United States Environmental Protection Agency

Questions?



"HOW ON EARTH DO WE TURN IT OFF?"