Feasibility of CO_2 Sequestration in Deep Saline Reservoirs in the Midwestern USA

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Acknowledgements

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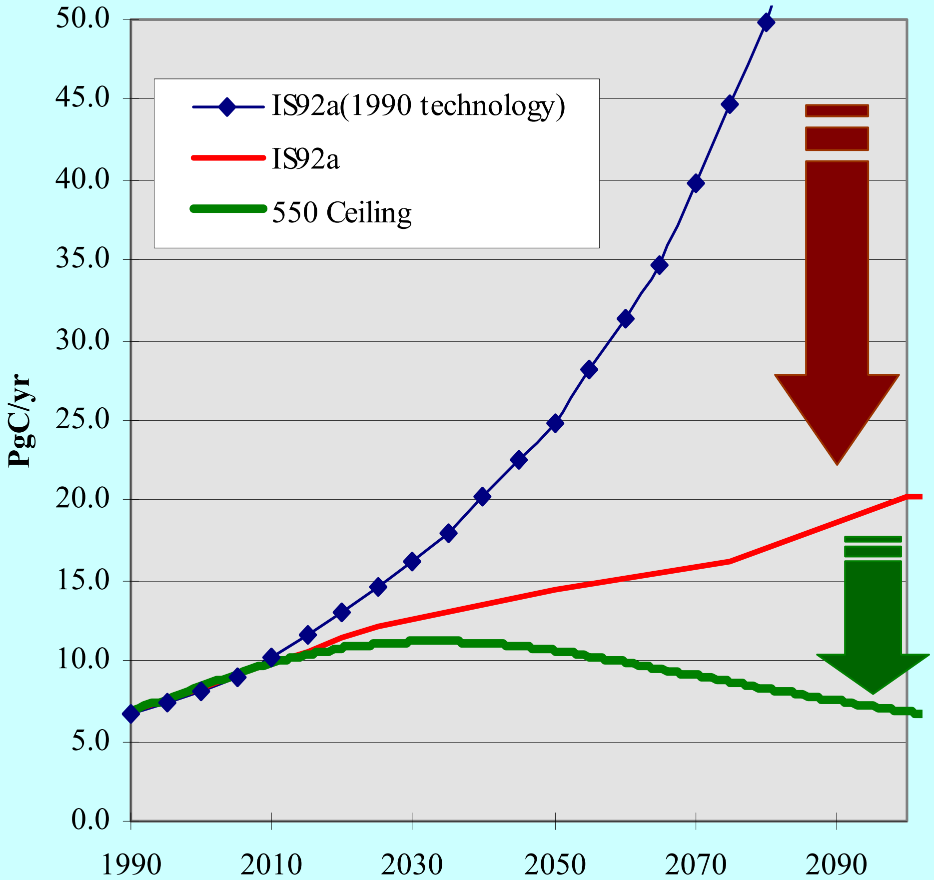
Presentation Outline

- Carbon Mitigation Background (from Edmonds et al.)
- Regional Setting and Capacity
- Site-Specific Reservoir Simulations
- Geochemical Aspects
- Regional Seismic Aspects
- Engineering and Economic Aspects

Energy Technologies Currently in the Pipeline Are Not Enough for CO_2 Stabilization



Based on Work by Edmonds et al. at Battelle/PNNL

This gap could be filled by <u>fully developed</u>:

Solar

Nuclear

Efficient Fossil Electric

Advanced Transportation

End Use Efficiency

<u>But stabilization requires additional Carbon S&T!</u>

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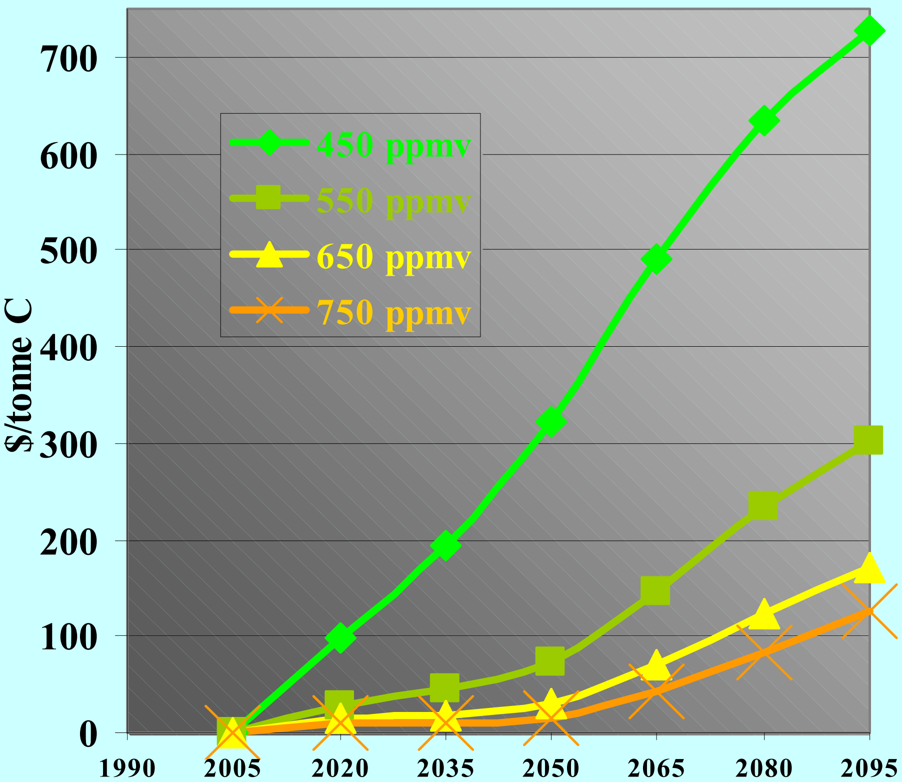
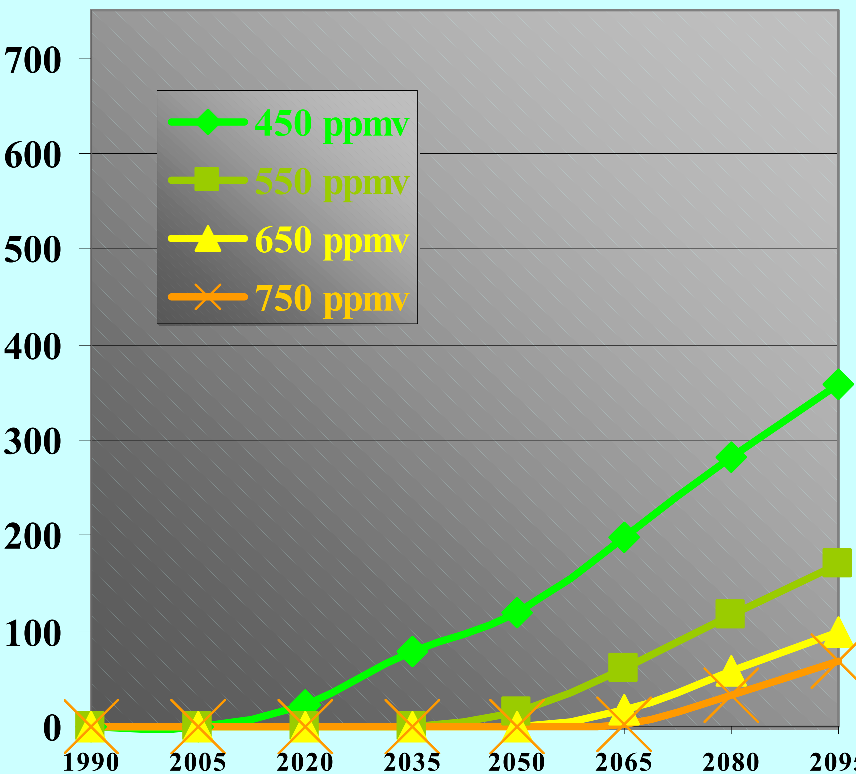
Modeling Carbon Sequestration

Value of Carbon Permit Prices 2005 to 2095 (CBF)

Energy Technologies Only



With Capture & Sequestration



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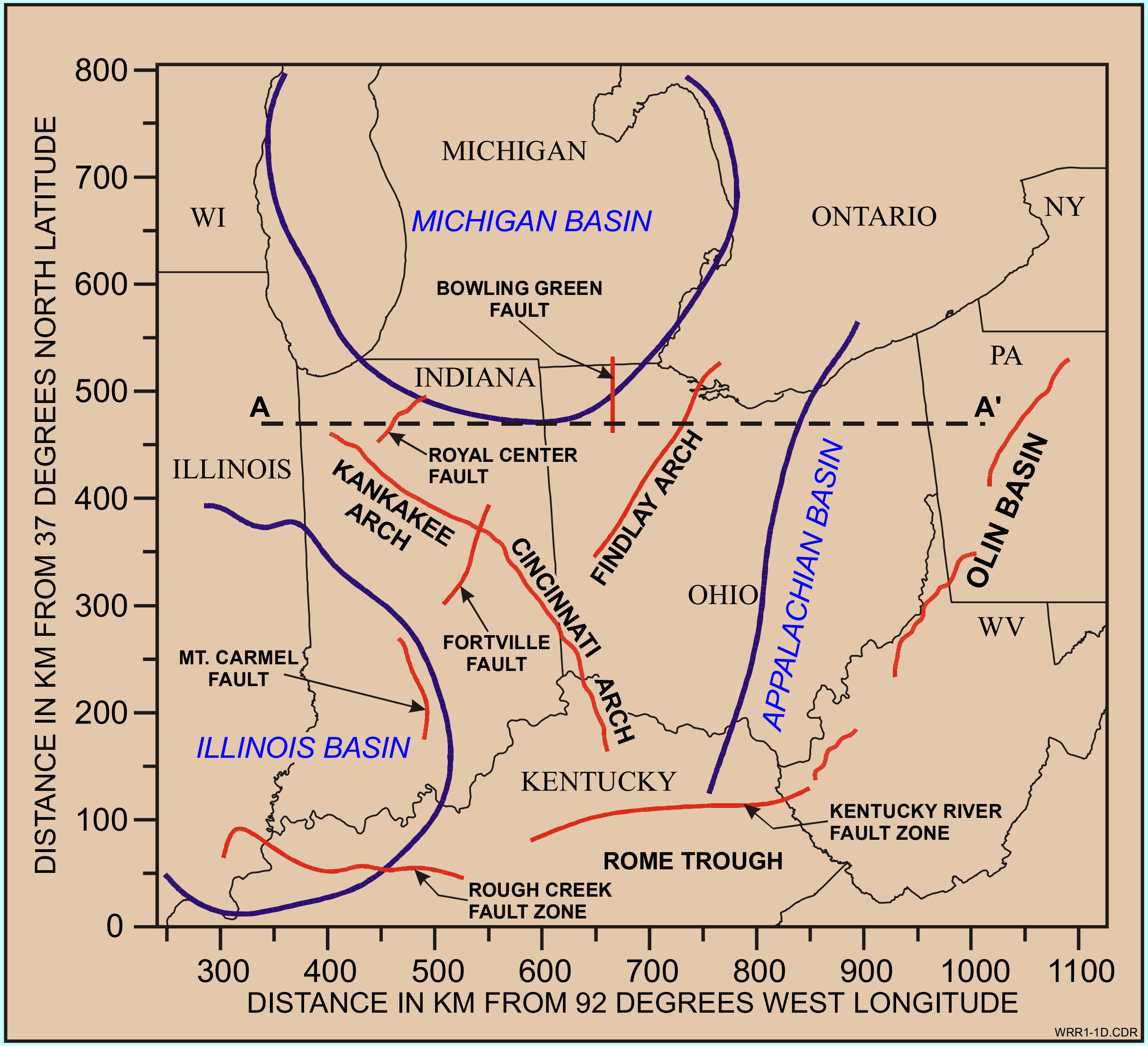
Geographic And Geologic Features in Midwestern USA



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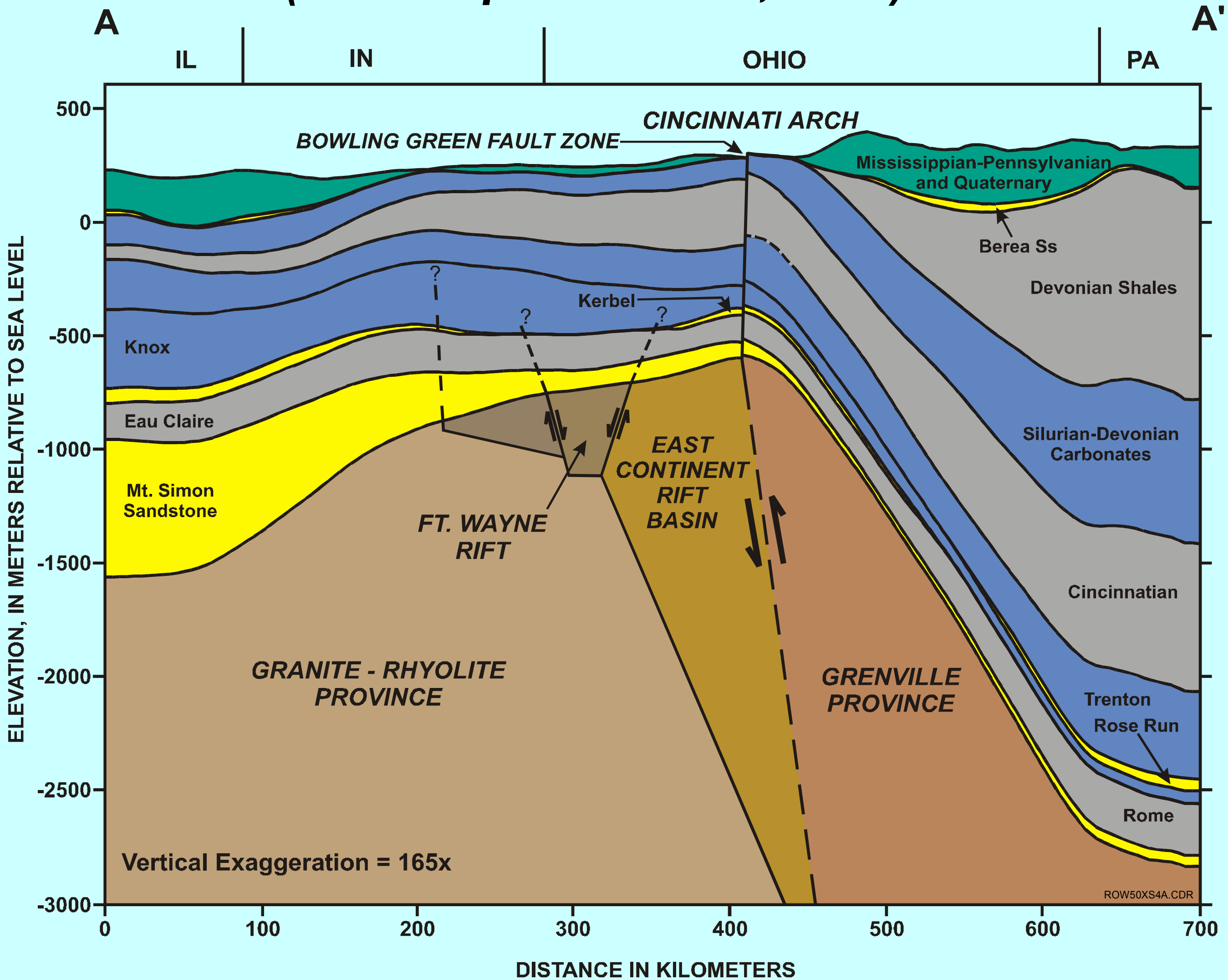
East-West Geologic Cross-Section Through Midwestern U.S. Showing Major Sedimentary Units
(after Gupta and Bair, 1997)



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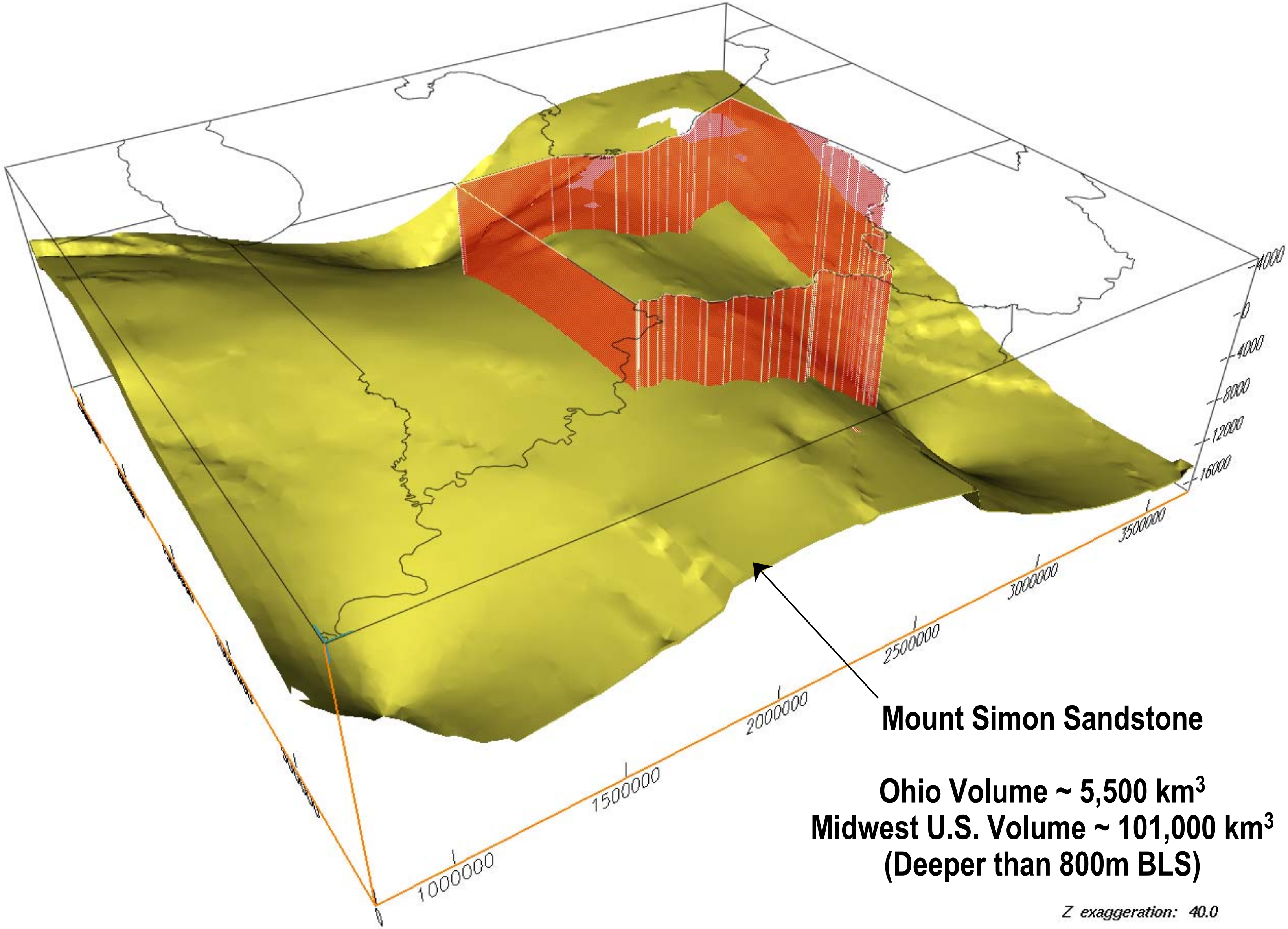
3D Block Diagram of Mount Simon Sandstone

(Ohio is outlined with red polygon curtain)



Ohio Volume ~ 5,500 km^3
Midwest U.S. Volume ~ 101,000 km^3
(Deeper than 800m BLS)

X,Y,and Z ScaleBar units = Feet

Regional CO_2 Storage Capacity Calculation for Mt. Simon and Rose Run Sandstones

Storage Capacity = Vp x Storage Efficiency x density of CO_2
(Joule II Report)

- Vp = Bulk aquifer volume x Net:Gross x Porosity
- Bulk aquifer volume from regional geologic data
- Net:Gross = 50 to 95%
- Porosity = 5 to 15%
- Storage efficiency = 6%
- Density of CO_2 = 700 kg/m^3

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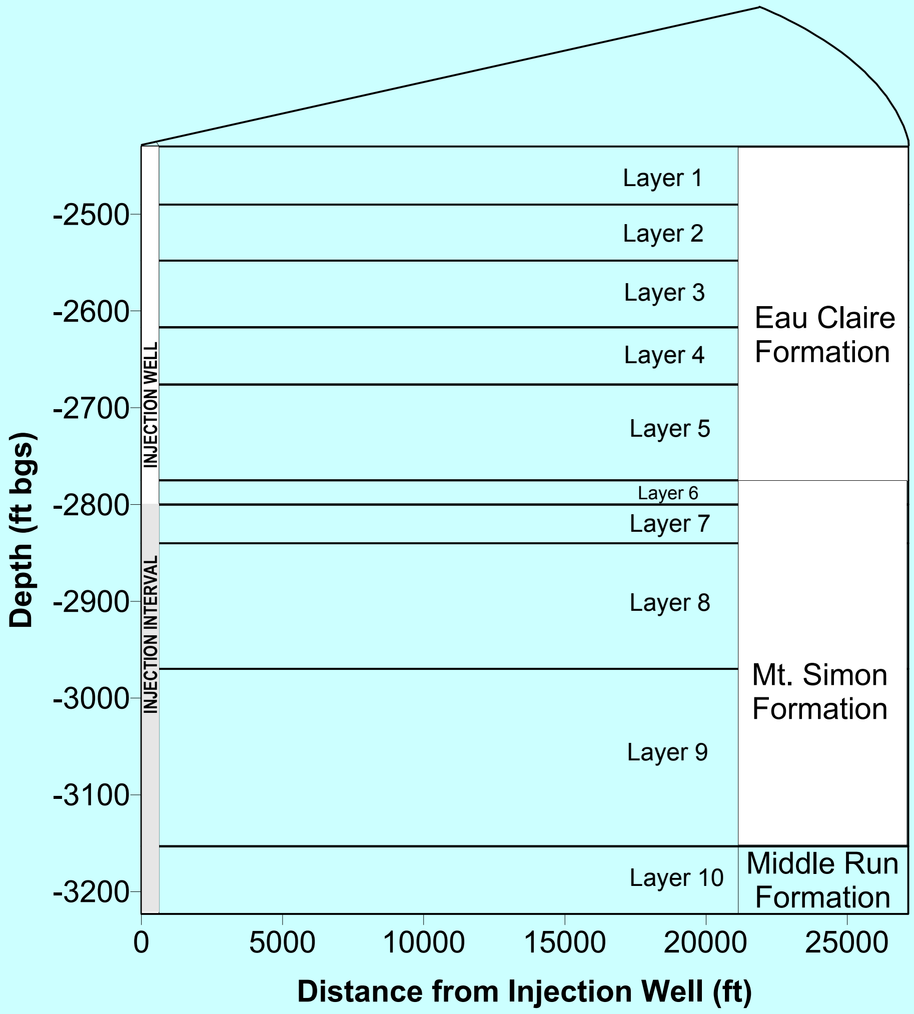
Estimated Regional CO_2 Storage Capacity

- Based on Joule II equation for continuous reservoirs:
  - Mt. Simon Sst. (Ohio) 6 – 34 Gt
  - Mt. Simon Sst. (Midwest) 115 – 655 Gt
  - Rose Run (Ohio) 1.5 – 8.6
  - Rose Run (Midwest) 8.5 - 48
- Bergman and Winter Estimate (U.S.) 5 - 500 Gt
- Power Plant Emissions (Ohio) ~150 Mt/Yr
- Conclusion: There is enormous potential capacity on a regional scale
- Note: Rose Run is a source of oil/gas

Flow and Transport Models

- More realistic estimates require local-scale evaluation using computer simulations:
  - Simulate pressure variations, fracture pressure limitations, and zone of influence
  - Evaluate injection capacity
  - Fluid density and viscosity effects
  - Lateral and vertical movement of CO_2
  - Containment time
- UTCOMP compositional code, modified by Dr. Peng Wang, was used

Radial Reservoir Model



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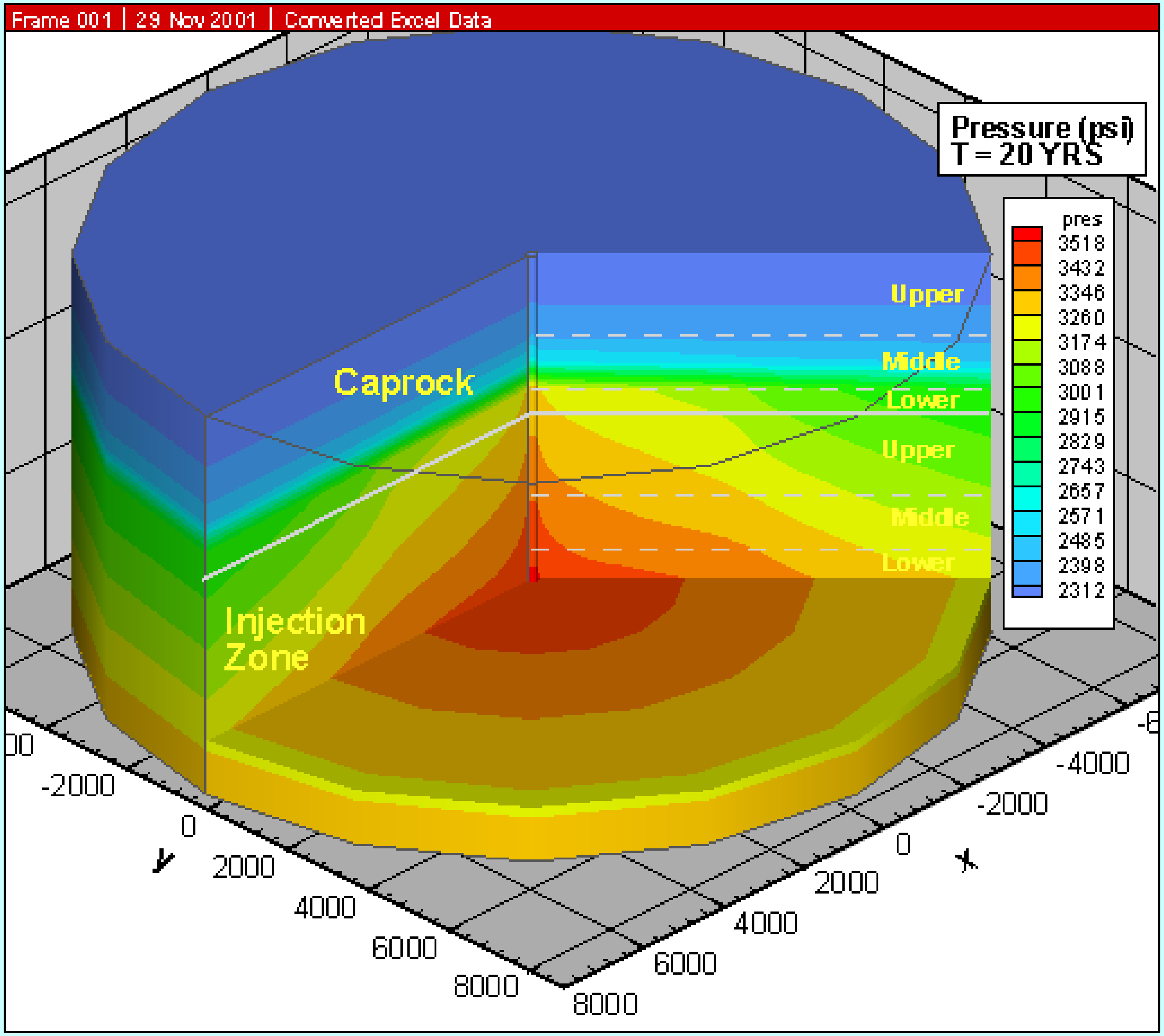
Example of Simulated Pressure Distribution



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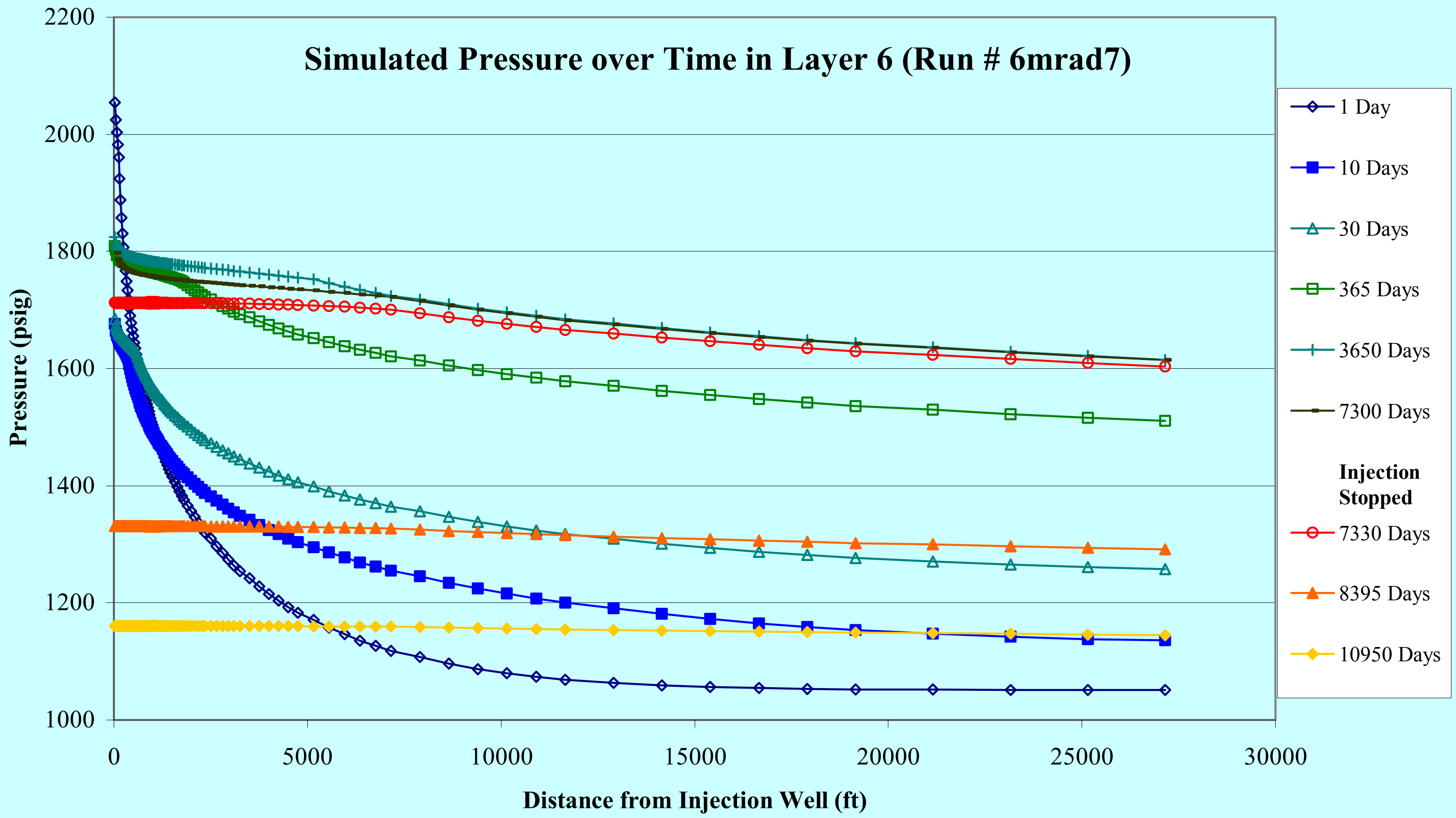
Example of CO_2 Simulated Pressure Profiles



Maximum injection rates and caprock integrity are affected by pressure increase

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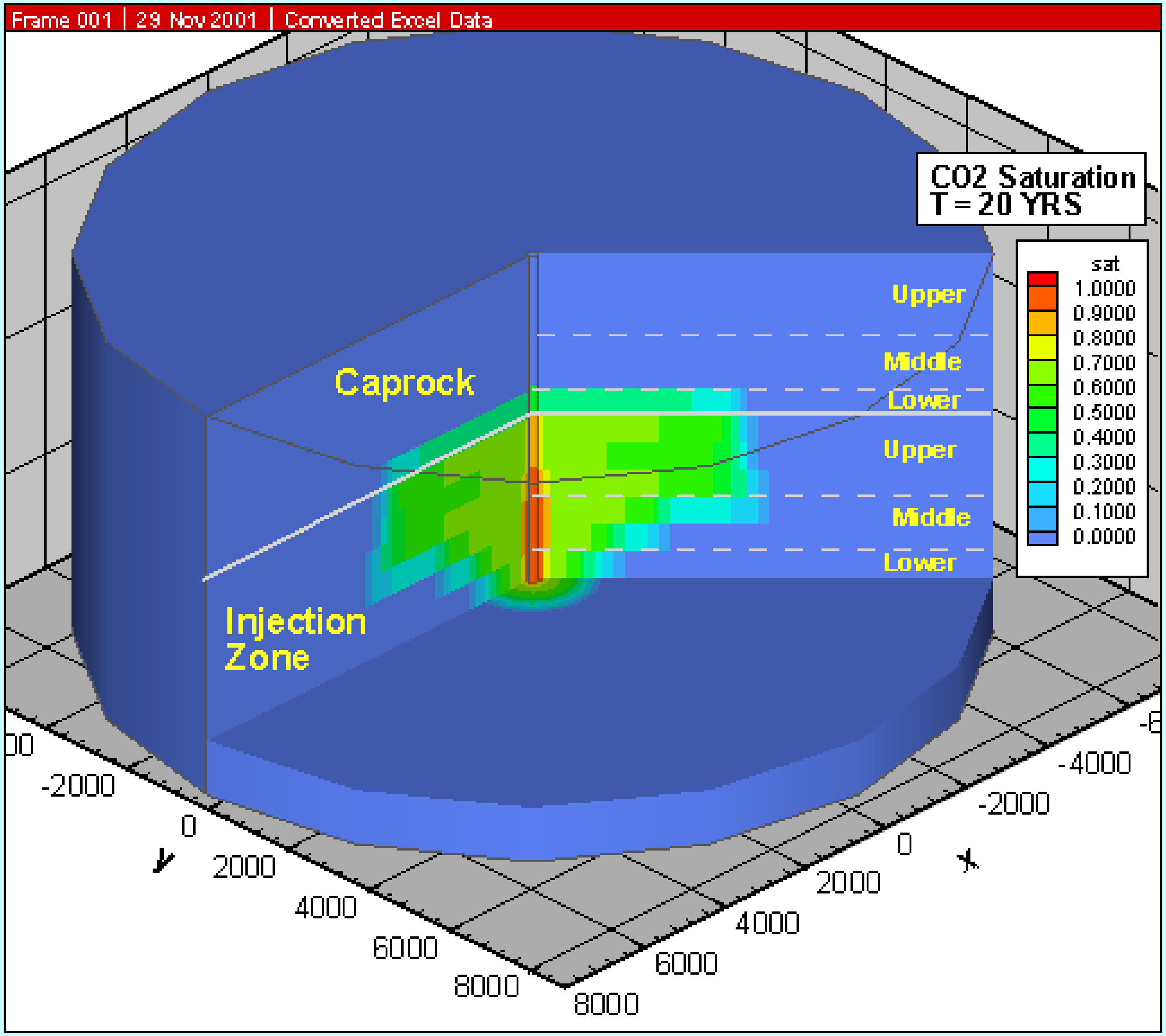
Example of Simulated CO_2 Phase Saturation



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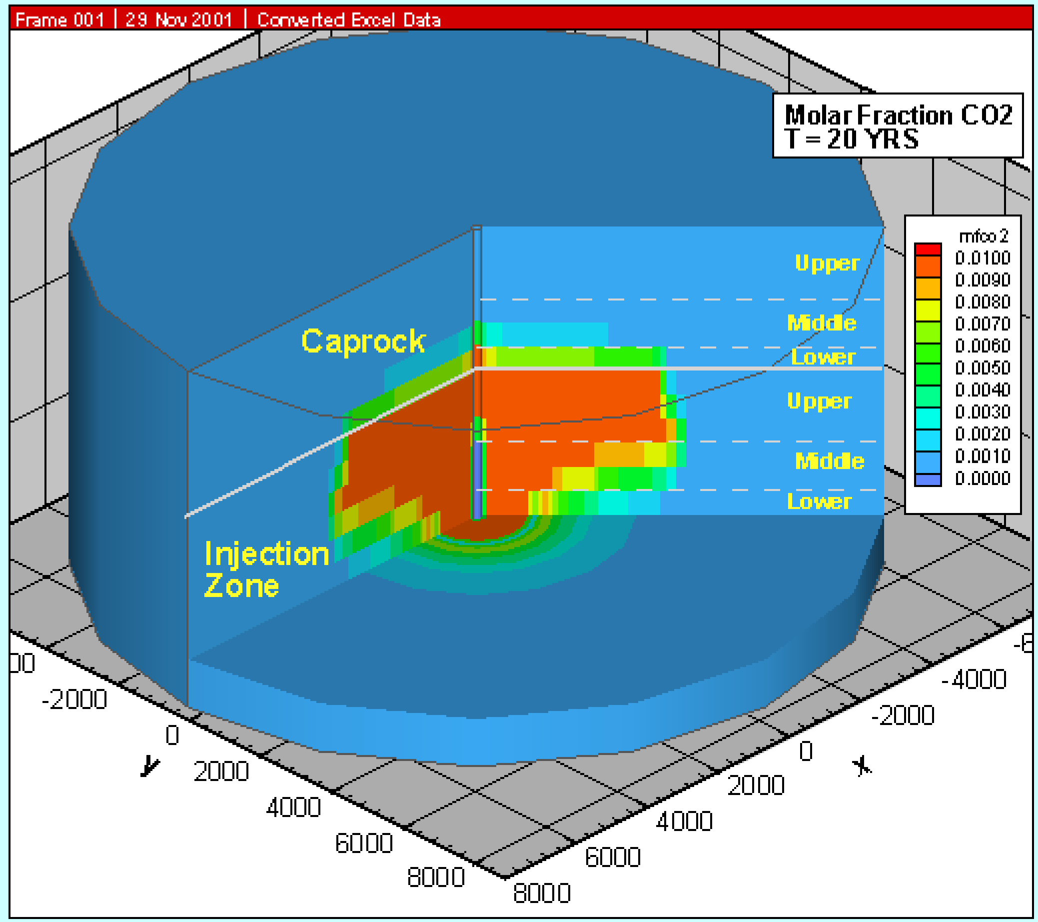
Simulated Dissolved CO_2 Distribution

Function of Pressure, Temperature, Salinity

Simulated Dissolved % about 4-6%,

Increases Slowly Over Time

Typical CO_2 Mole Fraction ~0.009 (2.3%)

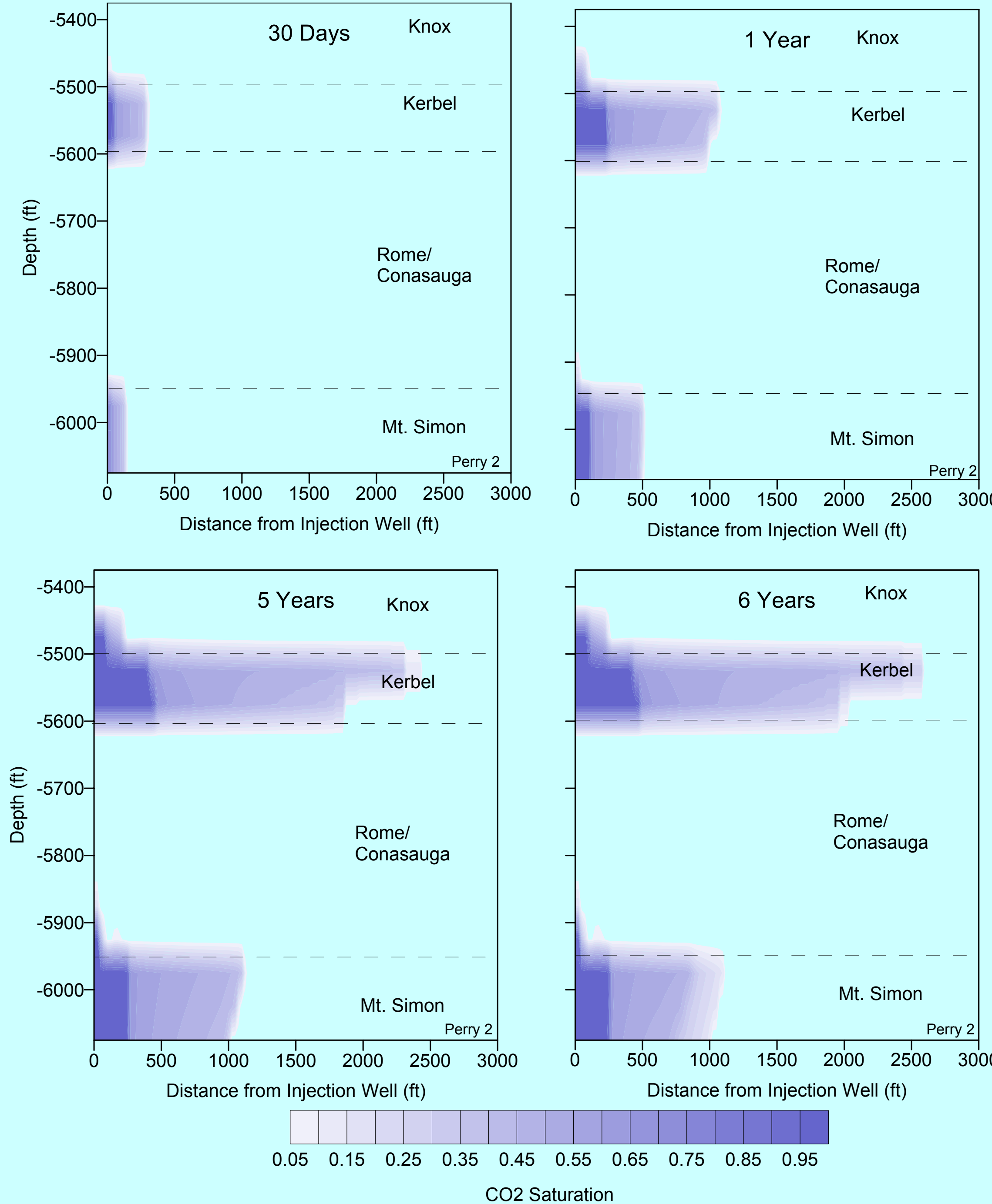


CO_2 Phase Saturation for NE Ohio Simulation

Constant Pressure Injection

Injectivity ~ 206,000 ton/yr

Injectivity may be increased with Enhanced k



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Geochemistry Objectives

- Perform laboratory experiments to determine the potential for long-term sequestration of CO_2 in the Mt. Simon sandstone.
- Corroborate the experimental results by modeling the interaction of CO_2, brine, and pure mineral phases at the same P-T conditions.

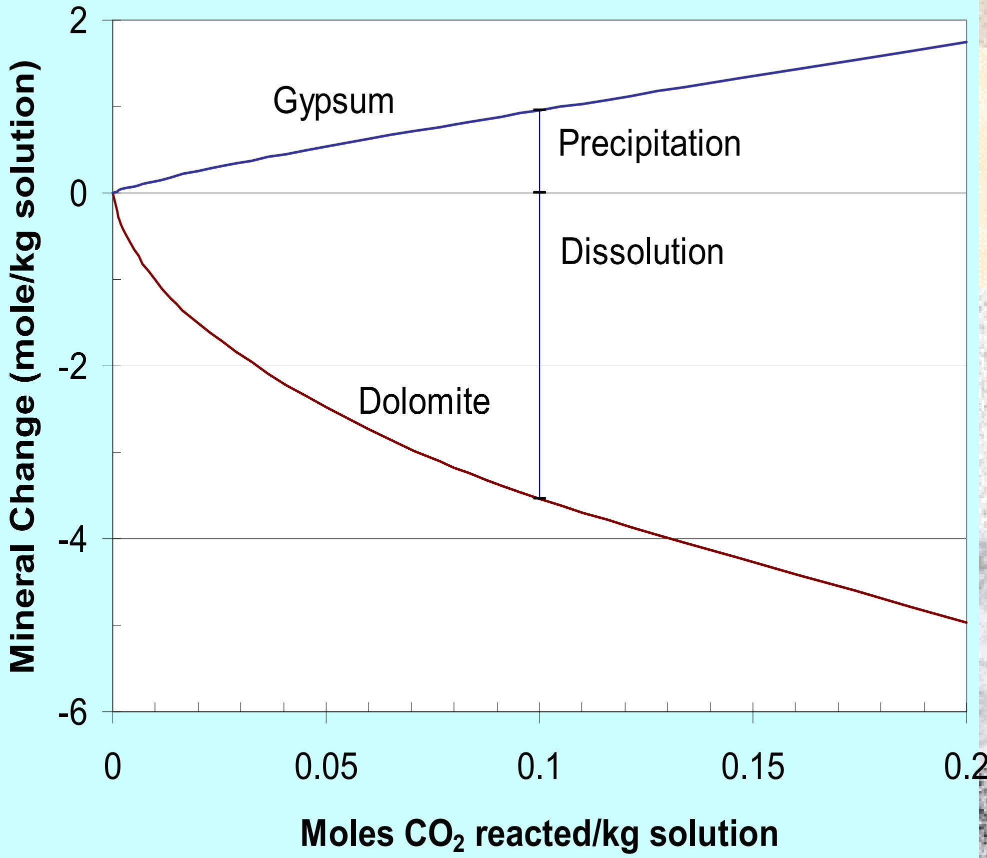
Potential Reactions Between CO_2 and Minerals

In the absence of iron or calcium-bearing mineral phases, geochemical modeling predicts dolomite dissolution and gypsum precipitation according to the following reaction stoichiometry:

$$\textbf{Dolomite} + 2CO_2 + 4H_2O + SO_4^{-2}$$

$$\rightarrow \textbf{Gypsum} + 4HCO_3^{-} + Mg^{+2}$$

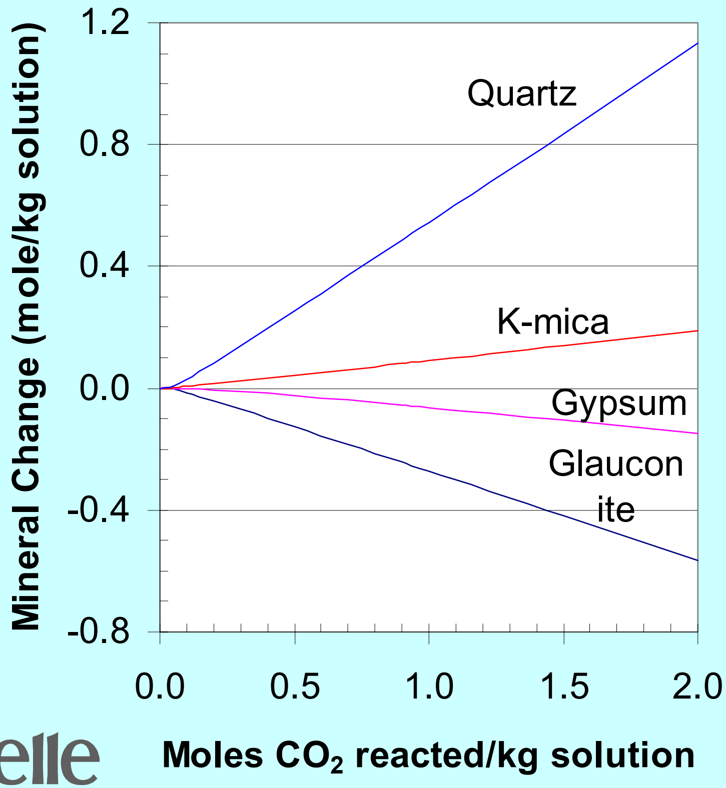
Note that 2 moles of CO_2 are converted to aqueous carbonate species for each mole of dolomite consumed

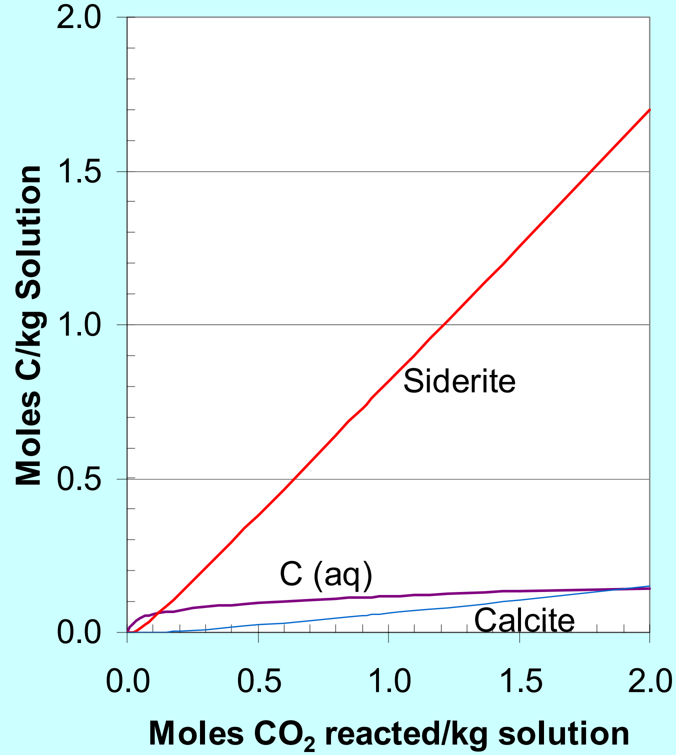


Potential Reactions Between CO_2 and Minerals

Glauconite, an iron-bearing phase, may react with CO_2 to form siderite. Geochemical modeling predicts the following changes in mineralogy:

◆Dissolution of glauconite and gypsum (if present) and Precipitation of siderite, K-mica, and silica (quartz), <u>leading to permanent sequestration of carbon</u>.





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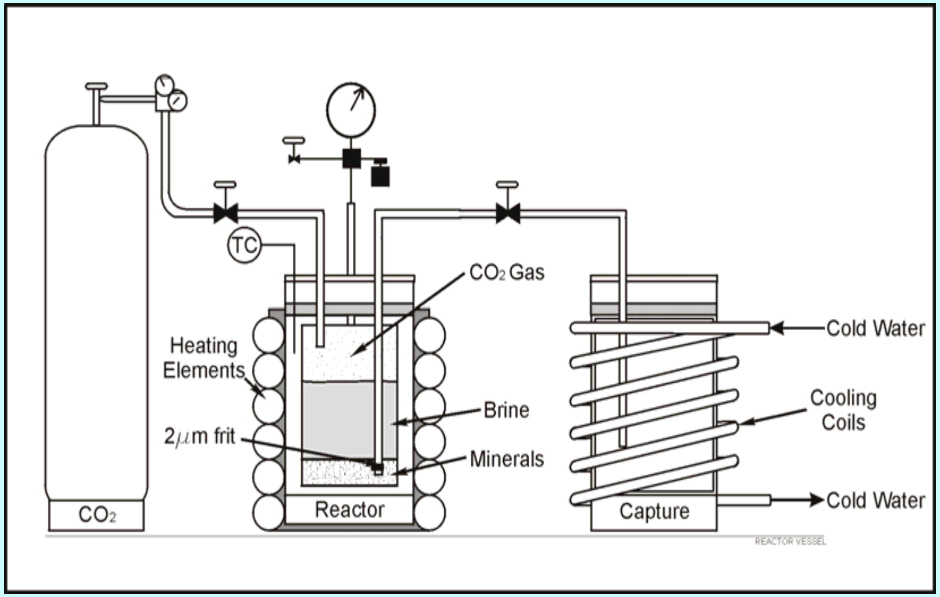
Design for Mineral Equilibration Runs

Typical Experimental Conditions:

- 50 – 150 ºC
- 2000 – 2500 psi
- Variable P-CO_2
- Variable P-SO_2
- Natural rock cores
- Pure minerals
- Monitor gas & liquid
- Bulk and surface analysis of solid phases



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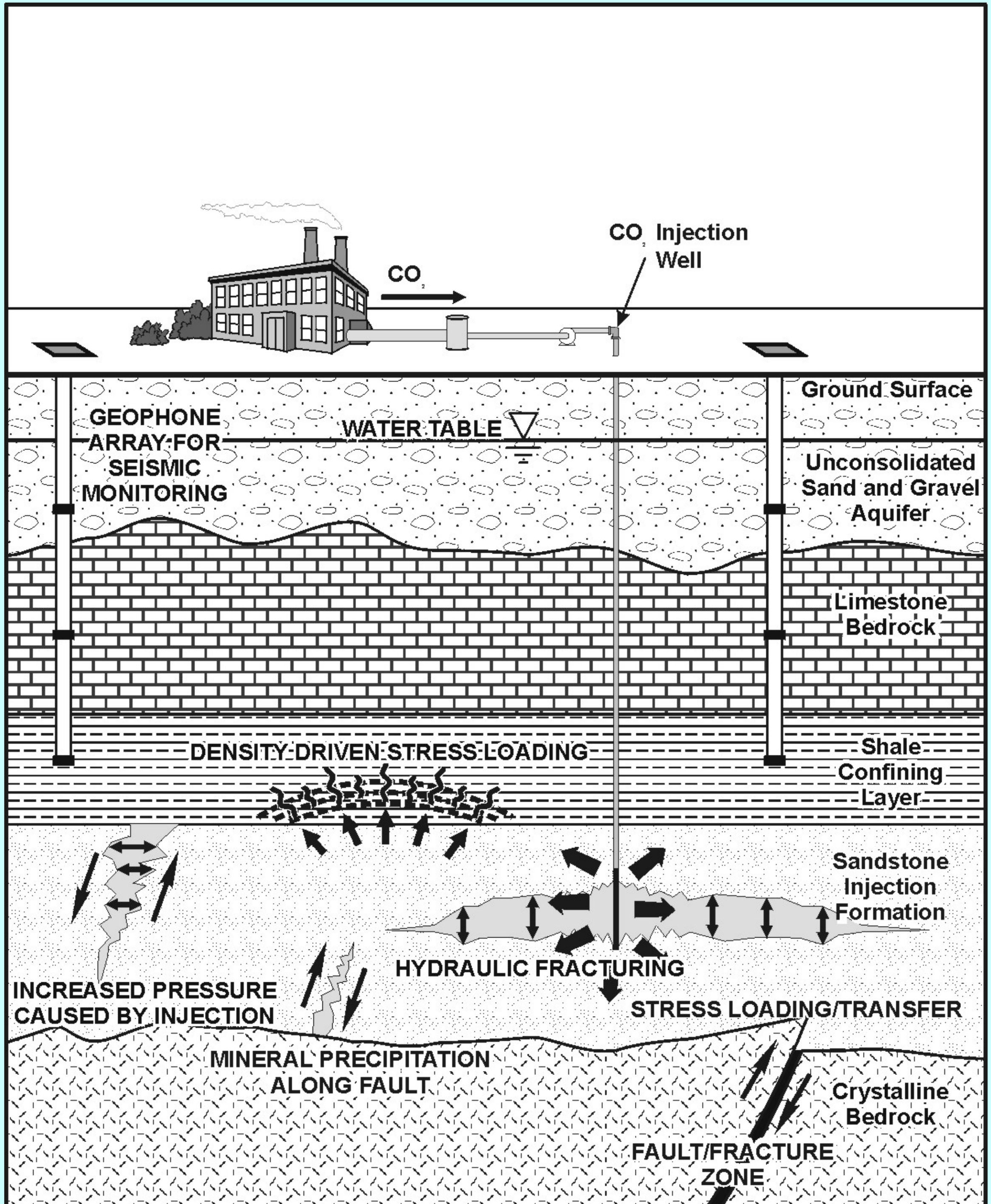
Materials used in Experiments

- Mt. Simon Sandstone
- Rome Dolomite and Eau Claire Shale
- Frio Formation (Gulf Coast)
- Pure Anorthite
- Mixtures with pure glauconite, kaolinite and montmorillonite.
- Temperatures between 50 and 150°C
- Pressure up to 2200 psi
- Pure CO_2 and mixtures of CO_2/SO_2

Key Conclusions of Geochemical Investigation

- Experiments with Mt. Simon sandstone (host rock) reveal no adverse consequences of interaction with CO_2.
- Experiments to verify mineral trapping show progress toward that end, but are generally too slow to be accomplished during short time periods (< 1 year).
- Geochemical modeling predicts mineral dissolution behavior and was used to assess carbonate precipitation under equilibrium conditions.
- Enhancements in experimental design are expected to speed reaction progress.

Induced Seismicity



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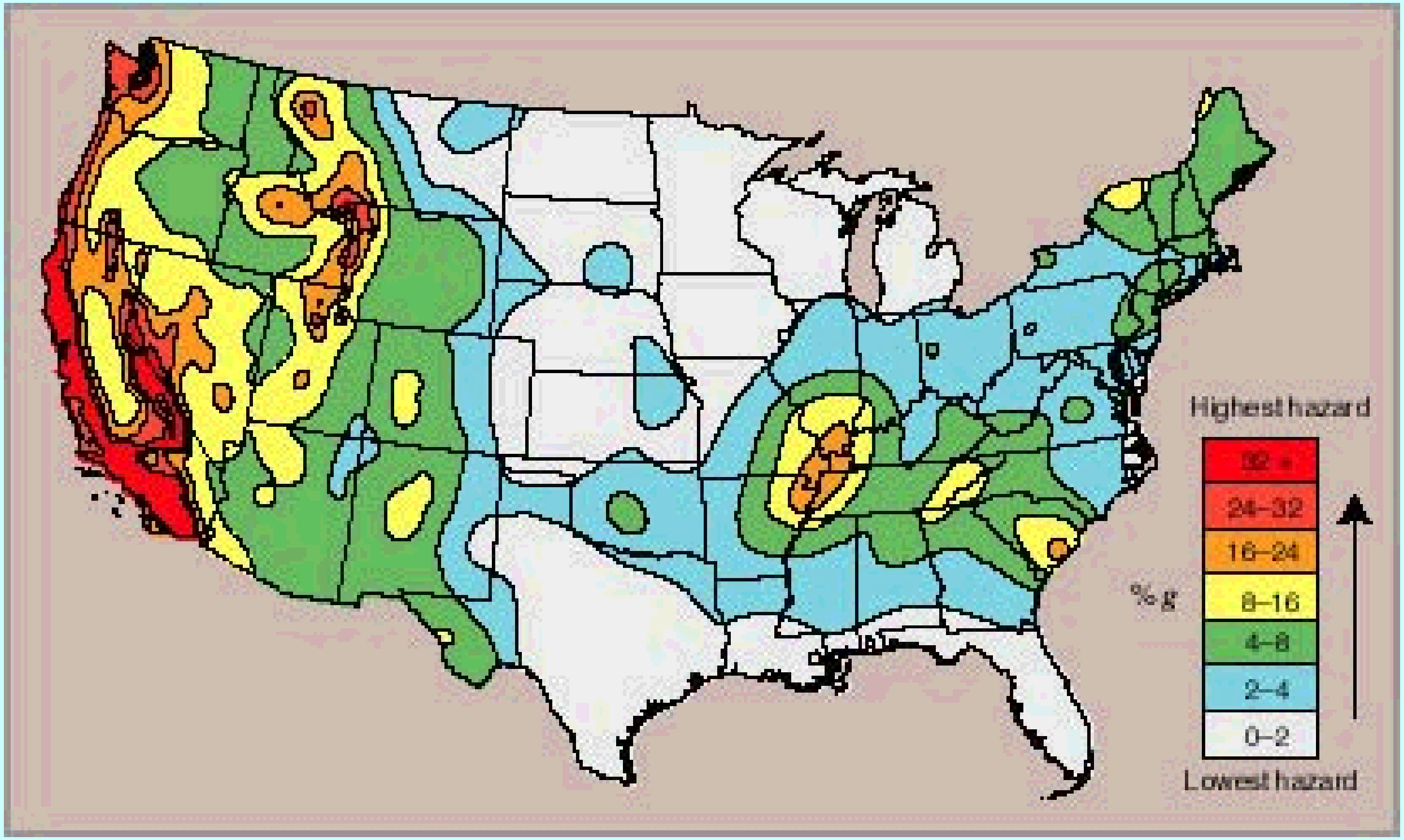
Seismic Hazard Map for the United States
(USGS National Seismic Hazard Mapping Project)



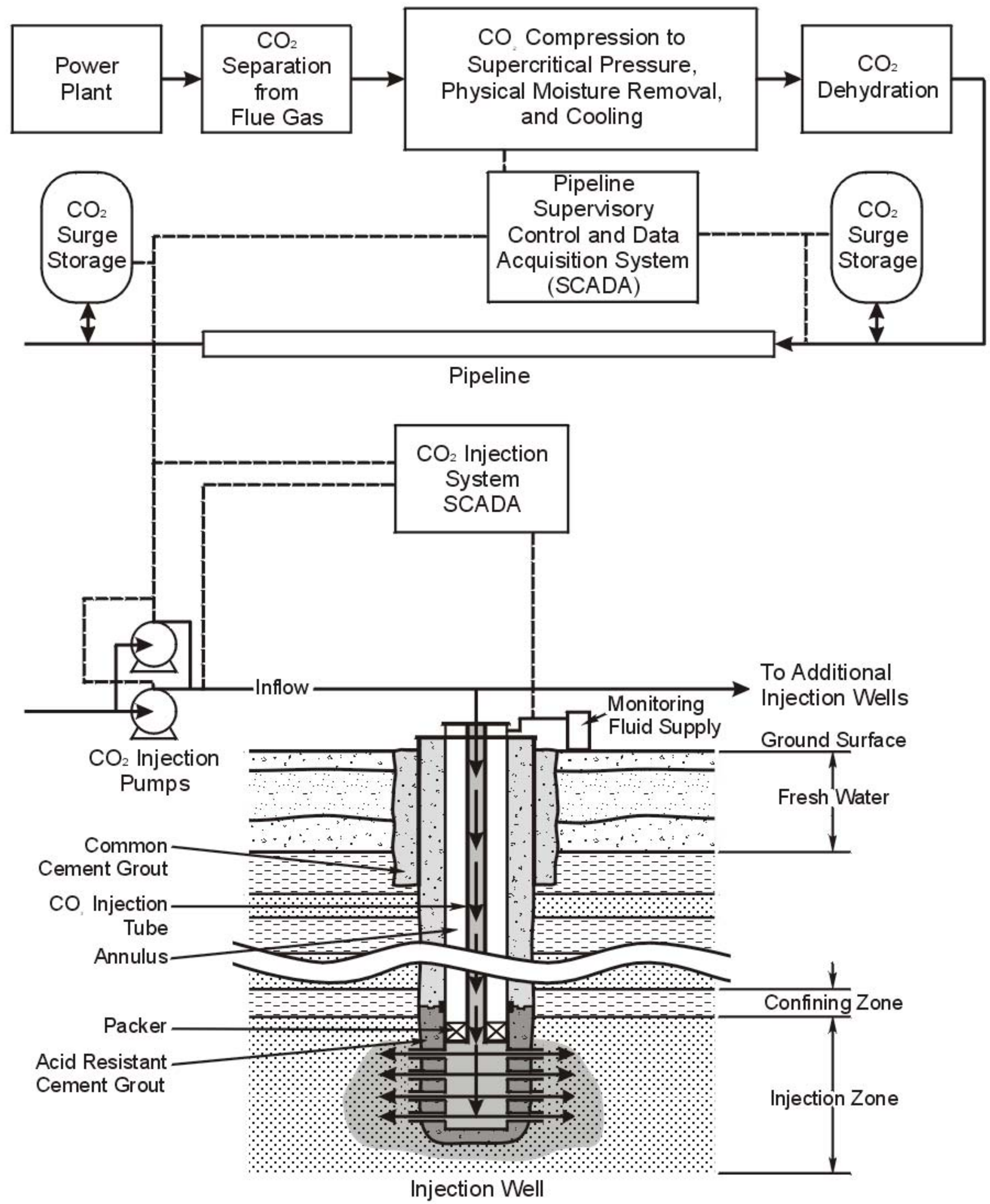
Seismic Evaluation Summary

- Seismic activity induced by deep well disposal of CO_2 is a real possibility under certain conditions.
- Most seismic activity caused by deep well injection is the result of frictional failure along previously faulted rocks.
- Formation weakening, mineral precipitation, and density driven stress loading should also be evaluated in light of the special properties of supercritical CO_2.
- Through proper siting, testing, and monitoring, induced seismicity may be prevented.
- Areas in the central, midwestern, and southeastern United States are generally seismically suitable for deep well injection of CO_2 However, site-specific assessment must be performed.

Engineering and Economic Analysis

- Capture CO_2 from the flue gas from 4 types of plants
- Preparation of the CO_2 for transmission as a supercritical liquid (compression and dehydration)
- Transmission of the CO_2 through a pipeline
- Injection of the CO_2 into a suitable aquifer
- Sensitivity Analysis
  - Power plant types PC, Coal with O_2, IGCC, NGCC
  - Transportation distance 15, 100, and 400 km
  - Injection depth 1,000, 2,000, and 3,000 m
  - Normal, hilly/rocky, and urban terrain

CO_2 Storage System Components



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Coal-Fired Plant Cost Breakout

Annualized Cost for 500 MWe Plant and 25 Years of Operation

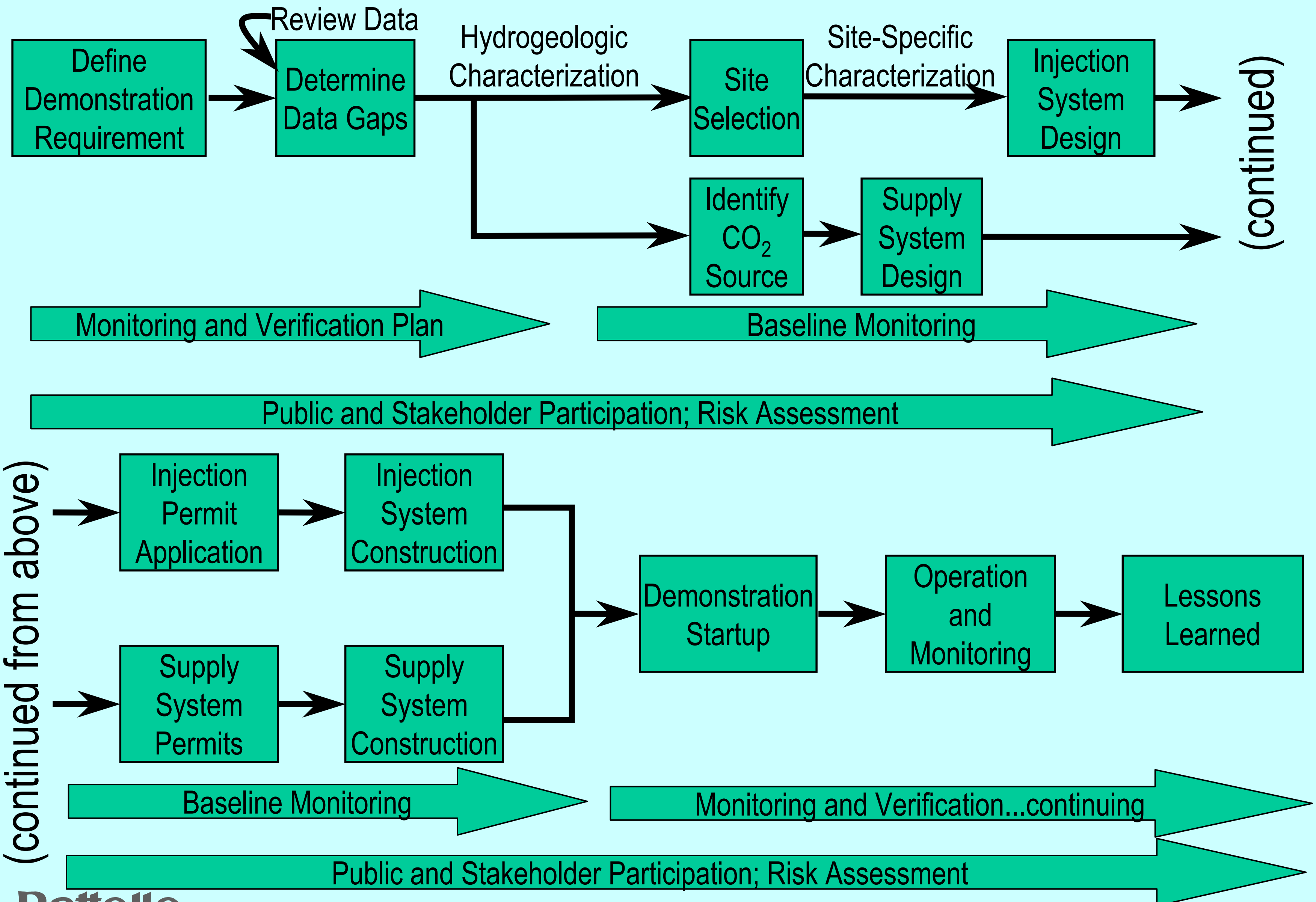
Plant Type	Depth (m)	Pipeline (km)	Terrain	Capture ($mil/yr) A	Compression ($mil/yr) B	Capture and Compression ($mil/yr) C[c]	Pipeline ($mil/yr) D	Injection ($mil/yr) E	Total Cost ($mil/yr) F[d]
PC/FGD (e,f)	2,000	15	Normal	20.04	33.39		1.79	3.88	
Scenario totals						53.43			59.10
PC/FGD	2,000	100	Normal	20.04	33.39		7.66	3.88	
Scenario totals						53.43			64.97
PC/FGD	2,000	400	Normal	20.04	33.39		28.89	3.88	
Scenario totals						53.43			86.20
PC/FGD	1,000	15	Normal	20.04	33.39		1.79	2.79	
Scenario totals						53.43			58.01
PC/FGD	3,000	15	Normal	20.04	33.39		1.79	6.11	
Scenario totals						53.43			61.33
PC/FGD	2,000	15	Rocky	20.04	33.39		2.06	3.88	
Scenario totals						53.43			59.37
PC/FGD	2,000	15	Urban	20.04	33.39		2.19	3.88	
Scenario totals						53.43			59.50
IGCC[g]	2,000	15	Normal	4.07	28.28		1.79	3.59	
Scenario totals						32.35			37.73

Unit Cost ($/ton CO_2 Avoided) - PC ~ 60-80, IGCC ~ 40

Summary

- On a regional basis there is enormous potential sequestration capacity due to favorable formation thickness, hydrogeology, seismicity, and proximity to sources of CO_2
- The key issues are local capacity, long-term fate, engineering, cost, safety, and public acceptance
- The site-specific sequestration potential varies due to local thickness, permeability, porosity, structural features, and depth
- Detailed Engineering and Economic Assessment has been Performed

CO_2 Capture and Disposal Demonstration Plan



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