An Assessment of Geological Carbon Sequestration Options in the Illinois Basin: Year One

MGSC Project Team

Presented by

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Midwest Geological Sequestration Consortium
www.sequestration.org

Team Members

- Illinois State Geological Survey
- Indiana Geological Survey
- Kentucky Geological Survey
- Brigham Young University (seismicity, geophysics)
- Southern Illinois University (coal testing)
- Douglas Nyman & Associates (pipeline)
- Dave Thomas, Consultant (review)

Collaborating Organizations

- IL Department of Natural Resources
- Illinois Office of Coal Development (cofunder)
- IL, IN, and KY Oil and Gas Associations
- Illinois Corn Growers Association
- Interstate Oil and Gas Compact Commission
- Electric Power Research Institute
- Air Liquide (in-kind cofunder)
- Ameren
- Aventine Renewable Energy
- Cinergy
- Louisville Gas & Electric
- Peabody Energy

Overview of Year One Activities

Robert J. Finley

Illinois State Geological Survey

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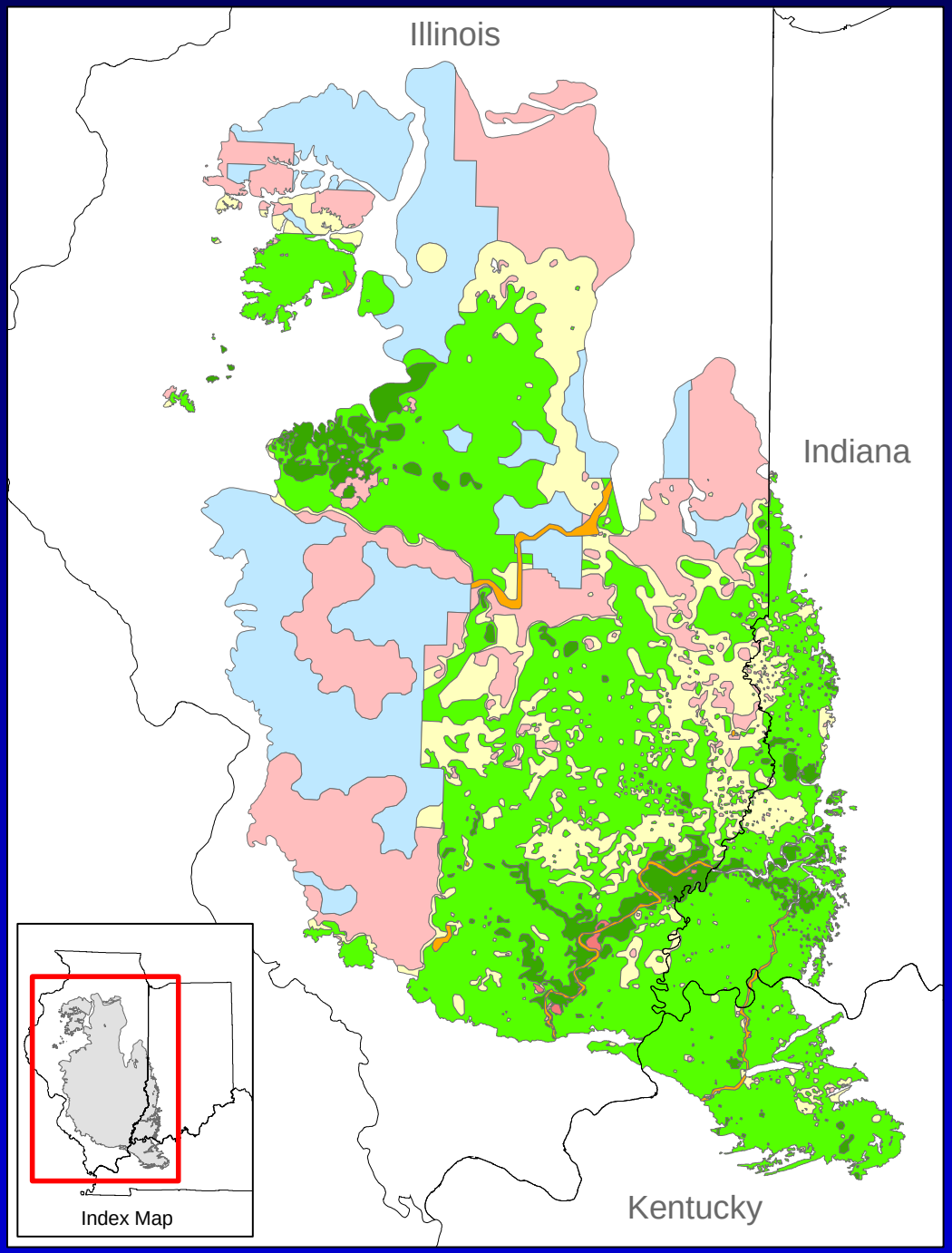
Year One Tasks 1-3 Completed

- Task 1: Initial data acquisition, file organization completed, structure created for ongoing data acquisition and development
- Task 2: CO_2 emission sources and carbon capture options for fixed sources in the Illinois Basin were assessed, costs developed and compared, and particular attention given to different generation/capture scenarios
- Task 3: Comprehensive assessment of CO_2 transportation options, both pipeline and truck/rail

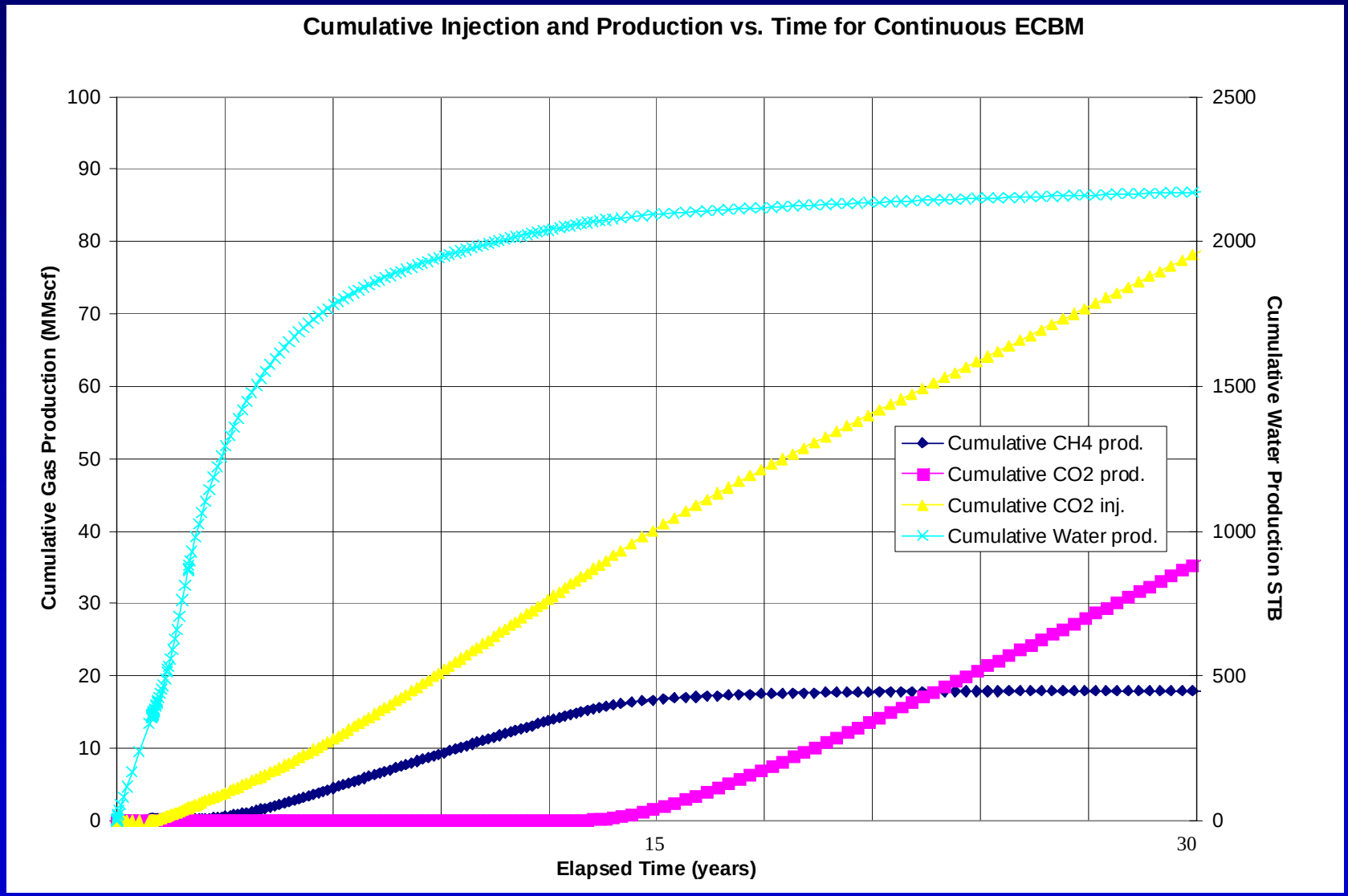
Year One Tasks 4-6 Status

- Task 4- Coal Beds: Mapping of major seams updated, coal parameters defined by depth class, coal adsorption testing, COMET simulations underway
- Task 5- Oil Reservoirs: Developing example reservoir studies for CO_2-EOR estimate, new Basin OOIP estimate developed, VIP reservoir simulations underway
- Task 6- Saline Reservoirs: Variability in Mt. Simon defined from cores and logs, geostatistical reservoir parameters developed, 2-D seismic structural interpretation in progress

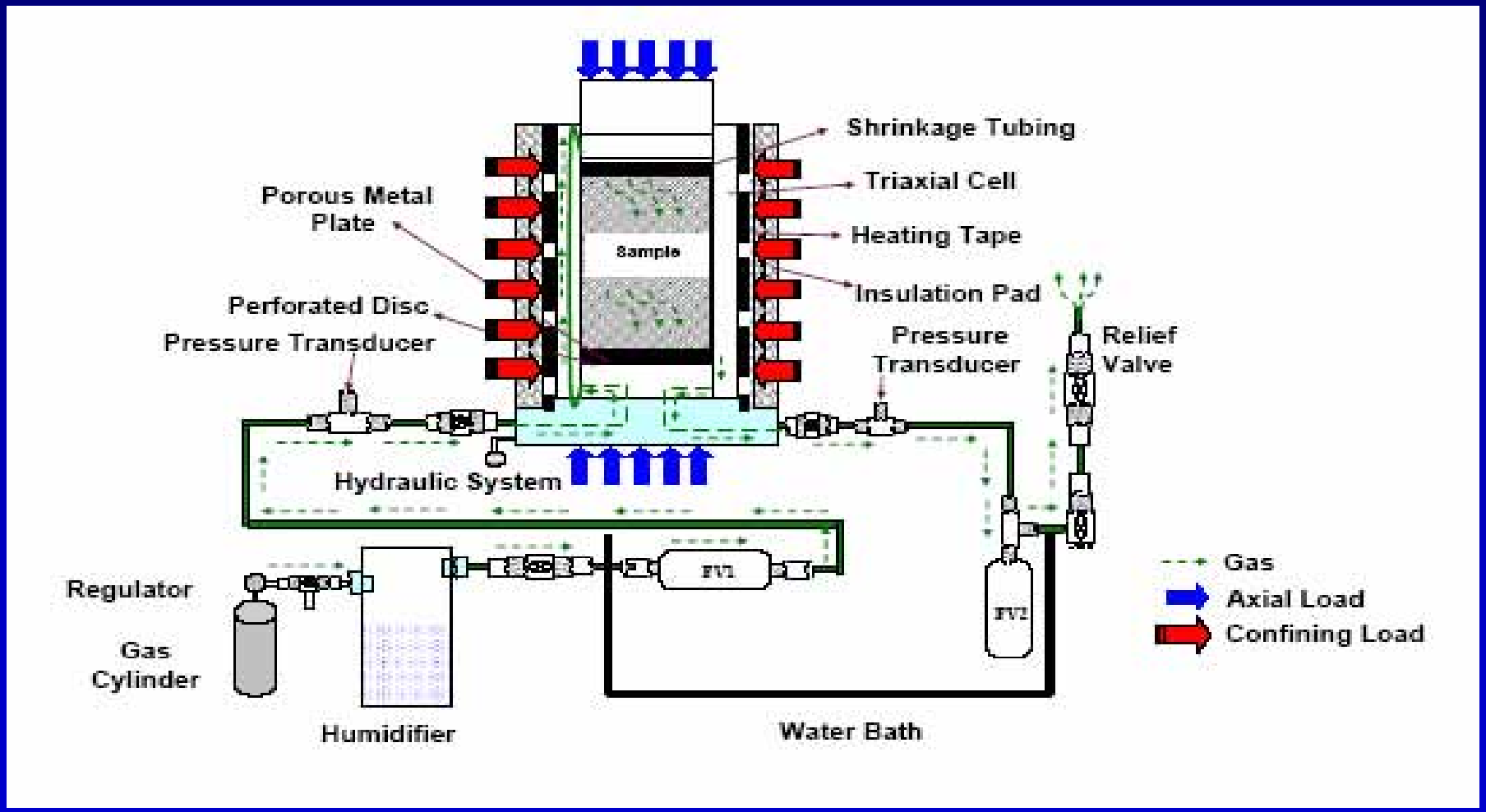


Springfield Coal Thickness

Cumulative CO_2 Injection and CBM Production



Triaxial Cell In-Situ Stress Testing of Permeability in Illinois Basin Coal



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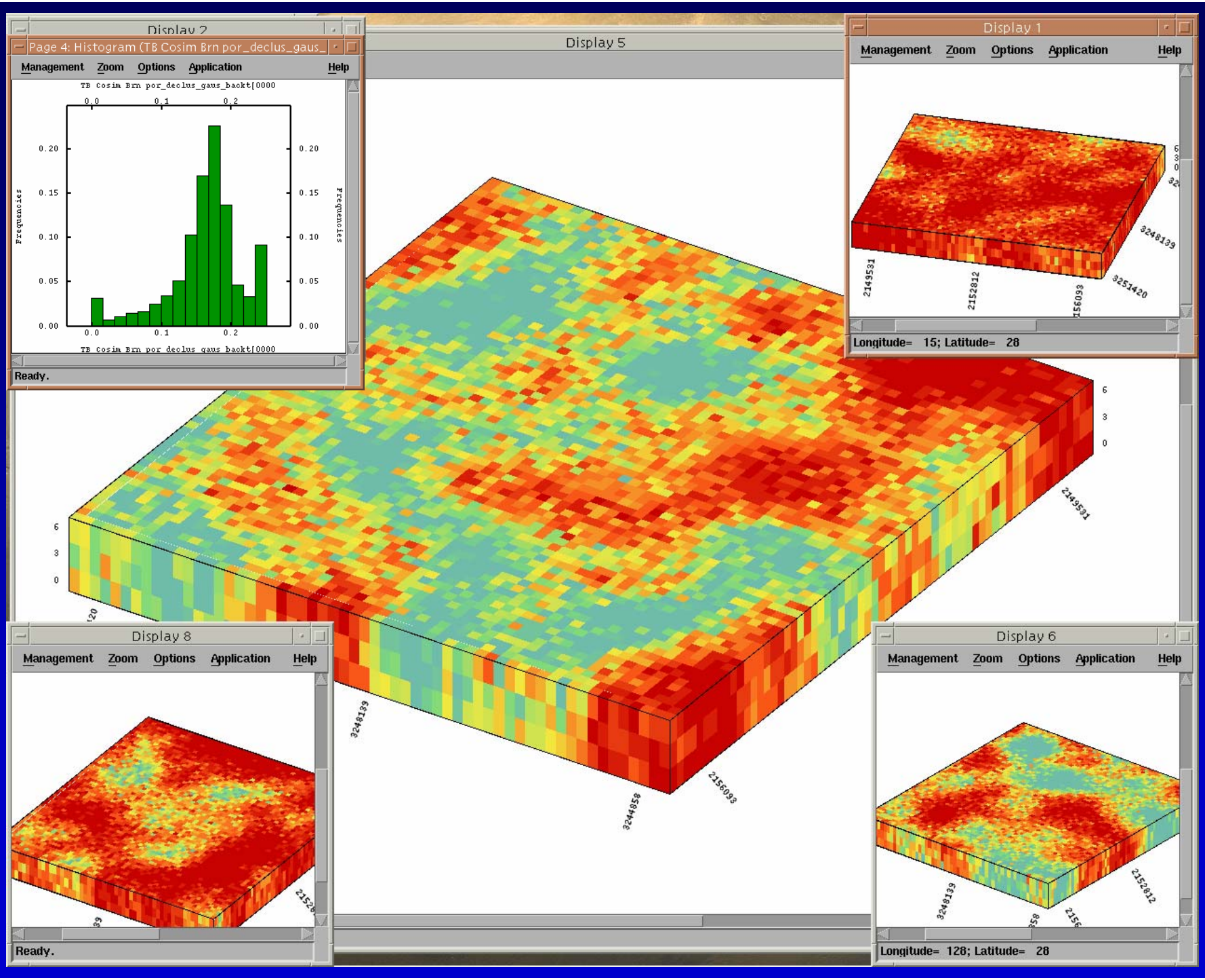
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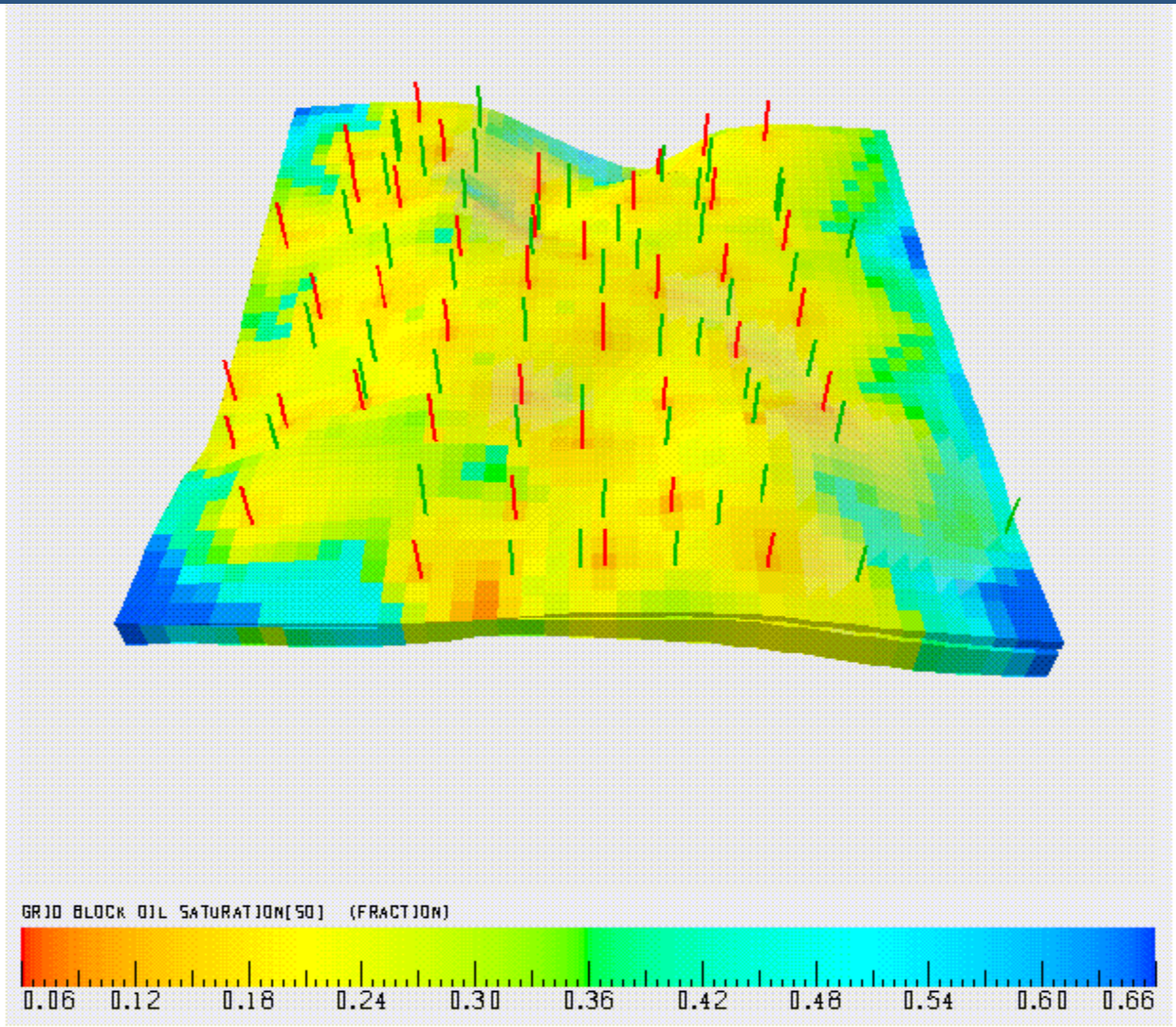
CO_2 Flood (10 yrs; t = 80 yrs)



Oil Saturation

Year One Tasks 4-6 Status

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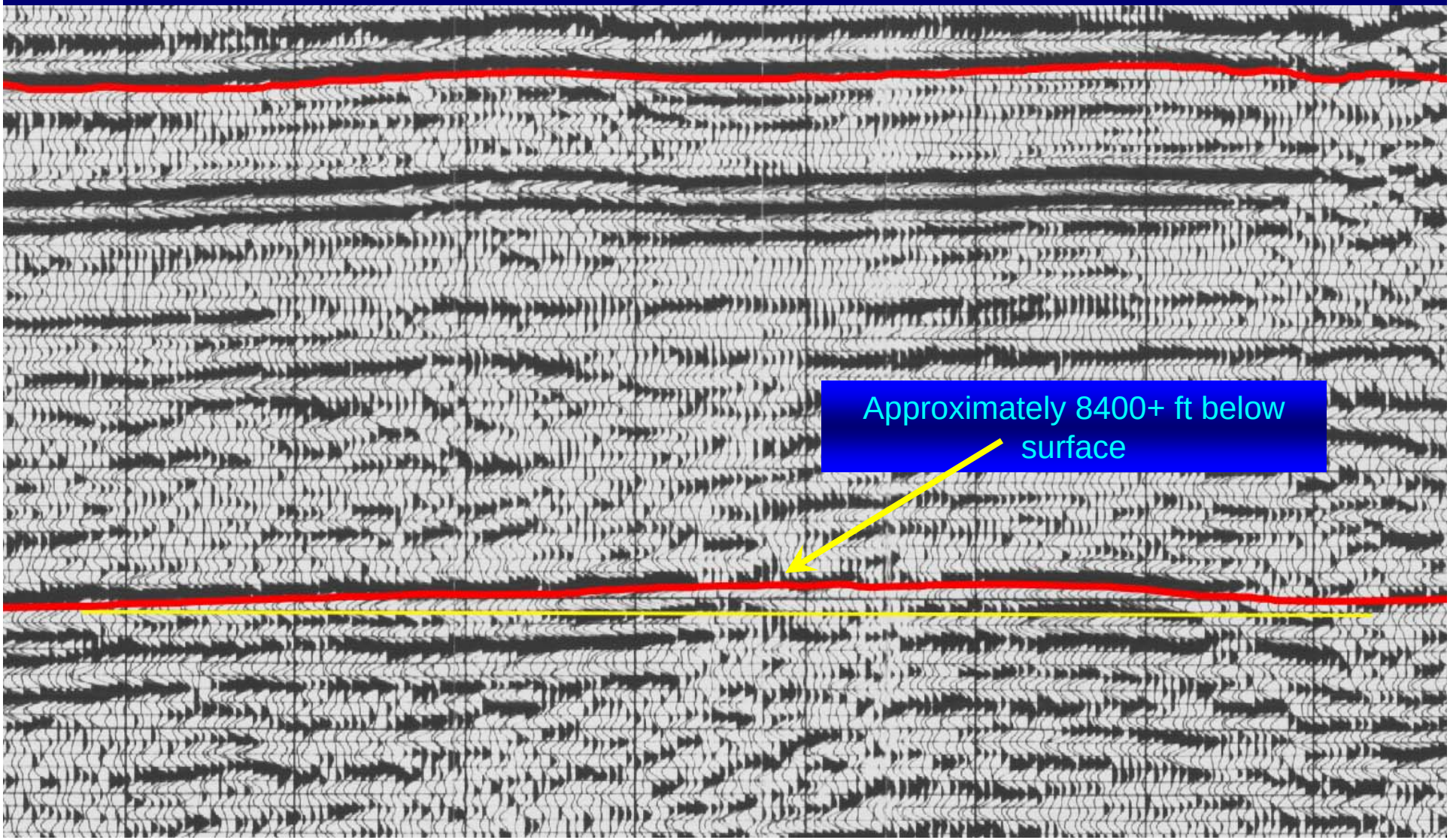
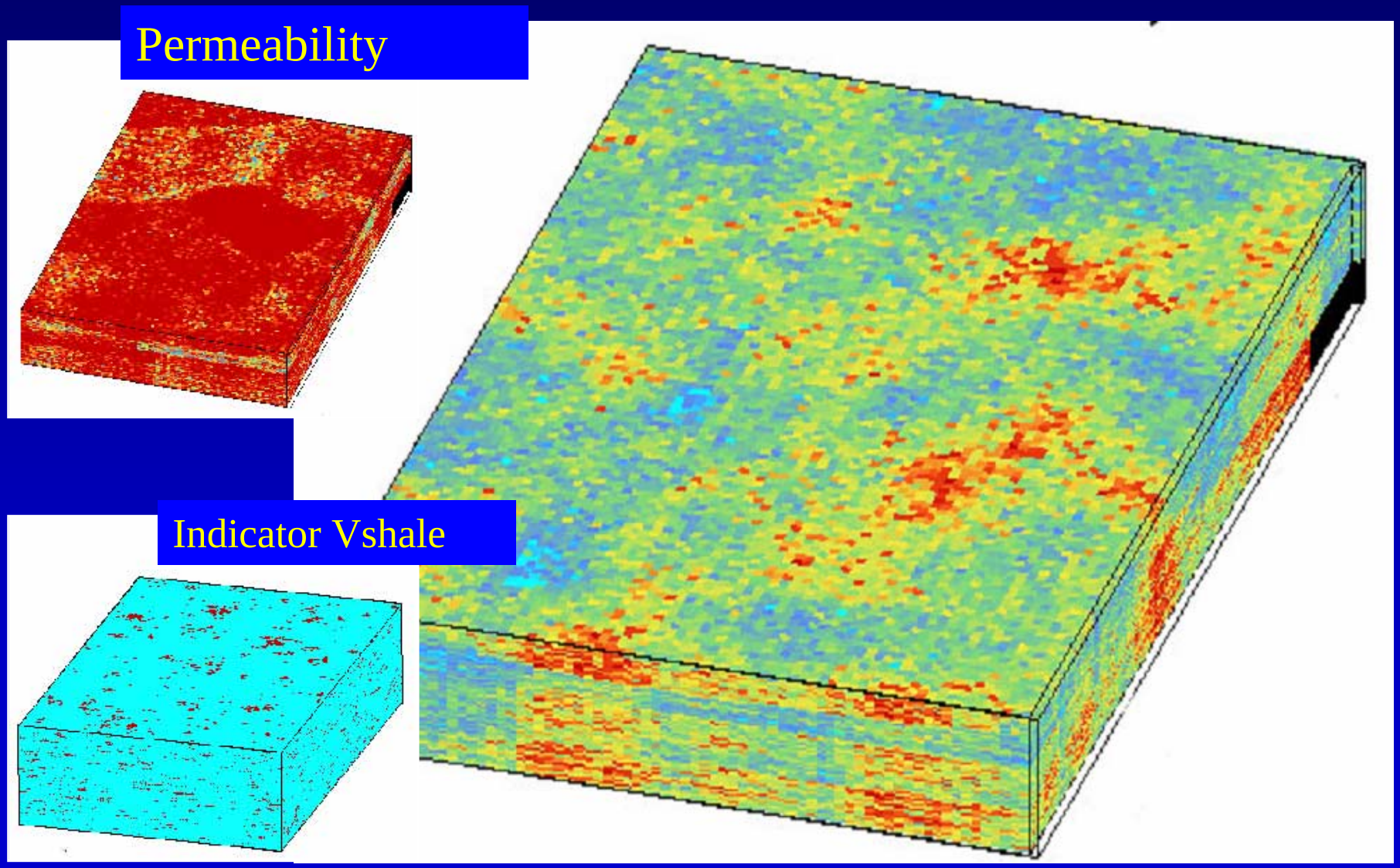
Clay City Consolidated Field
Northern Jasper County, Illinois



Manlove Gas Storage Field Porosity Model



Year One Additional Highlights

- Collaborated with NATCARB development for initial testing and implementation, provided 34 Illinois Basin or state (IL, IN, KY) GIS layers
- UIC Class I well files yielded abundant Mt. Simon and Eau Claire (caprock) data, including k_h, k_v, Ø, tracer injectivity, petrophysical data, and flow modeling results
- Collecting and analyzing in-situ stress data
- Established web site at www.sequestration.org
- Geological characterization has defined a potential sequestration fairway in the central Illinois Basin

Task 2

Assessment of Carbon Capture Options for Illinois Basin CO_2 Sources

Massoud Rostam-Abadi,

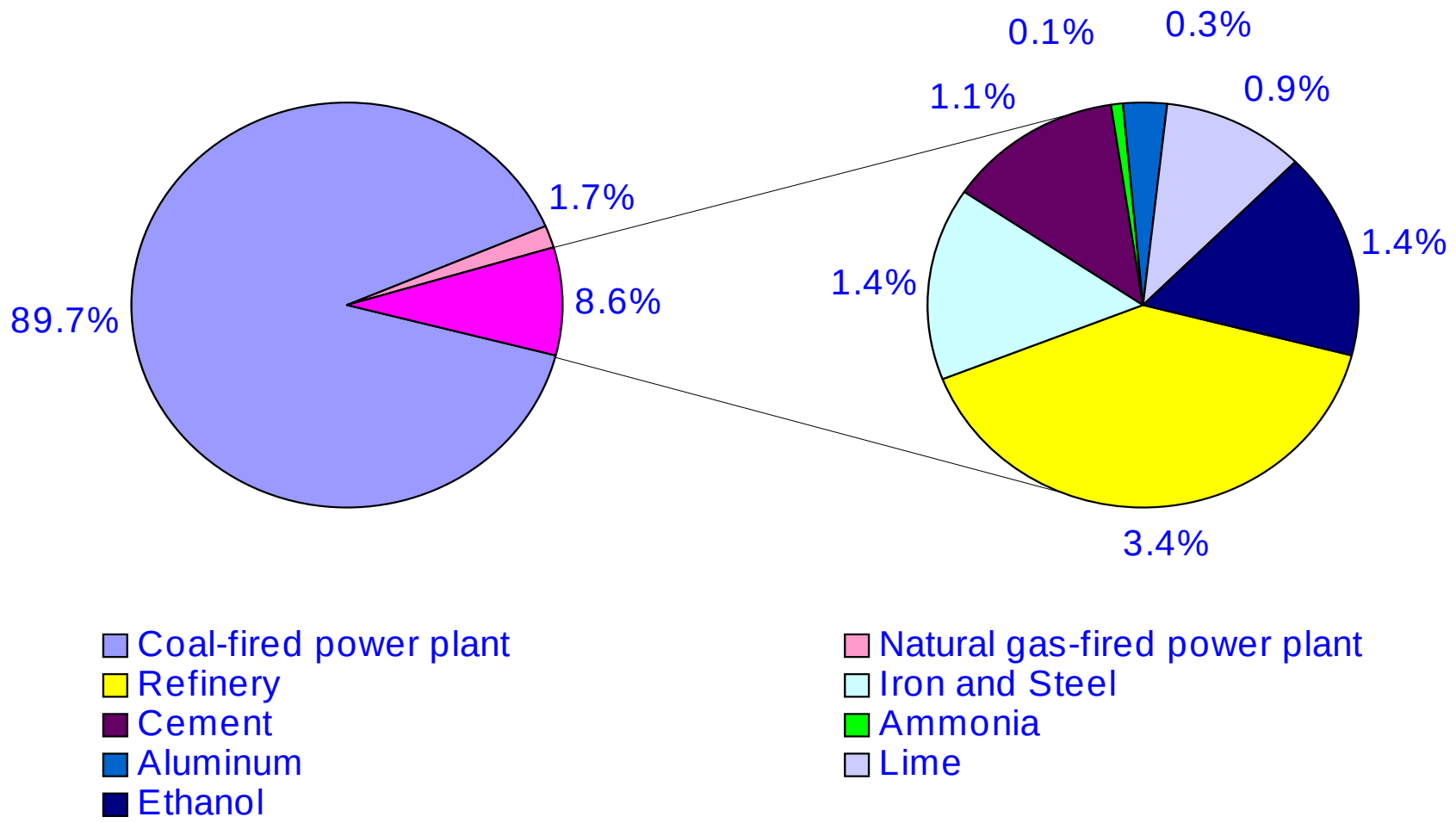
S. Scott Chen and Yongqi Li

Illinois State Geological Survey

Midwest Geological Sequestration Consortium

www.sequestration.org

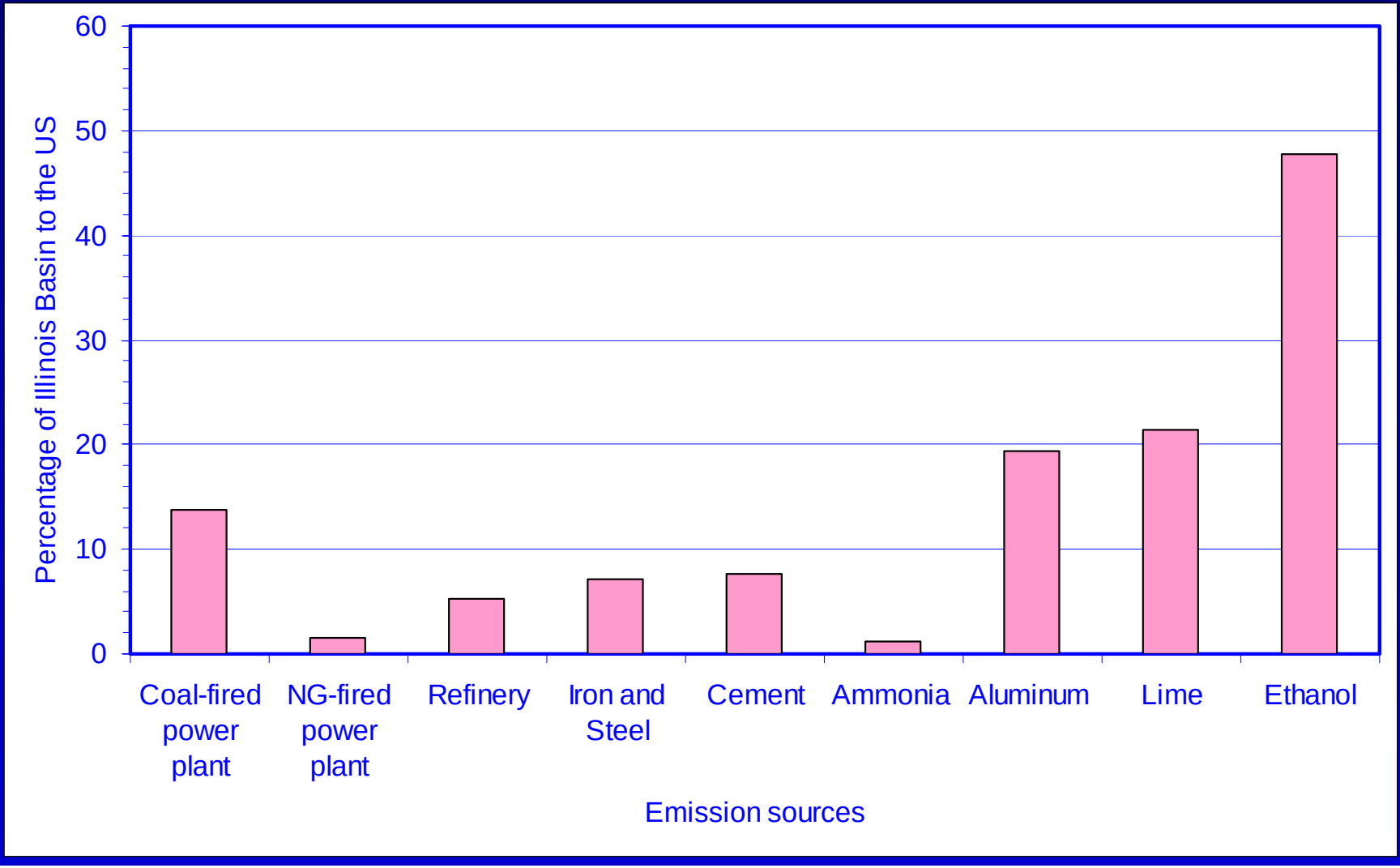
CO_2 Emissions in the Illinois Basin



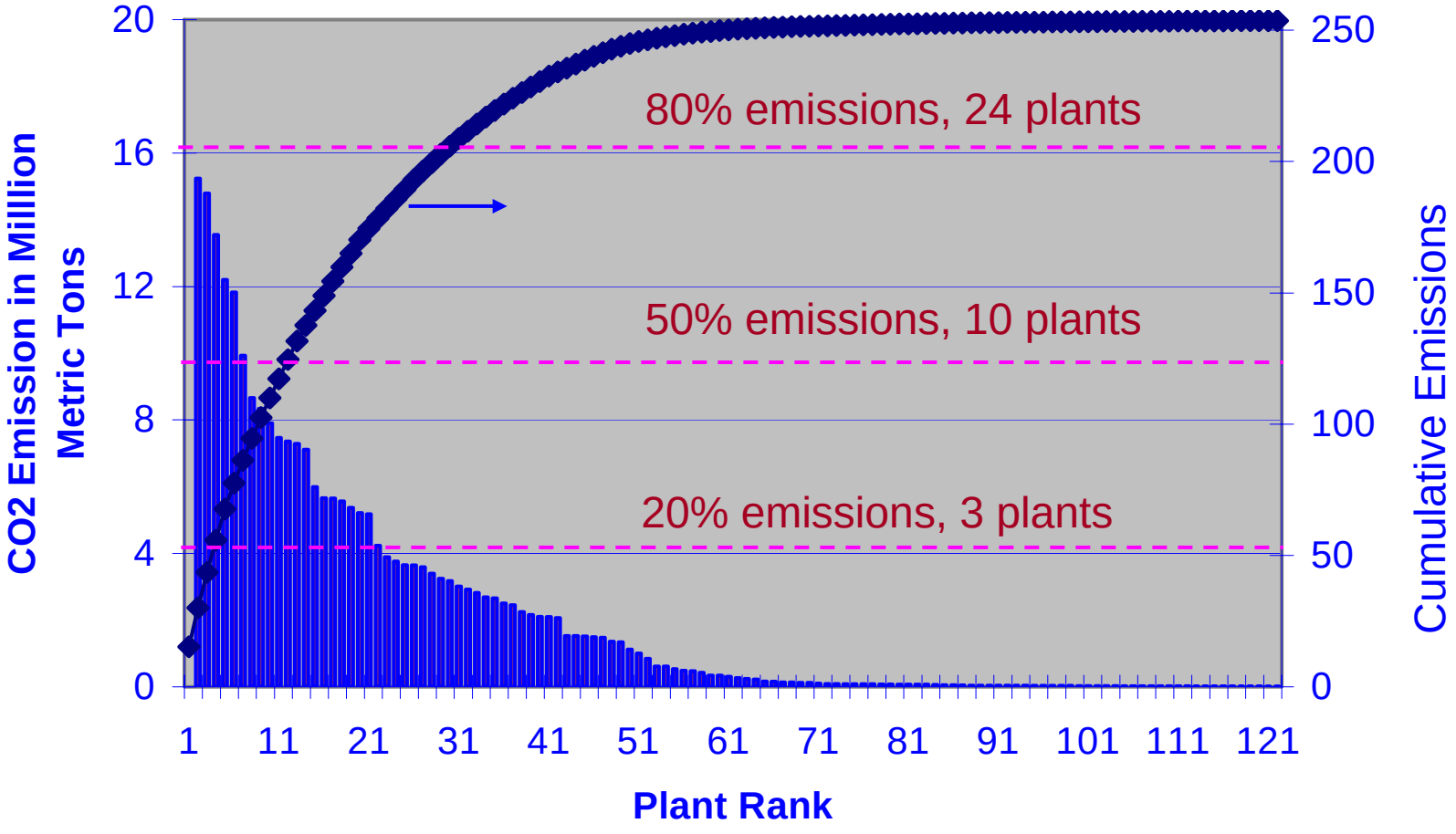
Total emissions: 276.1 million ton CO_2

Industrial emissions: 21.8 million ton CO_2

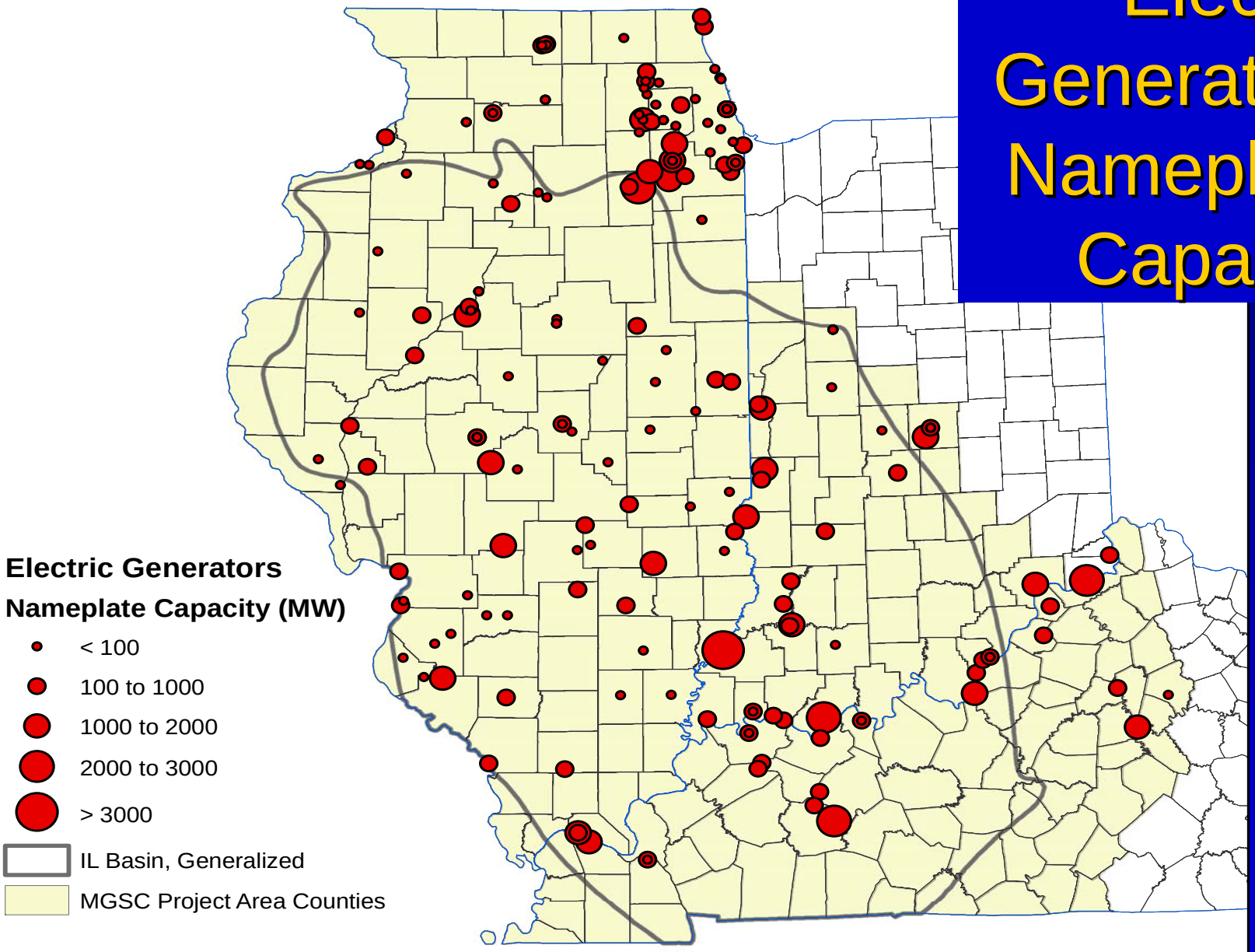
CO_2 Emissions in the United States and Illinois Basin



CO_2 Emissions from Power Plants in the Illinois Basin

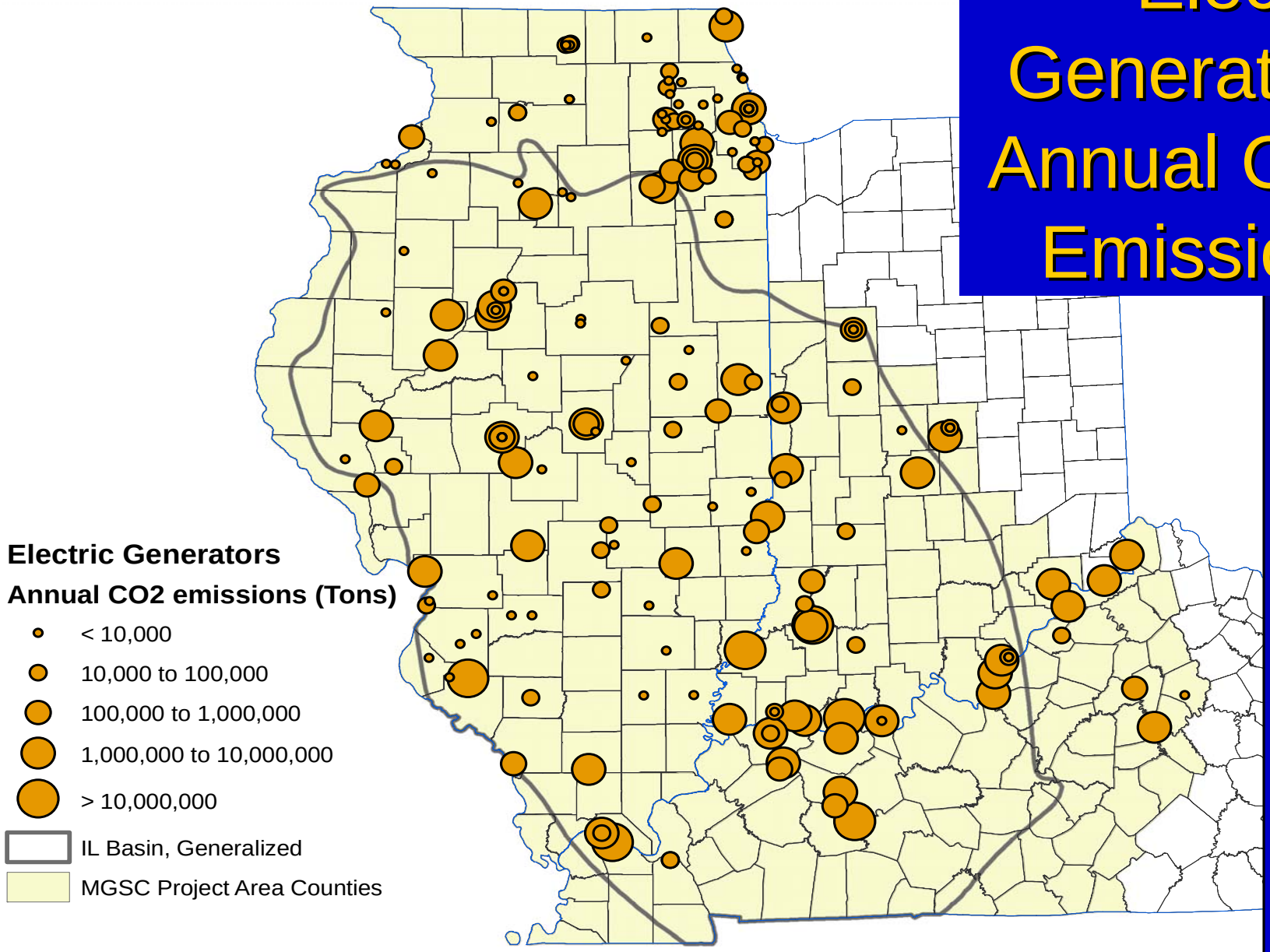


Electric Generators Nameplate Capacity



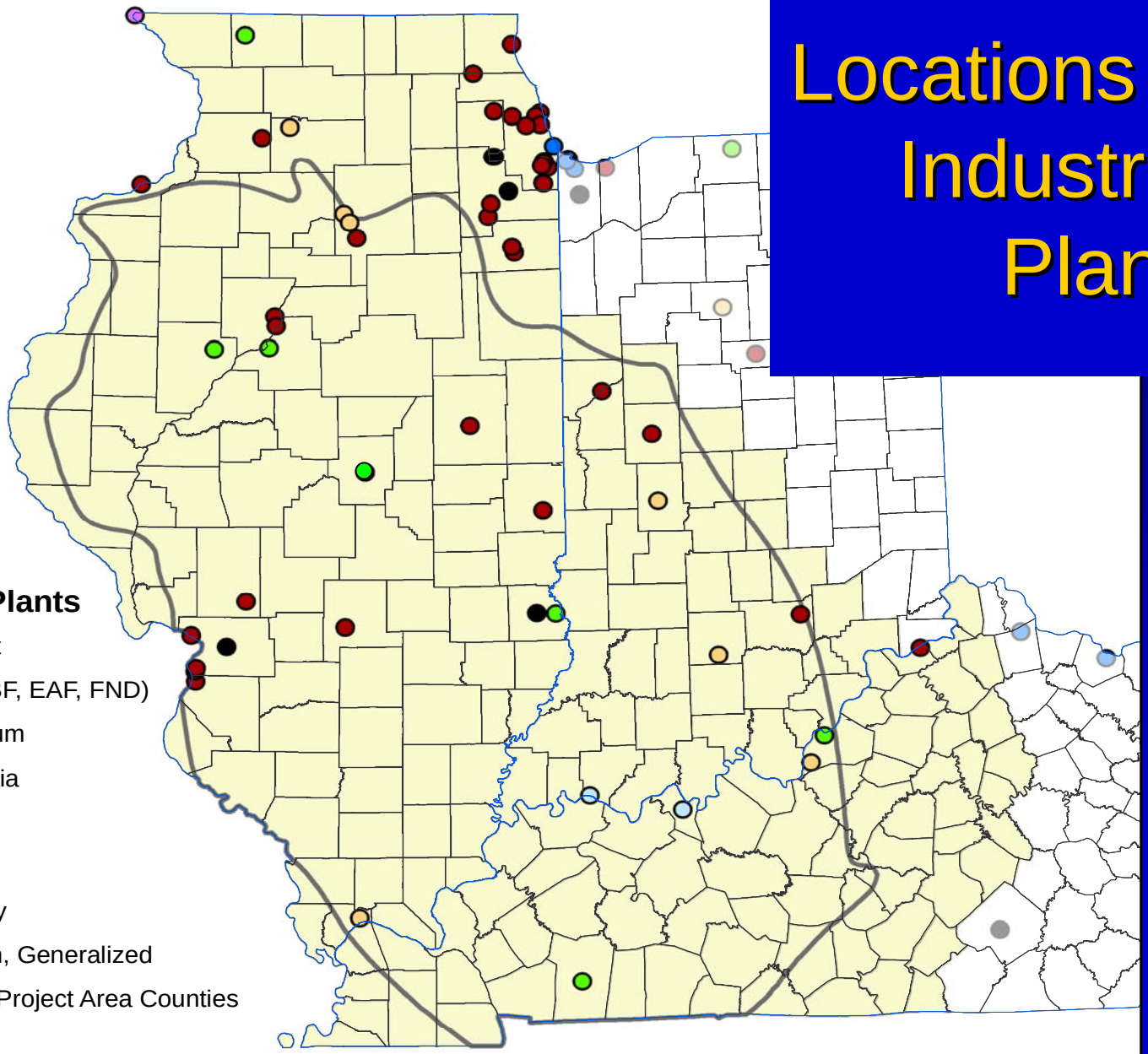
Source: US DOE Energy Information Administration 2002.

Electric Generators Annual CO_2 Emissions



Source: US DOE Energy Information Administration 2002; US EPA Acid Rain 2002, EGRID 2000.

Locations of Industrial Plants



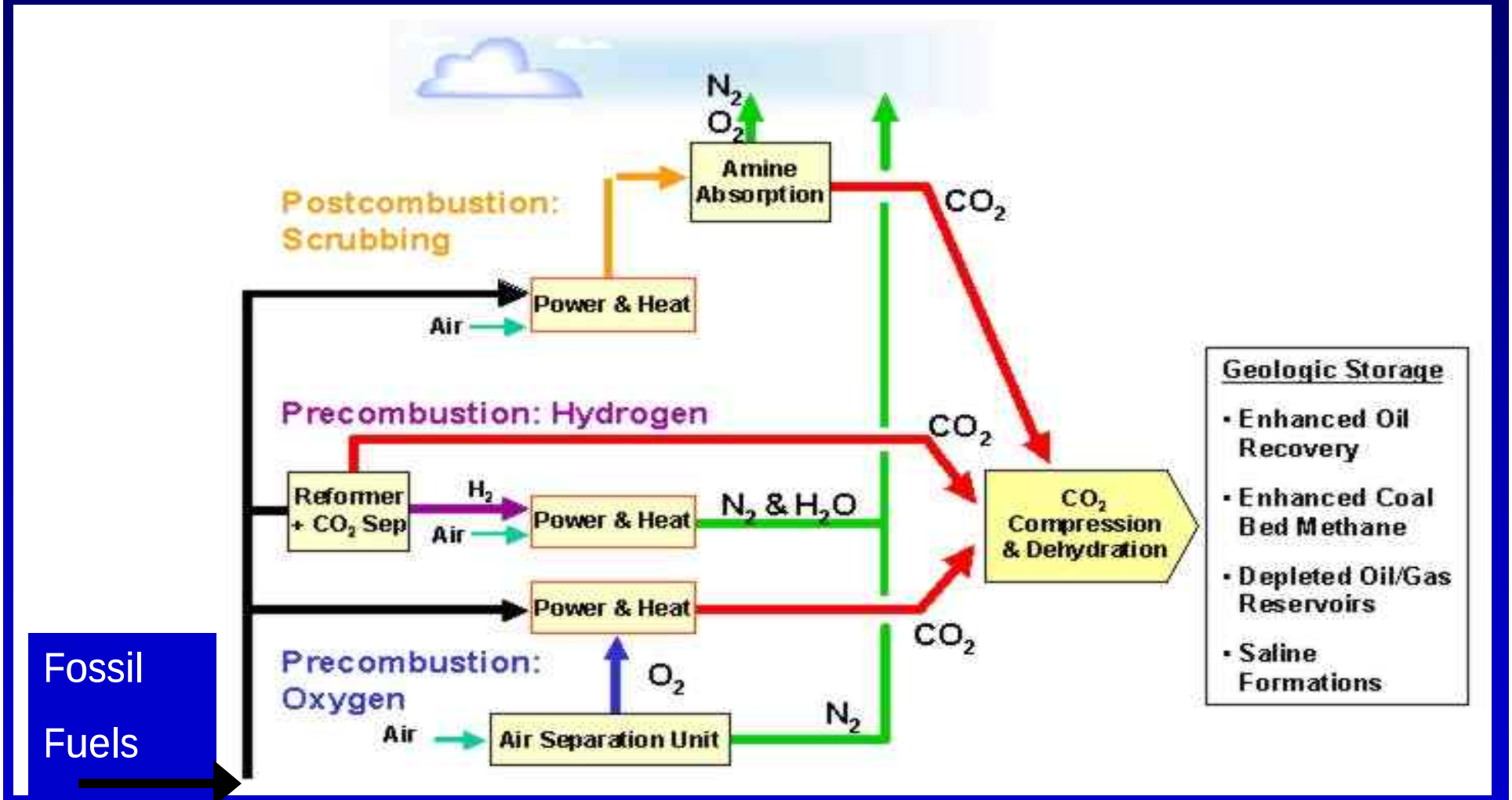
Industrial Plants

- Cement
- Steel (BF, EAF, FND)
- Aluminum
- Ammonia
- Ethanol
- Lime
- Refinery
- IL Basin, Generalized
- MGSC Project Area Counties

CO_2 Concentrations in Flue Gases

Source	CO_2 concentration (vol.%)
PC power station flue gas	14
Iron and steel blast furnace gas	20-27
Cement kiln off-gas	13-33
Lime manufacturing	13-33
Ammonia	>95
Oil refinery	8-15
Ethanol Plants	>85

Different Configurations for CO_2 Separation Processes



Information source: http://www.co2captureproject.org/technologies/index.htm

Potential CO_2 Capture Technologies: A General Comparison

Potential Capture Options

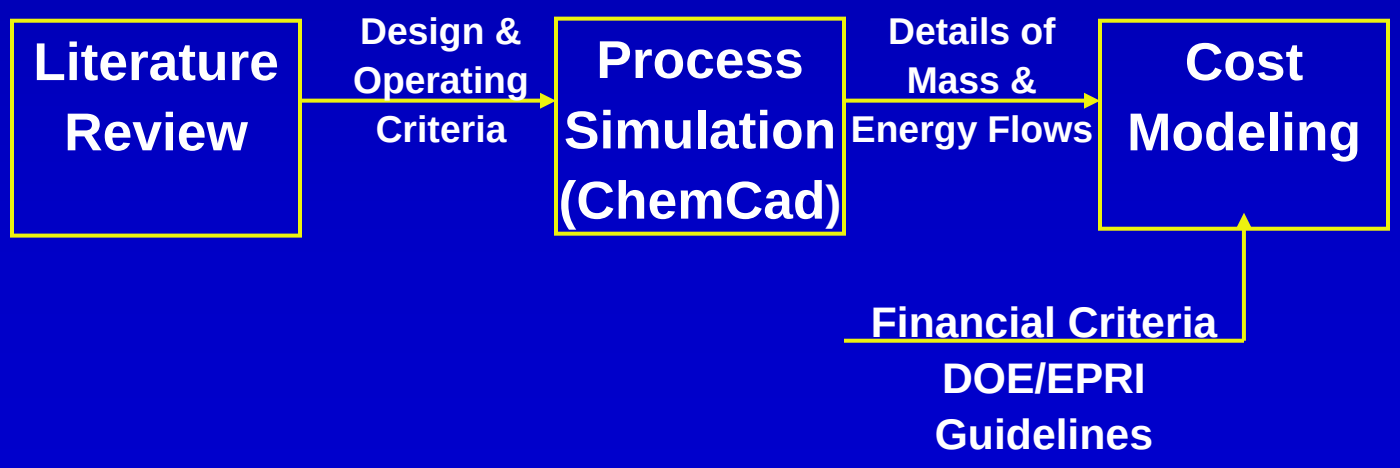
- **Absorption** →
  - ✓ Suitable for low CO_2 partial pressure streams
  - ✓ Energy intensive
- **Adsorption** →
  - ✓ Low recovery and capacity
  - ✓ Not suitable for post-combustion
- **Membrane** →
  - ✓ Attractive for H_2 separation
  - ✓ Currently very costly
  - ✓ Low purity, low recovery
- **Cryogenic** →
  - ✓ Suitable for relatively pure CO_2 streams
  - ✓ Energy intensive

Capture Scenarios for Illinois Basin CO_2 Sources

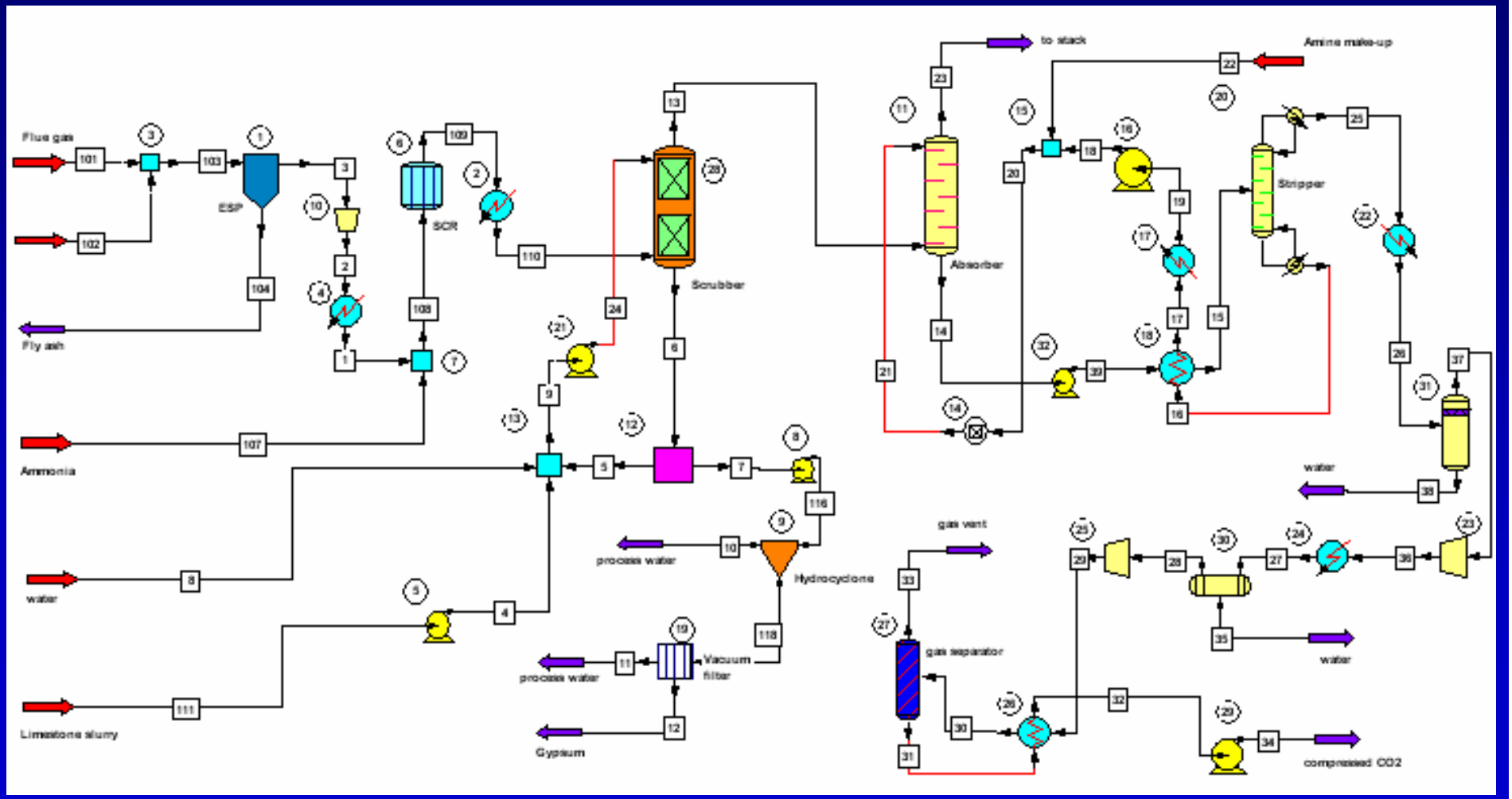
- Base case PC power plant
- PC plant plus chemical absorption process
- IGCC + shift + physical absorption process (Selexol)
- Oxy-combustion

Scenario Analysis and Methodology

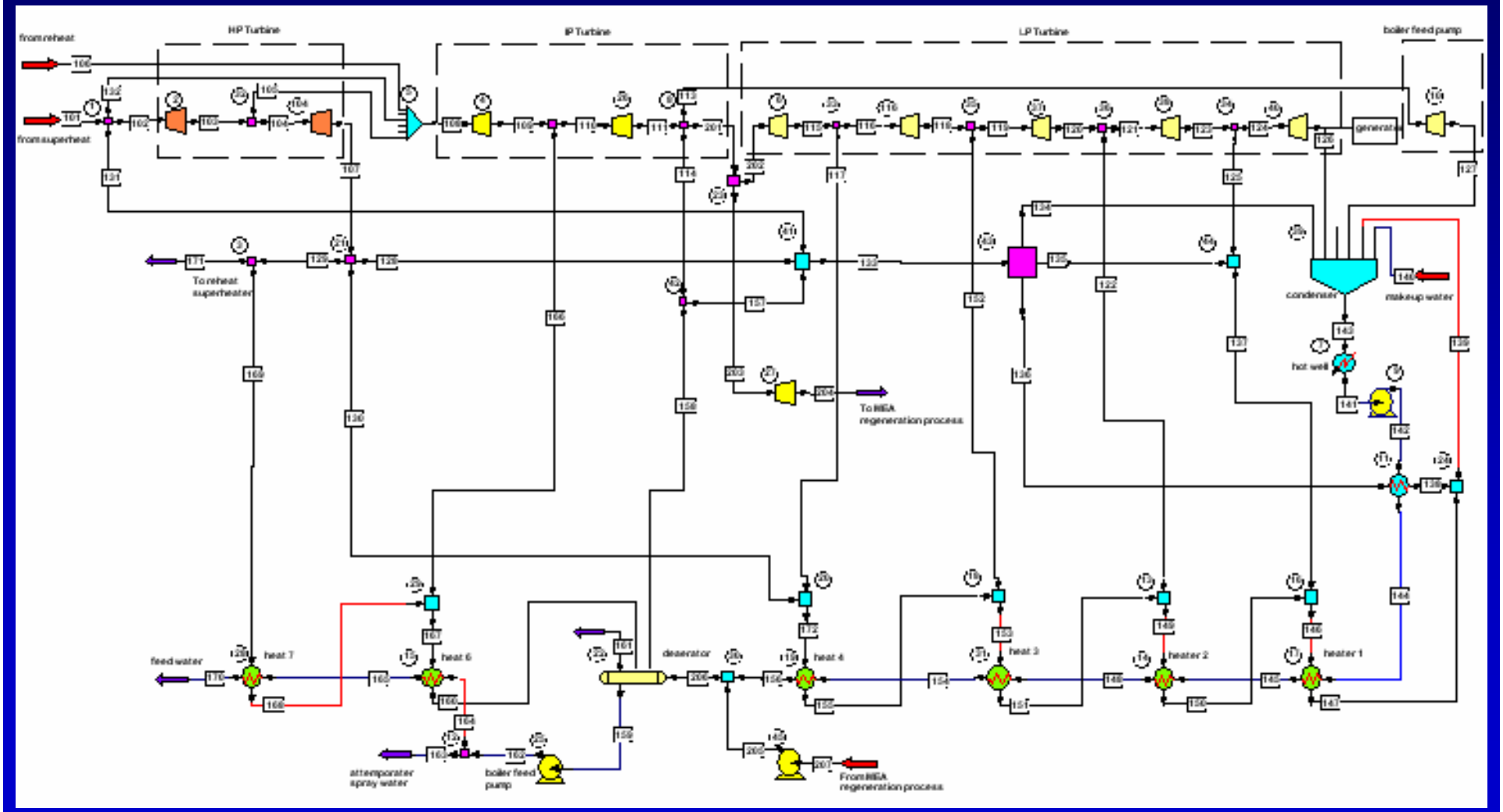
- Scenarios
  - 4 processes: PC, PC + MEA, IGCC + Selexol, OC
  - 3 plant sizes: 250, 500, 1000 MW
  - 2 coals: IL coal, PRB coal
  - 2 applications: new plant and retrofit
- Methodology:



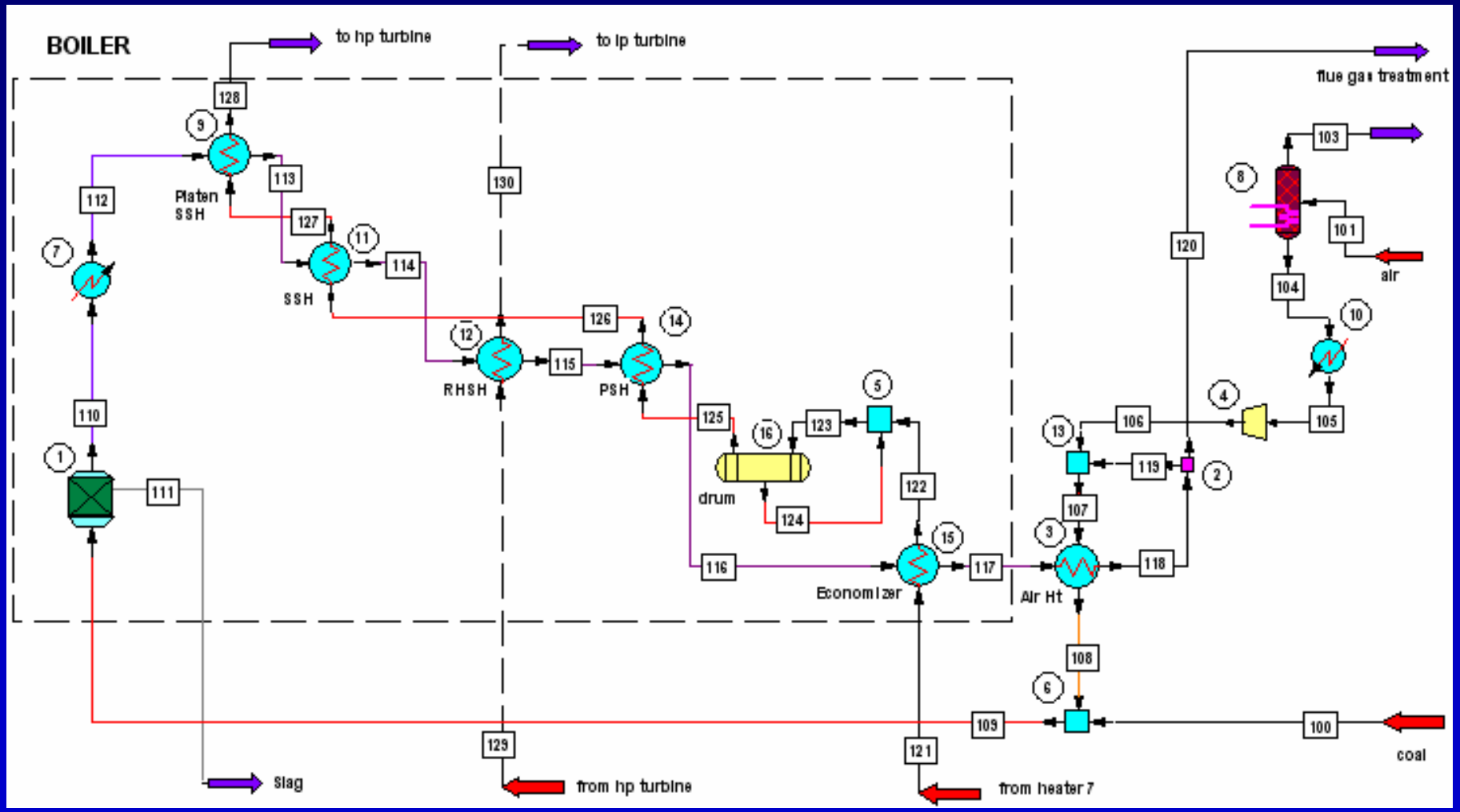
PC +MEA: Flue Gas Treatment



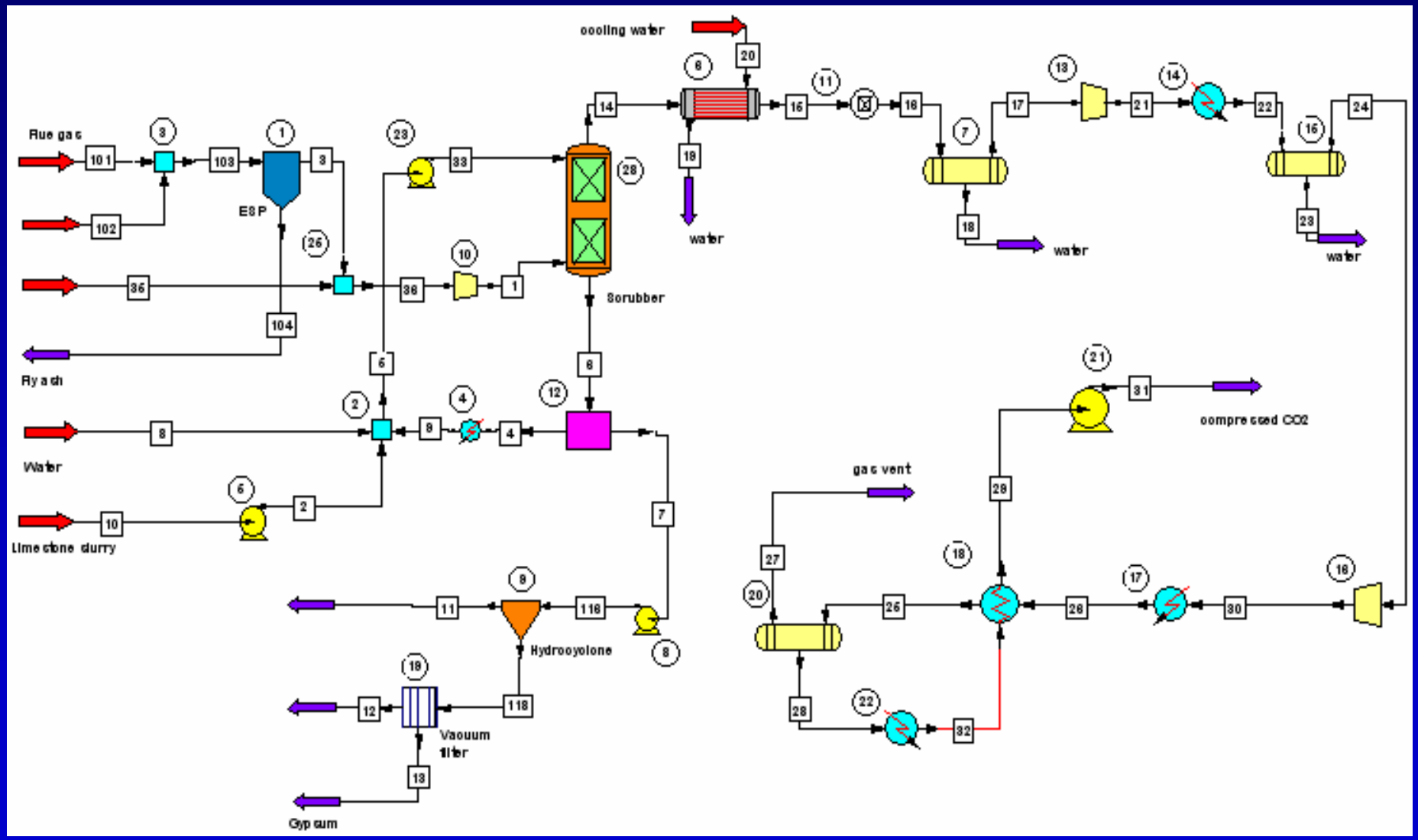
PC +MEA: Steam Turbine



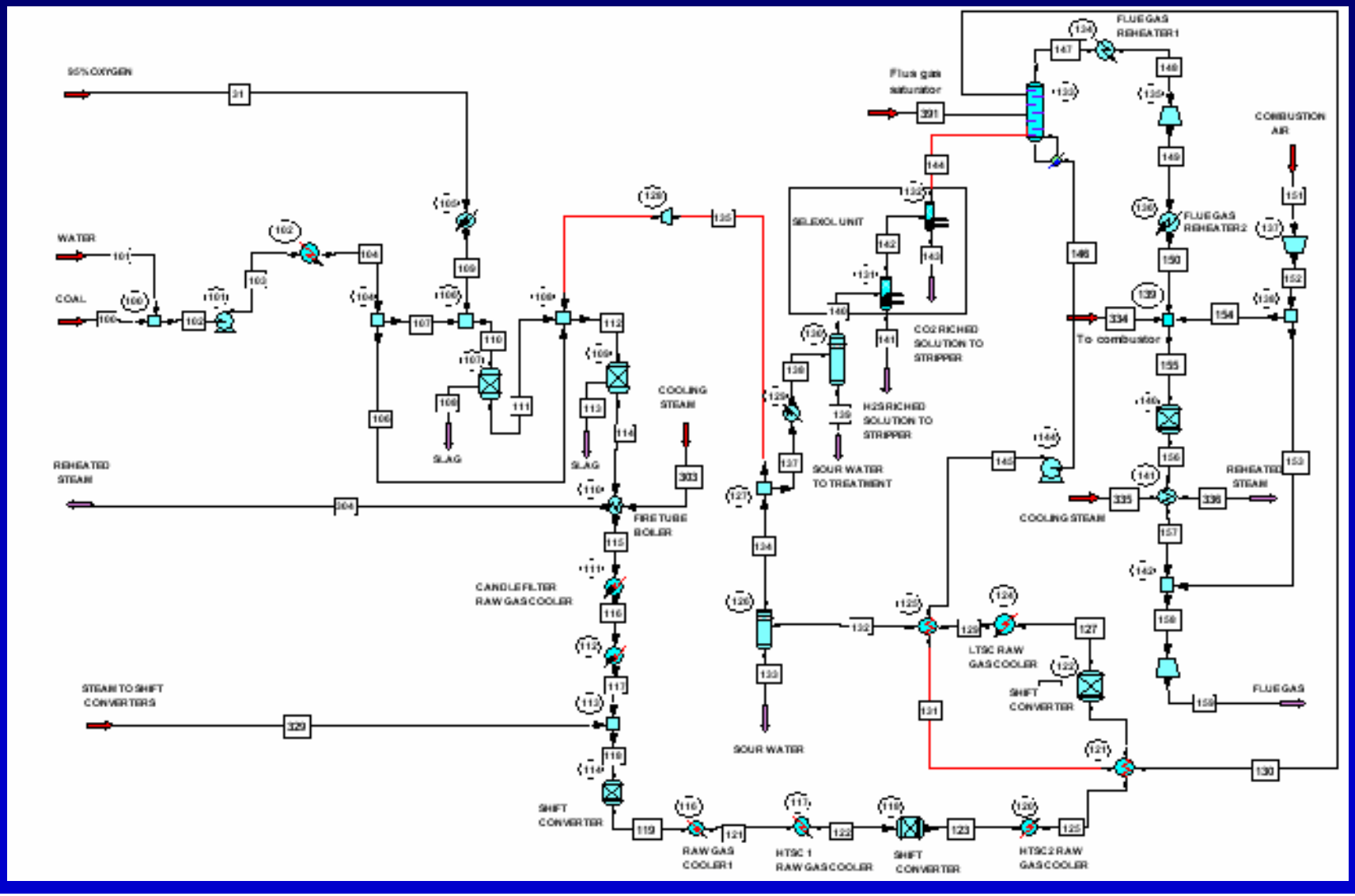
Oxy-Combustion Process: Boiler



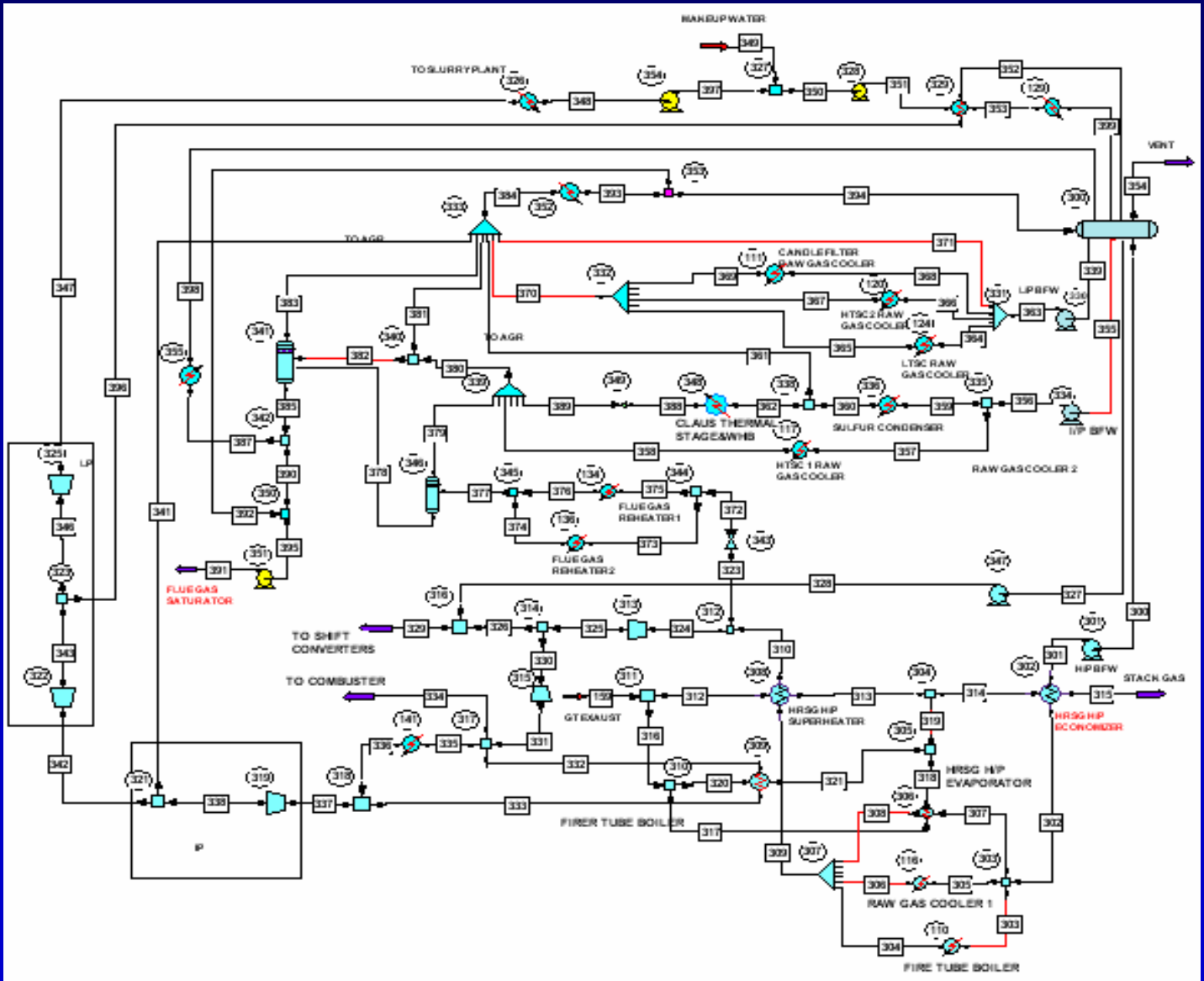
Oxy-Combustion: Flue Gas Treatment



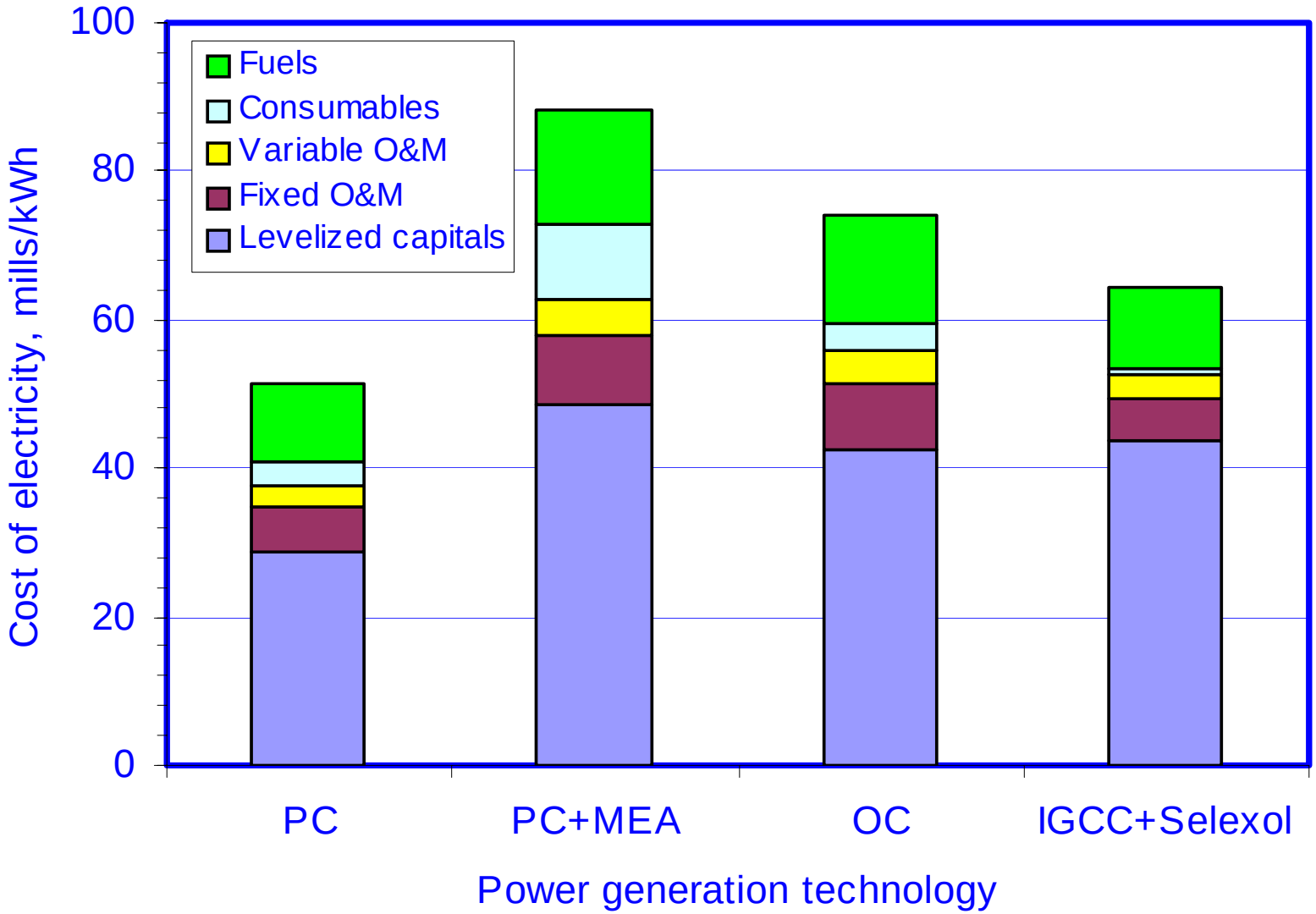
IGCC+Shift+Selexol: Gasifier, Gas Cleaning and Gas Turbine



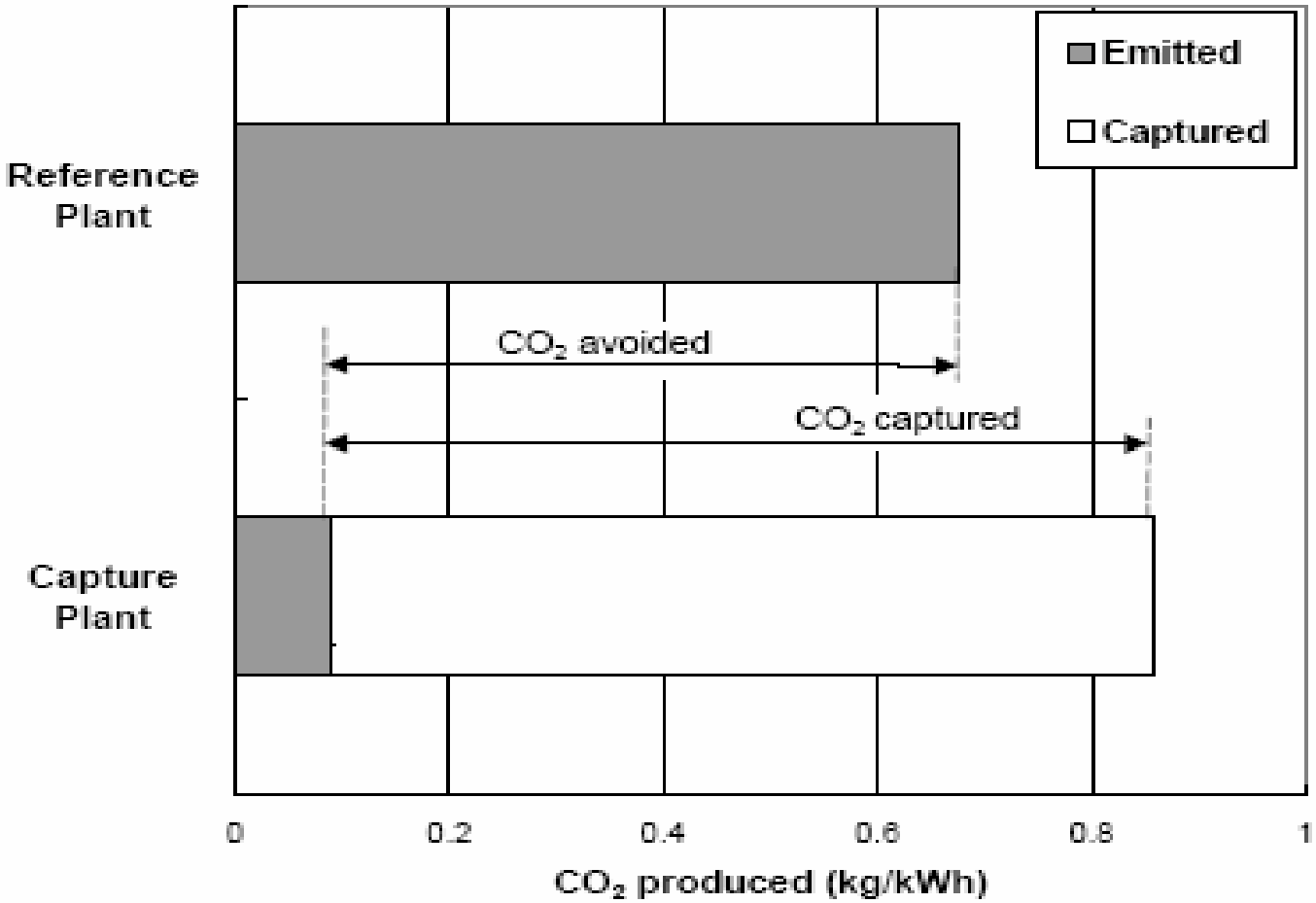
IGCC+Shift+Selexol: Steam Turbine Cycle



Cost of Electricity for a 533 MW (gross) Power Plant



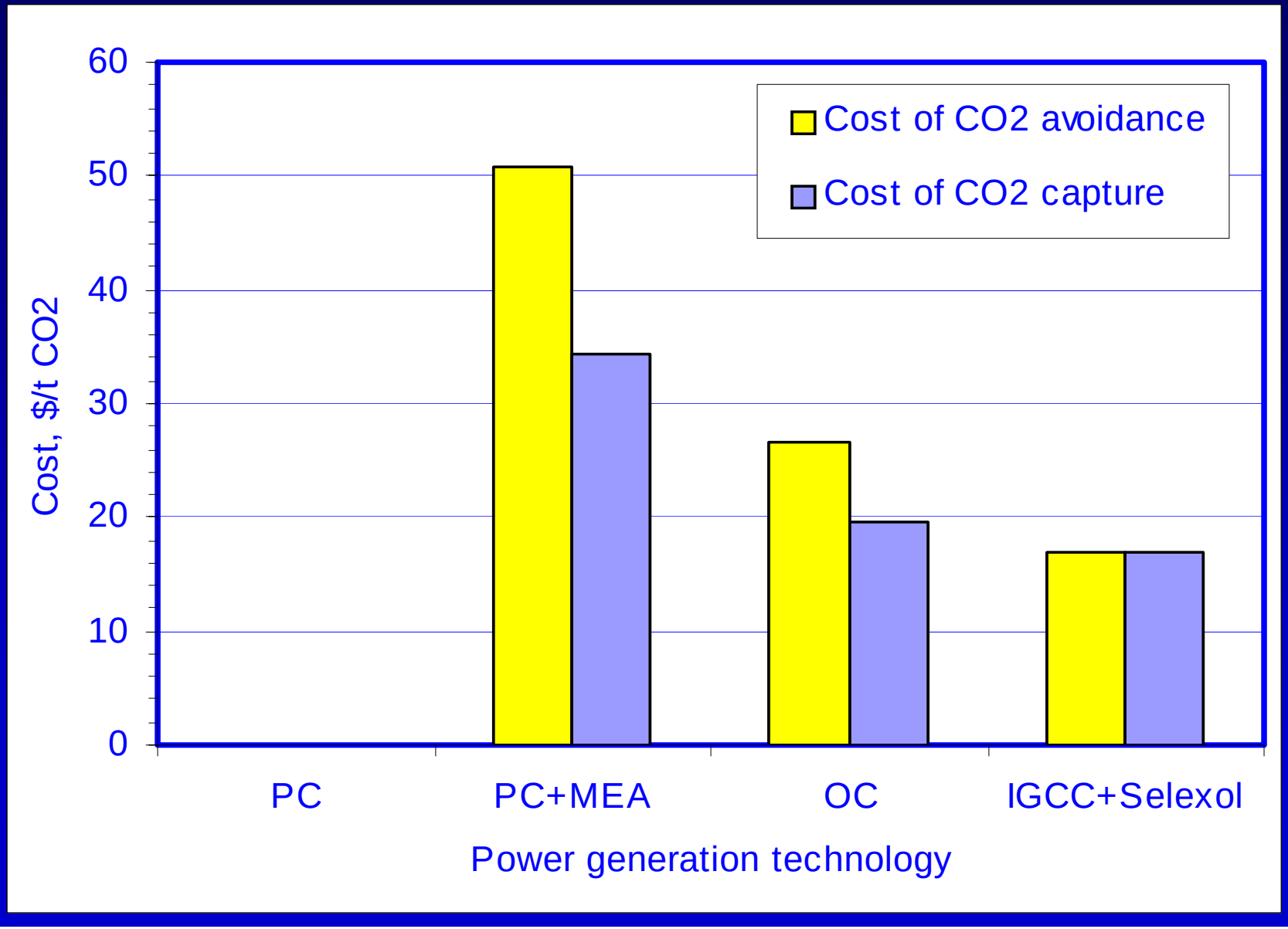
CO_2 Avoidance and CO_2 Capture



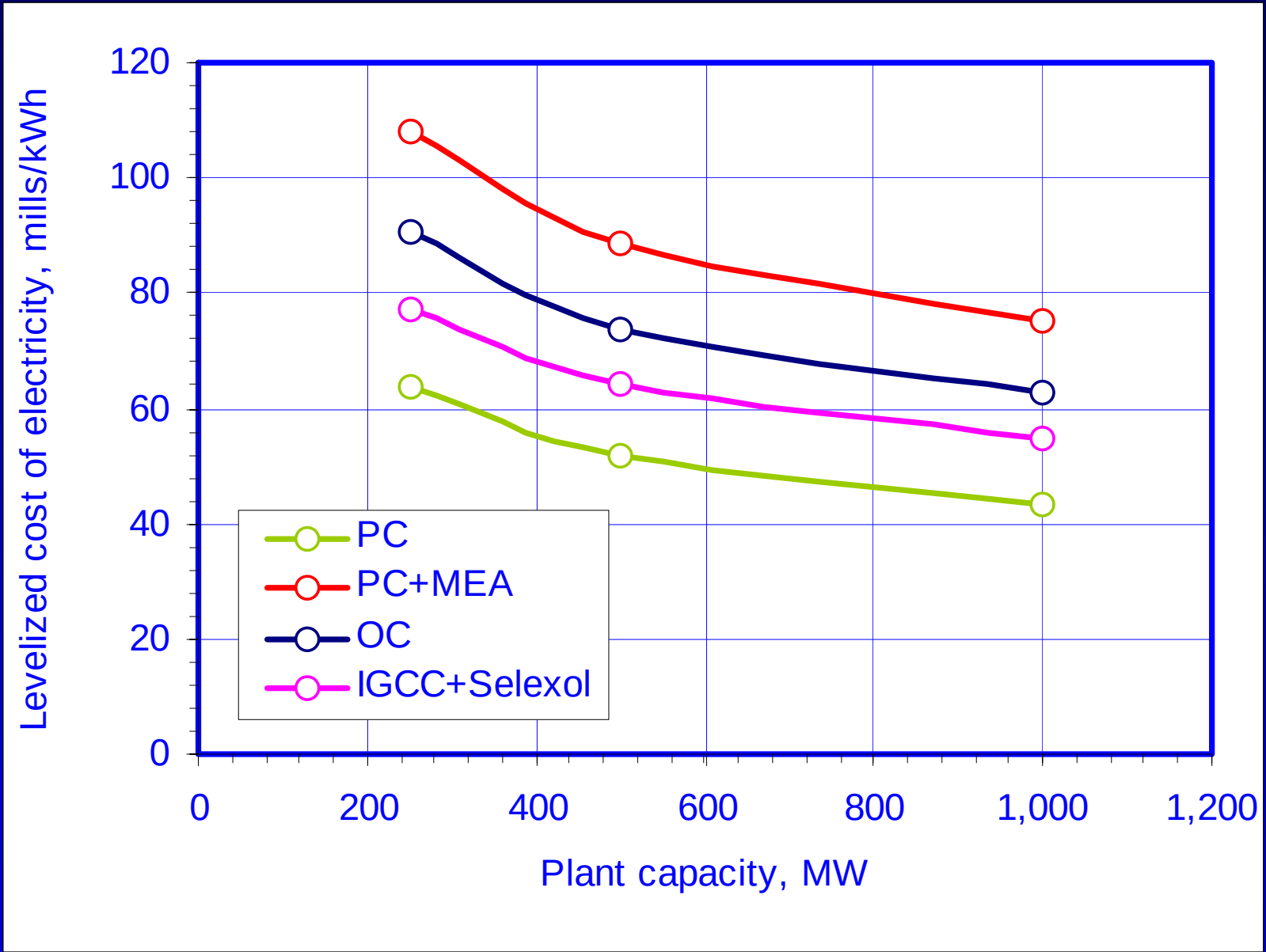
Cost of CO_2 avoidance = Δ cost of electricity / CO_2 avoided

Cost of CO_2 capture = Δ cost of electricity / CO_2 captured

Costs of CO_2 Avoidance and CO_2 Capture 533 MW (gross) Plant



Effect of Plant Scale, IL No.6 Coal



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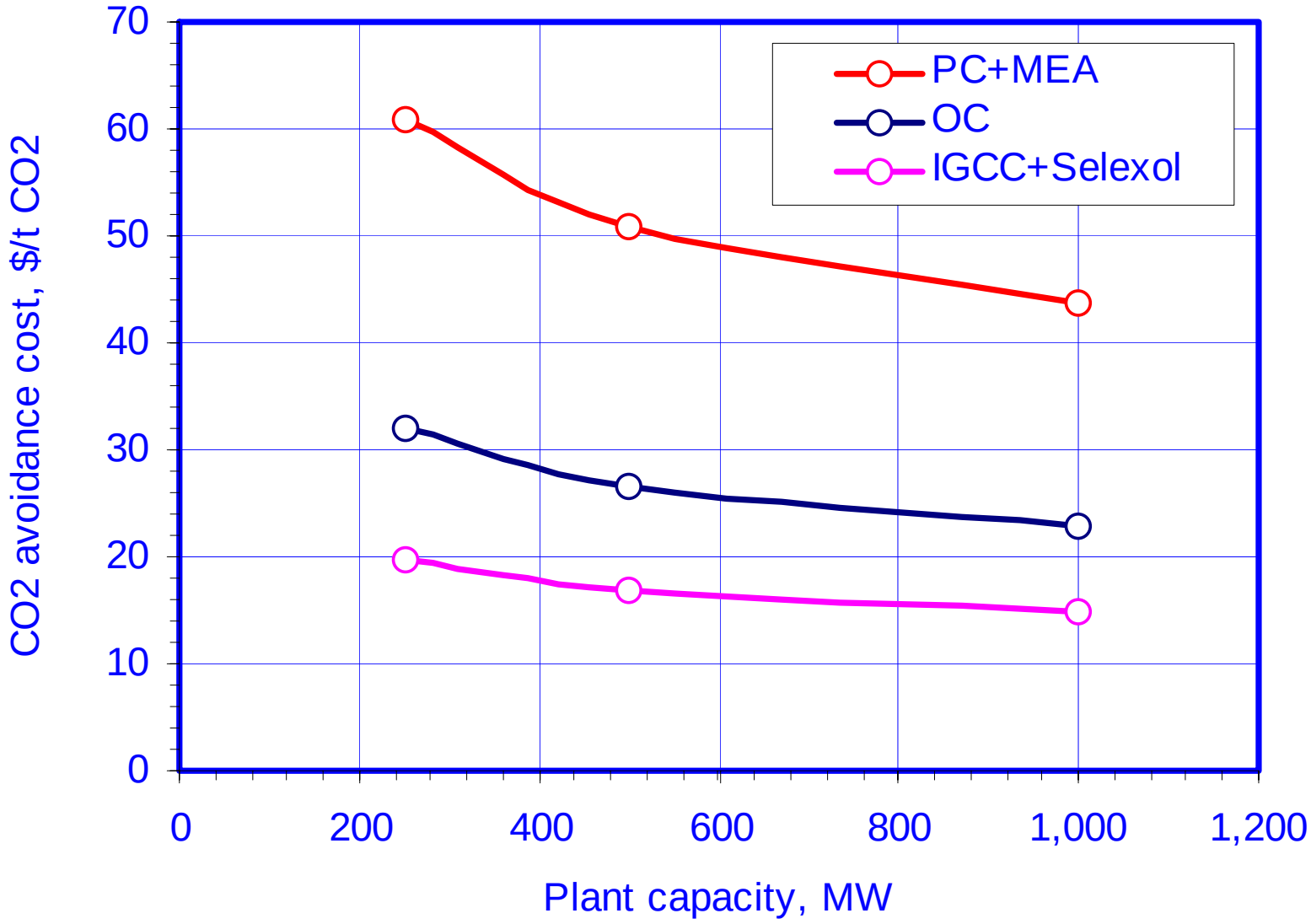
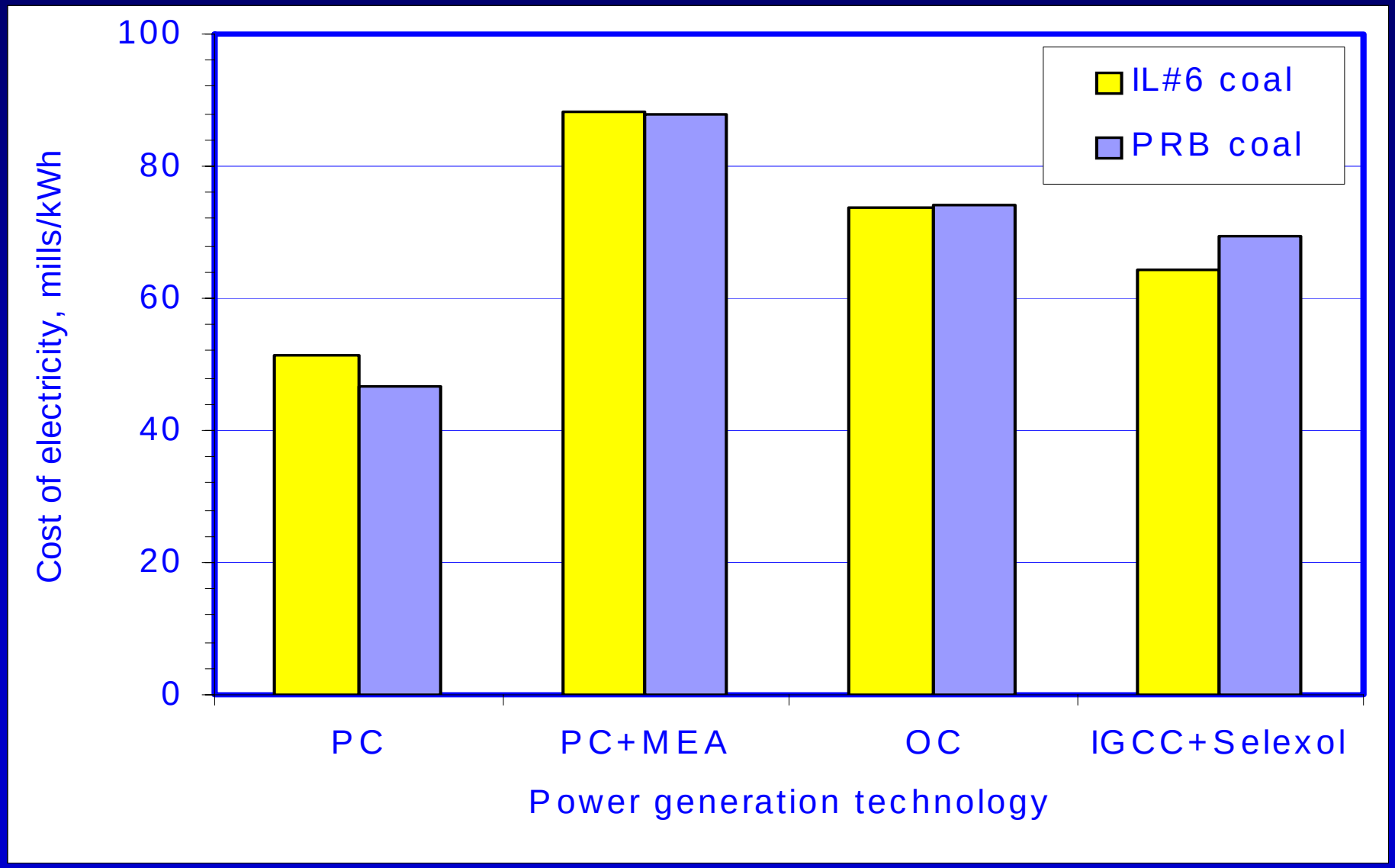


IL No.6 Coal vs. PRB Coal, 533 MW (gross) Power Plant



Potential Options for Reducing CO_2 Avoidance Cost

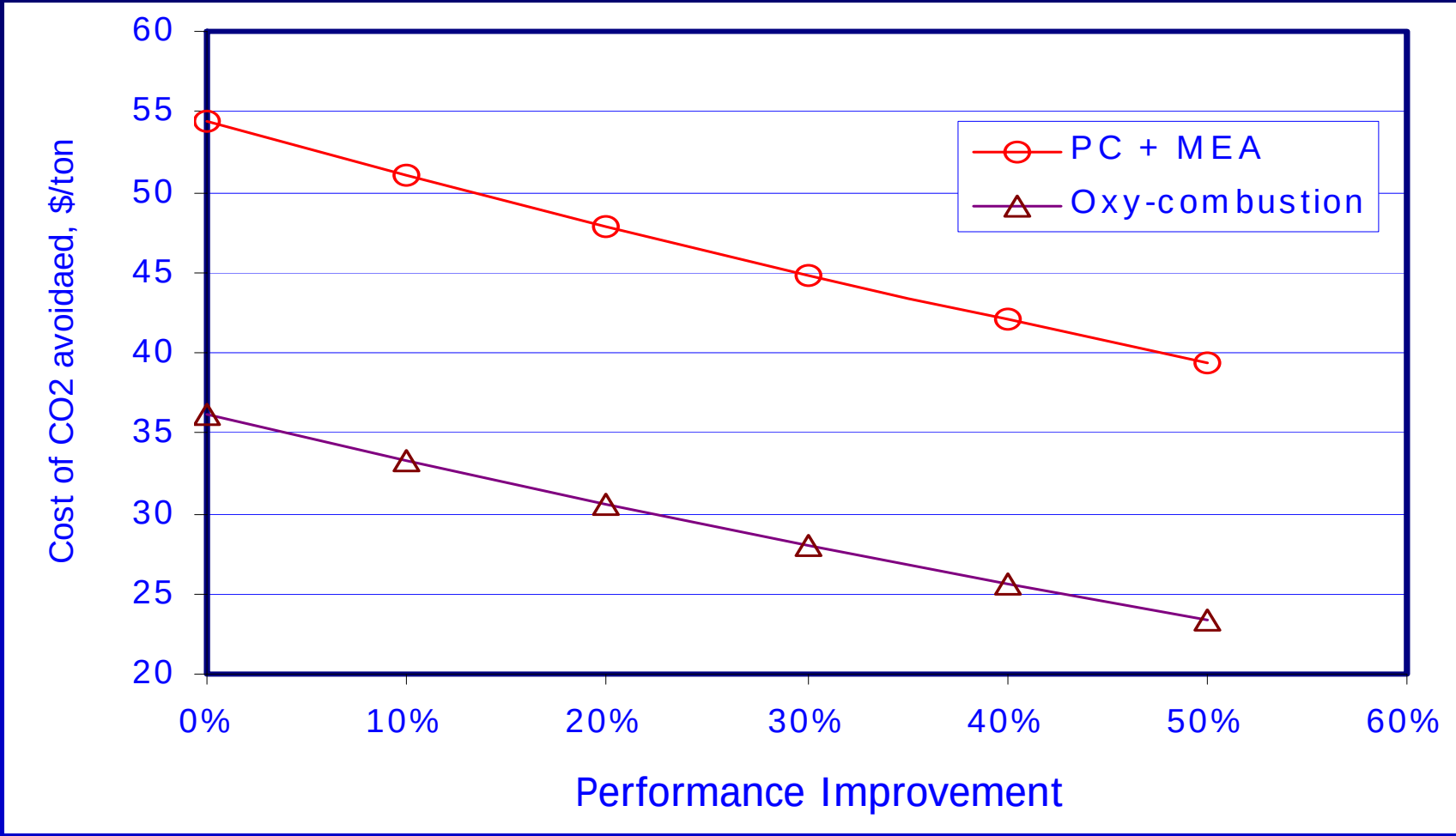
PC + Chemical Absorption

- Absorbents with lower regeneration energy requirement
- Absorbents with higher CO_2 loading capacity
- Absorbents with lower degradation
- Process integration and optimization

$20/ton CO_2 Avoidance Cost (533MW)

- Reducing amine regeneration energy by 80%
- + lowering amine degradation (loss) by 50%
- + lowering absorption process capital cost by 50%.

Sensitivity of CO_2 Avoidance Cost vs. Process Performance Improvement



MEA: Improvement in heat requirement for absorbent regeneration

Oxy-combustion: Improvement in energy use for air separation unit

Task 3

Assessment of Carbon Dioxide Transportation Options In the Illinois Basin

Douglas J. Nyman (Nyman & Associates)

J. Steve Dracos (Universal Ensco, Inc.)

William J. Hall (University of Illinois)

and Rajani Varagani (Air Liquide)

Midwest Geological Sequestration Consortium

www.sequestration.org

CO_2 Transportation Task Scope

- Elements of a CO_2 pipeline system
- Design and construction practices
- Right-of-way considerations and permitting
- Operating practices
- Prepare a model pipeline cost estimate
- Truck and rail transportation options for research-scale and field test quantities

Conceptual Route

Peoria, Illinois southward to Springfield, then southeasterly toward the Indiana-Kentucky border for 200 miles

Data Sources

- A CO_2 pipeline in Wyoming and the Alliance natural gas line in Illinois, both recently completed by Universal Ensco
- Industry publications and web sites
- Vendors (unit costs for material)
- Local union contractors (construction costs)

CO_2 Pipeline Components

- Metering and pressure regulating facilities
- Lateral pipelines (gathering and delivery)
- Main pipeline
- Booster facilities for longer lines
- Control center
- Operations and maintenance facilities

Unique Design Considerations for CO_2 Pipelines

- Must operate at high pressure to maintain CO_2 as a liquid
- Specify materials for pipeline construction that can withstand the refrigeration temperature that can be expected during a pressure reduction
- Water content in CO_2 must be controlled to avoid corrosion

Regulation of CO_2 Pipelines

- Title 49 Code of Federal Regulations (CFR), Parts 190–199
- Illinois Commerce Commission regulates safety of intrastate gas pipelines, but defers to the U.S. DOT 49 CFR 195.

Route Selection and Design

- Preliminary route selection
- Detailed route selection
- Detailed route design
- Corridors

Existing Corridors – A Major Consideration for Routing

- Power line corridors are generally preferred
  - Usually owned by power company
  - Usually have adequate work space
  - Requires consideration of high voltage interference
- Underground utility corridors are not owned; require permission from landowner
- Railroad right-of-ways are owned by railroad, but usually too narrow to be considered

Illinois Basin Pipeline Geohazards

- Earthquake – source event: New Madrid (500-yr to 1,000-yr recurrence) and Wabash Seismic Zones
- Coal Mining Subsidence – avoid where possible
  - Room-and-pillar mining
  - Long wall mining
- Numerous existing natural gas and products pipelines safely operated

Cost Elements for Pipeline Installation

- Right-of-way (easement and crop loss)
- Materials (pipe and valves)
- Construction
- Design, acquisition and inspection services

Permits Required

- Illinois Commerce Commission business permit
- U.S. Army Corps of Engineers – dredge and fill – wetlands and navigable waters
- Illinois Dept. of Natural Resources – crossings of rivers, lakes, and streams
- County land use permits
- Crossing permits for roads, utilities, county highways, railroads

Right-of-Way (Easement)

- Enables pipeline company to operate, test, inspect, repair, maintain, replace, and protect pipelines on property owned by others
- Agreement based on:
  - Fair market value
  - Damages to crops, grazing lands, timber, or structures
- Failure to reach negotiated agreement
  - Court proceedings
  - Right of eminent domain

Illinois Basin Right-of-Way Costs

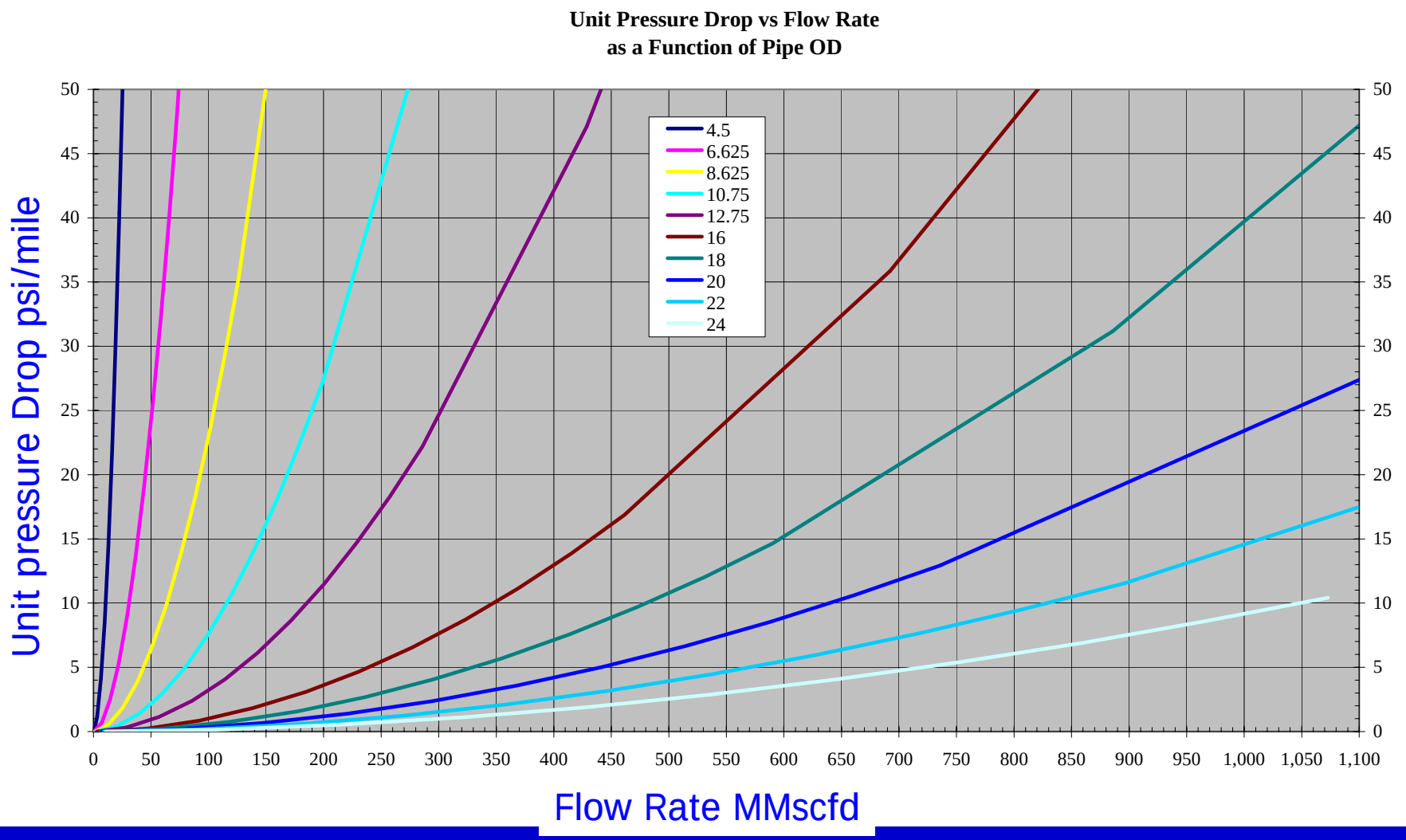
Diameter (inches)	$/mile	$/diameter inch/mile	$million/ 200 miles
4	36,713	9,178	7.3
6	36,713	6,119	7.3
8	44,500	5,563	8.9
10	44,500	4,450	8.9
12	51,731	4,311	10.3
16	66,750	4,172	13.4
18	66,750	3,708	13.4
20	66,750	3,338	13.4
22	66,750	3,034	13.4
24	66,750	2,781	13.4

Pipeline Design

- Capacity (diameter)
- Wall thickness
- API pipe grade
- Mill testing
- Welding and inspection
- Burial depths (4-5 ft)

Flow Rate Design

- Initiation pressure above 2,500 psig
- Delivery pressure ~ 1,500 psig.



Pipeline Material Cost

Diameter (inches)	$/mile	$/diameter inch/mile	$million / 200 miles
4	24,303	6,076	5
6	47,630	7,938	10
8	79,370	9,921	16
10	115,424	11,542	23
12	159,084	13,257	32
16	247,199	15,450	49
18	310,766	17,265	62
20	381,893	19,095	76
22	460,465	20, 930	92
24	546,136	22,756	109

Illinois Basin-Related Pipeline Construction Issues

- Flat to rolling farm land:
  - Unstable trench conditions
  - Intermittent high ground water
  - Drain tiles used for farming low areas
- Construction in agricultural areas works best mid-summer to fall
- Work around load limits on county roads

Site prep and grade complete; ready for pipe stringing

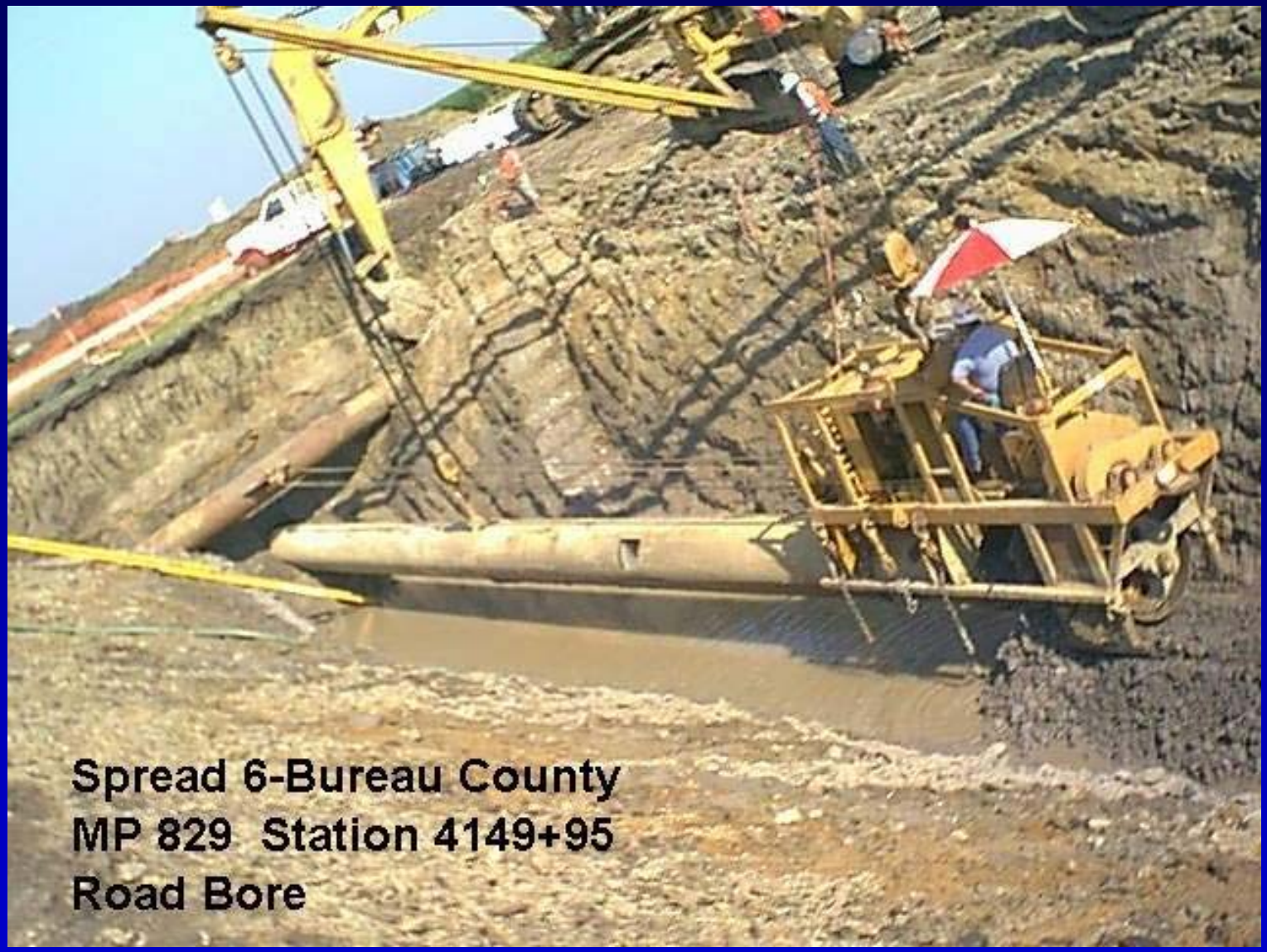
Pipe on skids and ditch complete; ready for pipe gang

Manual welding

Automatic welding

Pipe Welding

Lowering pipeline into trench



Road-boring operation

Areas of sandy soil and high water table may require sheet piling and dewatering systems

Completed Pipeline Right-of-Way in Agricultural Area

Illinois Basin Pipeline Construction Cost

Diameter (inches)	$/mile	$/diameter inch/mile	$million/ 200 miles
4	85,071	21,268	17
6	115,915	19,319	23
8	141,753	17,719	28
10	173,476	17,348	35
12	210,730	17,561	42
16	275,533	17,221	55
18	306,206	17,011	61
20	336,354	16,818	67
22	365,978	16,635	73
24	395,601	16,483	79

Pipeline Operations

- Remote operation of unattended facilities
- System and facilities continuously monitored by computer
- Control center could be anywhere; usually at one end of the line.
- Maintain liaison with public agencies
- Public outreach programs – for local residents and contractors

Total Cost: Illinois Basin Conceptual Route

Diameter (inches)	$/mile	$/diameter inch/mile	$million/200 miles
4	175,304	43,826	35
6	238,307	39,718	48
8	313,435	39,179	63
10	390,078	39,008	78
12	488,992	40,749	98
16	677,905	42,369	136
18	779,444	43,302	156
20	887,047	44,352	177
22	1,000,375	45,472	200
24	1,129,505	47,063	226

Pipeline Summary

- Technology and construction practice for CO_2 pipelines are well-established
- Permitting and right-of-way acquisition poses the greatest challenges (mainly time)
- Task 3 pipeline study provides basic cost and pipe sizing information for developing realistic source-sink transportation scenarios

Task 3

Truck and Rail Transportation

Rajani Varagani
Air Liquide, Chicago

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Sequestration Consortium
www.sequestration.org

Transportation for Field Test Site Operations

- CO_2 Transportation
  - Task 3 Assessment of:
    - Truck transportation
    - Rail transportation
    - Equipment/Secondary storage requirements at sink
- Specific path from source to sink after simulation results (Task 7)

Truck Transportation

- 20 to 22 tons of liquid CO_2 per truck
- Typical transportation cost* $1.75 - $2.00 per mile per truck
- CO_2 in truck
  - State: Liquid
  - Pressure: 275 – 300 psi
  - Temperature:

    0 to 10° F

* Assuming immediate loading/unloading and fees not included, mileage counted either loaded or empty truck

Rail Transportation

- 80 tons of liquid CO_2 per rail car (latest jumbo cars – 90 tons)
- Transportation cost
  - Minimal cost variation vs. distance
  - Depends on the 'route' from source and sink, e.g., rail transfers
  - Typical cost: $ 25 per ton of CO_2 (+ up to $ 5 per ton for additional charges)

Rail Transportation

- CO_2 in rail car
  - State: Liquid
  - Pressure: 350 psi venting pressure
  - Temperature: ~ 10° F
- Lease costs
  - $ 900/month per rail car
  - Duration: >12 months
  - Longer lease →cheaper rents
- 2 – 10 days for delivery
- Trucks may be needed to move CO_2 from rail car to sink

Secondary Storage

- Generally required to meet rates of injection
- Maximum “customer” tank available is 120 ton, most used are 50-60 ton tanks
- Standard liquid CO_2 tanks are generally used for long term usage (> 4 months)
  - Higher capacity
  - Easy availability
  - Rent: $1500/month for 1 year lease
- Number of storage tanks depend on injection rate, days of storage

Storage tanks: Left: 250 ton depot tank, right two: 45 ton customer tanks

Unloading and Injection Equipment

- Unloading equipment package costs
  - Pump/compressor: $ 20 – 25 k
  - Rail towers: $ 20 k each
- Injection equipment package costs
  - $ 50 k for 200 to 300 tons per day injection rates
- Equipment and cost depend on:
  - Injection rate, injection pressures, temperatures
  - Liquid/gaseous/super-critical injection

Long-Term Considerations

- Huge volume potential from sequestration:
  - 11-13,000 tons/day of CO_2 from a 500 MWe power plant
  - Current CO_2 merchant market of US: 30,000 tons/day (CO_2 truck and rail)
- Pipeline is the primary long-term option
- CO_2 purity not a concern for transportation as long as it is dry (<100 ppm of water)

Project Tasks 4 and 5

CO_2 Storage in Coal and Oil
(ECBM and EOR)

Scott M. Frailey

Illinois State Geological Survey

Midwest Geological
Sequestration Consortium
www.sequestration.org

Cross-Sink Studies

- Isotopes (K. Hackley, ISGS)
- In situ stress (R. Bauer, ISGS)
- Subsidence (R. Bauer, ISGS)
- Seismicity (J. McBride, BYU)
- MMV-underground gas storage technology (E. Mehnert, S. Frailey, H. Leetaru, ISGS)
- Regulatory (R. Finley, ISGS)

CO_2 Isotopic Characterization

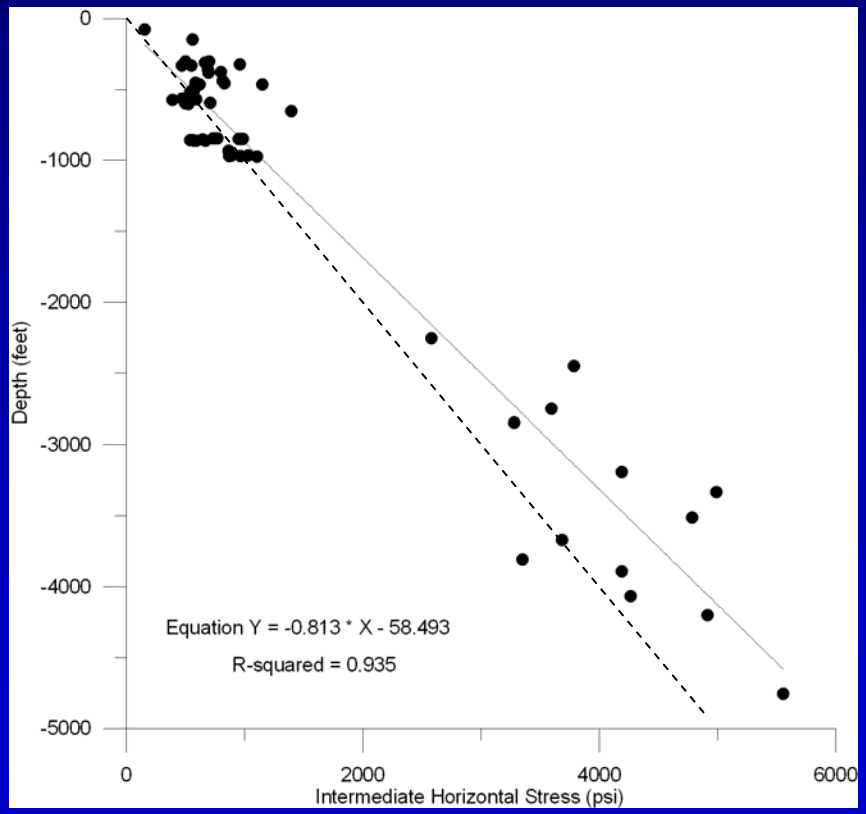
- Testing
  - radiocarbon isotope (^{14}C)
  - stable carbon isotope ($\delta^{13}C$)
- Domestic water well completed
  - Atypically high CO_2 concentration reported
  - Measured CO_2 concentration typical for reduced groundwater, $\delta^{13}C$ values within normal range
  - Cause of corrosion: addition of O_2 to well water CO_2, resulting from use of out-dated pumping and storage system technology

CO_2 Isotopic Characterization, contd.

- Coal seams tested (shallow seams)
  - Danville, Springfield, Herrin and Davis
  - Davis coal gave low $\delta^{13}C$ response
- Ethanol (fermentation) plant tested
  - ^{14}C > 100 pMC and $\delta^{13}C$ typical of corn type vegetation
- Additional sample acquisition planned
  - **Illinois Basin coal** burning power plant
  - **PRB** coal burning power plant
  - Inorganic carbon associated with Basin brines
  - Coal seams from deeper in the IL Basin

In Situ Stress Study

- Interest
  - prevent CO_2 injection induced fracture
  - estimate maximum formation pressure limit
- Observations
  - highest stress: horizontal
  - most intermediate stresses are horizontal
  - ~1psi/ft fracture gradient (with limited data)



Optimal Sinks

- High CO_2 storage capacity
- High CO_2 injection rate
- Centrally located
- Storage mechanism present
  - geologic (stratigraphic, structure)
  - phase trapping (capillary, surface tension)
  - dissolution

Project Task 4

Coal: CO_2 Storage Assessment

MGSC Project Team

J. Rupp, M. Mastalerz, and A. Drobniak IGS

C. Eble, KGS

T. Moore, C. Korose, A. Anderson, S. Frailey and R. Bauer, ISGS

S. Harpalani, SIU-C

Coal Bed Objectives

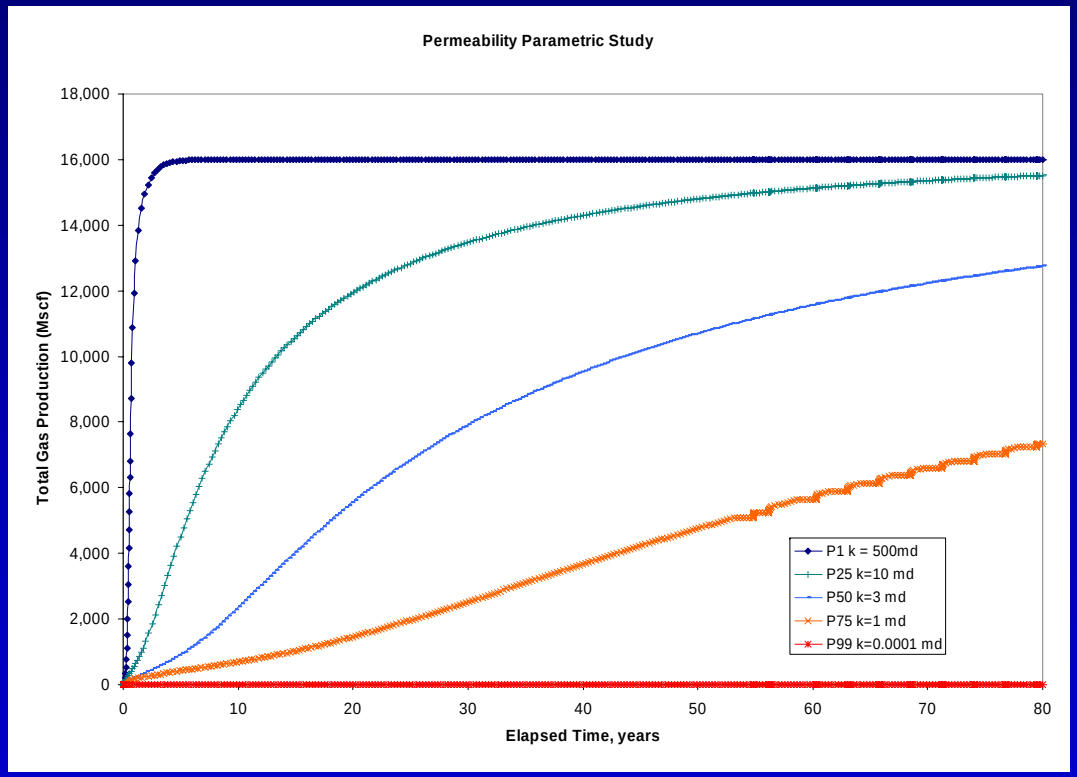
- Parametric study
- Coal Sequestered CO_2 Volume (CSCV)
- CO_2 Enhanced Coalbed Methane (ECBM)
- CO_2 ECBM injection rate
- CSCV and ECBM distribution

Parametric Study: ARI's COMET

- Coal petrophysical properties classification
  - 500-900', 900-1200', >1200, KY Grabens
  - probabilistic approach
- Reservoir simulation of CBM and CO_2 ECBM (COMET ECBM/CBM model)
- Model specifications
  - ¼ of 80 acre, CO_2 injection 5-spot pattern
  - hybrid grid, local well refinement

Parametric Study: COMET

- Scenarios
  - CBM (No ECBM)
  - CO_2 startup time
  - Multi-seam models
- ECBM and CSCV comparisons at:
  - CO_2 breakthrough
  - 1 PV CO_2 injection
  - 30 years injection



Coal: CSCV Equations

$$0.6168\rho_{CO2std}C_{CO2i}\rho_c Ah(1-\phi)(1-f_a-f_m)E_v$$

- CO_2 Adsorbed to Coal

$$19.76\rho_{CO2}hA\phi(1-S_w)E_v$$

- Mobile, Free Phase CO_2 (cleats)

$$3.519\rho_{CO2std}R_{sCO2/w}hA\phi S_w E_V$$

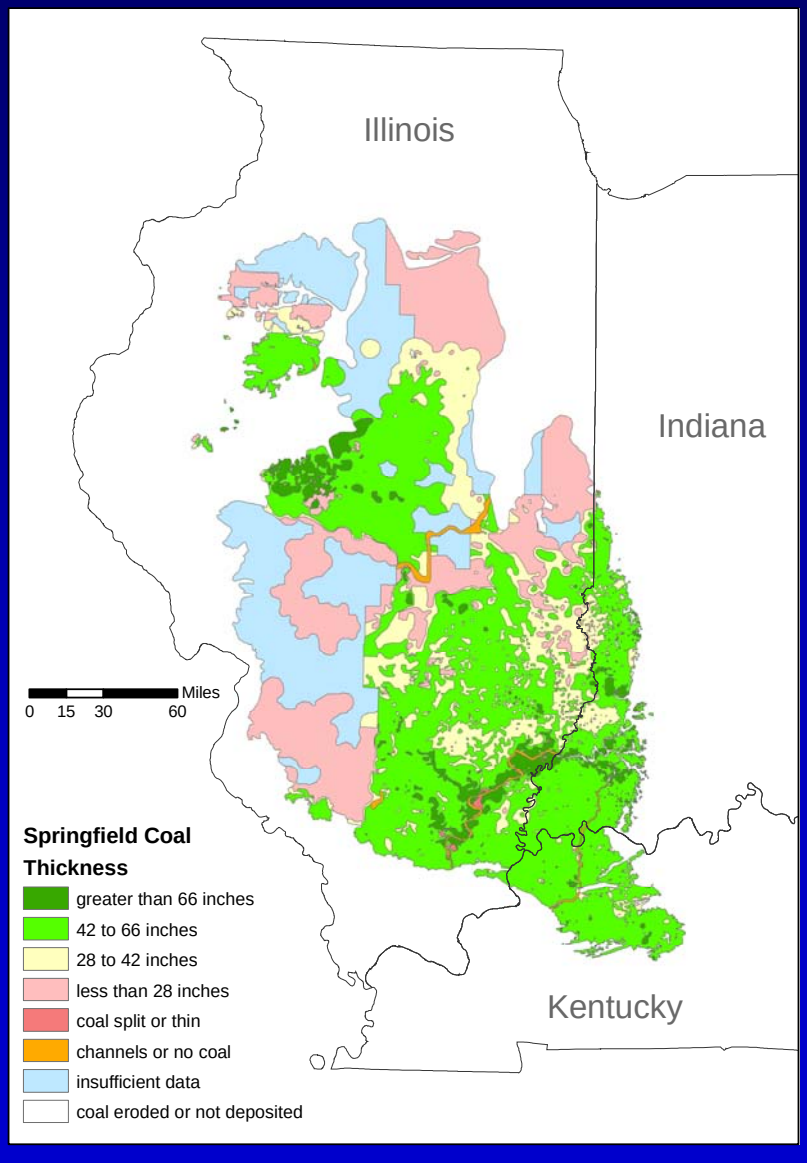
- CO_2 Saturated Water (cleats)

Coal CO_2 Storage: Parameters Required

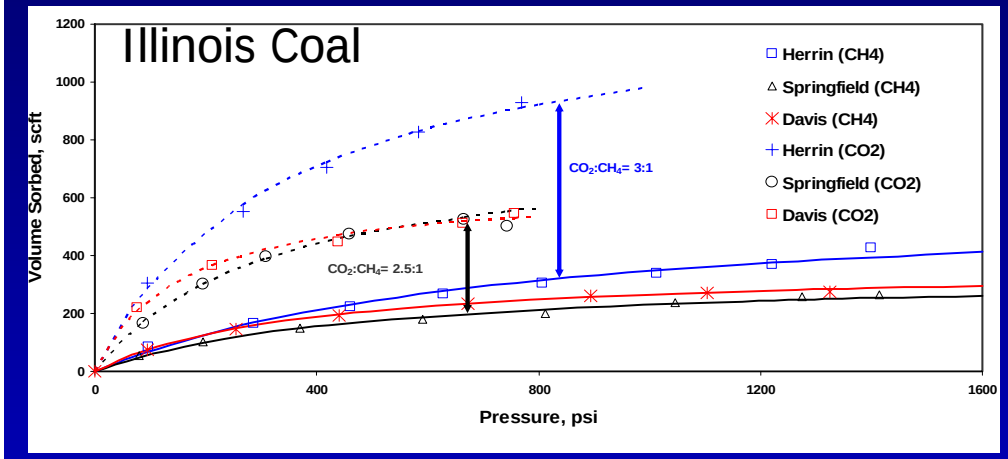
- Area and thickness (bulk volume)
- CO_2 adsorption (Langmuir isotherm)
- Porosity (cleat), ash and moisture content
- CO_2 solubility in reservoir water
- Volumetric displacement efficiency

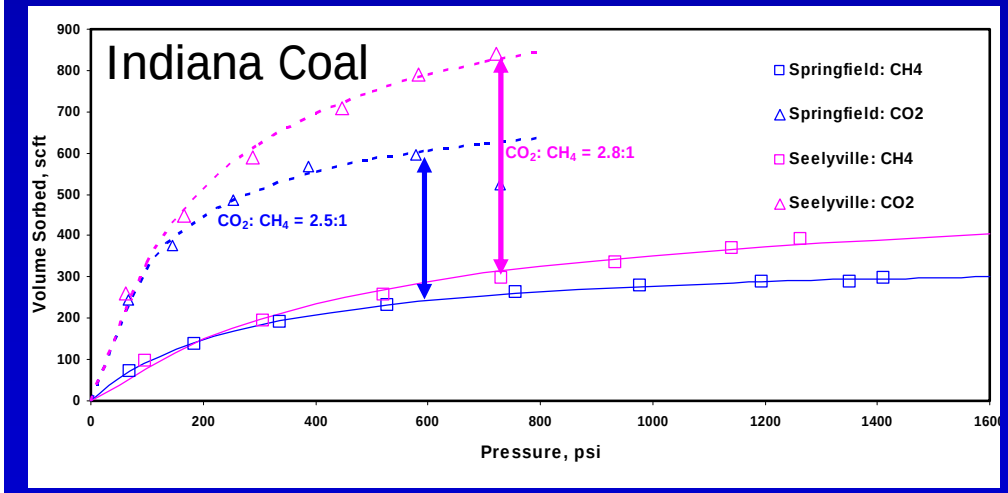
Area and Thickness

- Seven coal seam maps
- Screening criteria (to infer unminable)
  - thickness <42”
  - depth > 1000’



Sorption Isotherms

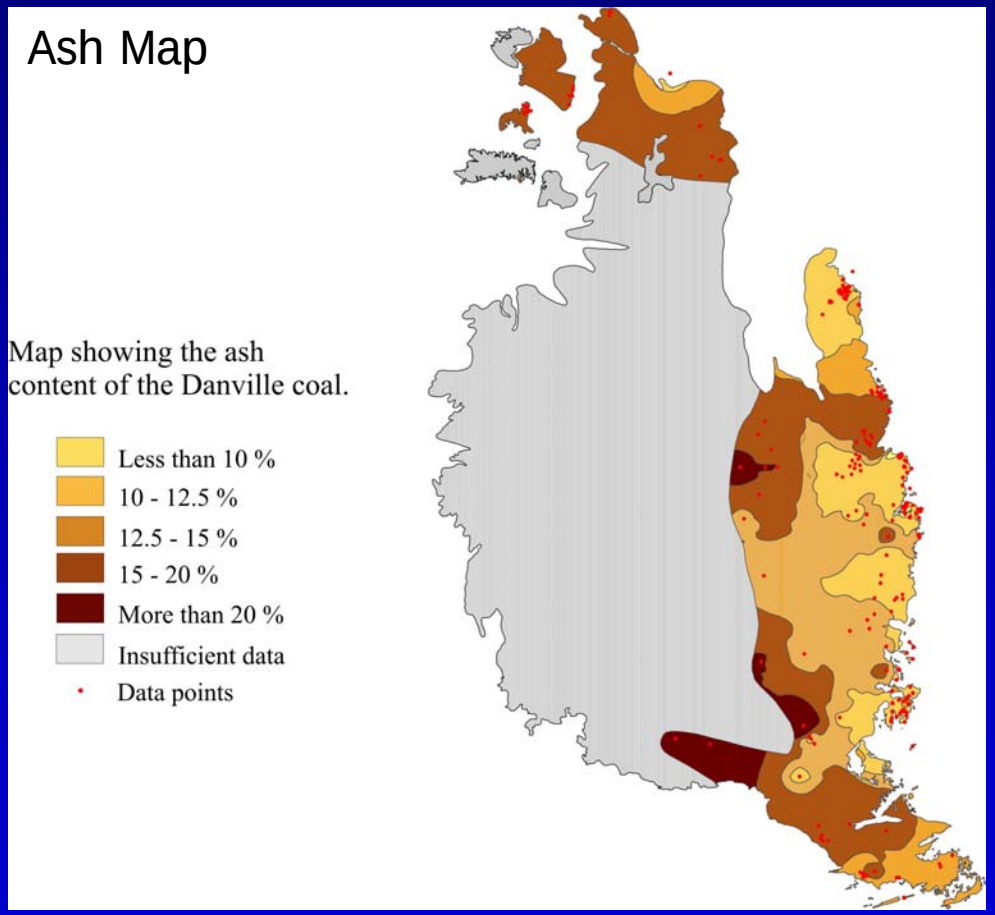




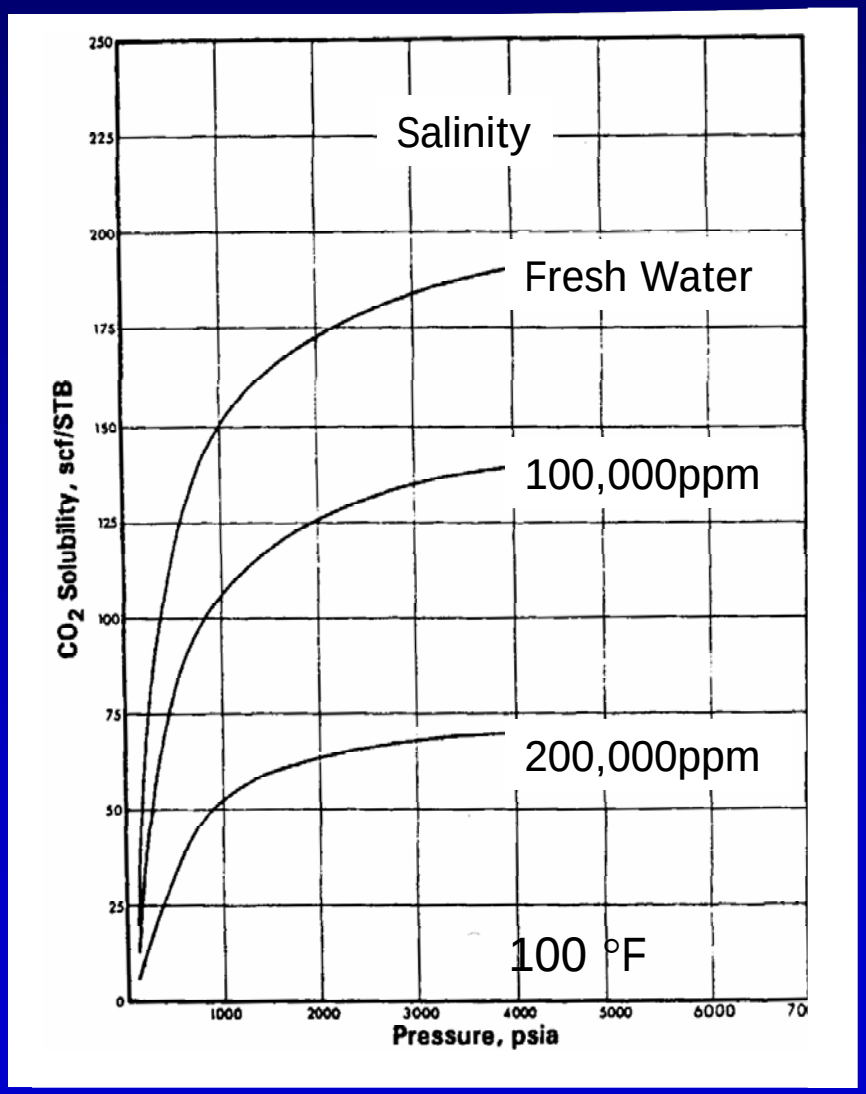
- Langmuir isotherms
  - four different coal seams (Herrin, Davis Springfield, Seelyville)
  - Methane 264-425 scf/t
  - CO_2 600-925 scf/t
  - CO_2/C_1 2.5-3.0 ratio
- Other experiments
  - competitive desorption
  - differential swelling (bulk volume)

Porosity (Cleat), Ash and Moisture Content

- Cleat
  - porosity
  - orientation
  - limited data
- Ash and moisture
  - limited data
  - maps in preparation



CO_2 Solubility in Reservoir Water

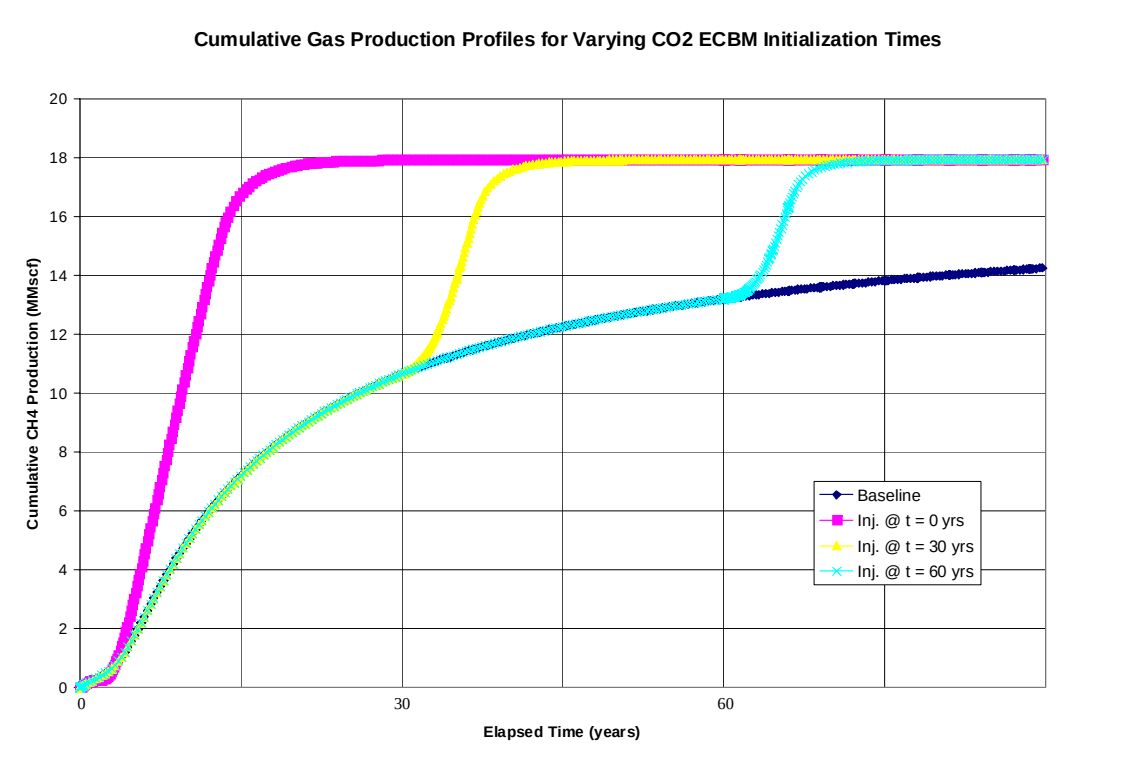


- Correlation available
- Function
  - pressure
  - temperature
  - salinity
- Pressure < 1000 psia, solubility change with pressure (scf/stb/psi) significant

"Phase Behavior", Whitson and Brule, SPE Monograph 20, 2000

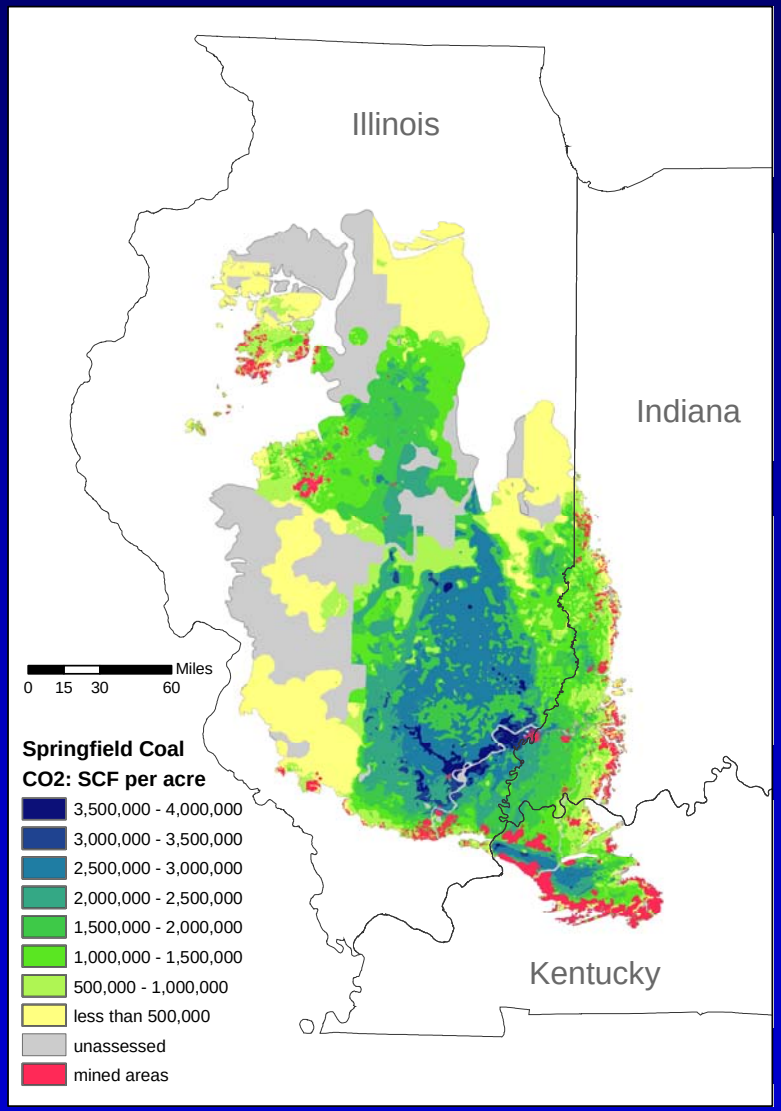
Volumetric Displacement Efficiency

- E_V: fraction of the coal bulk volume CO_2 contacts
- ECBM recovery and CSC factors from ECBM/CBM reservoir simulation

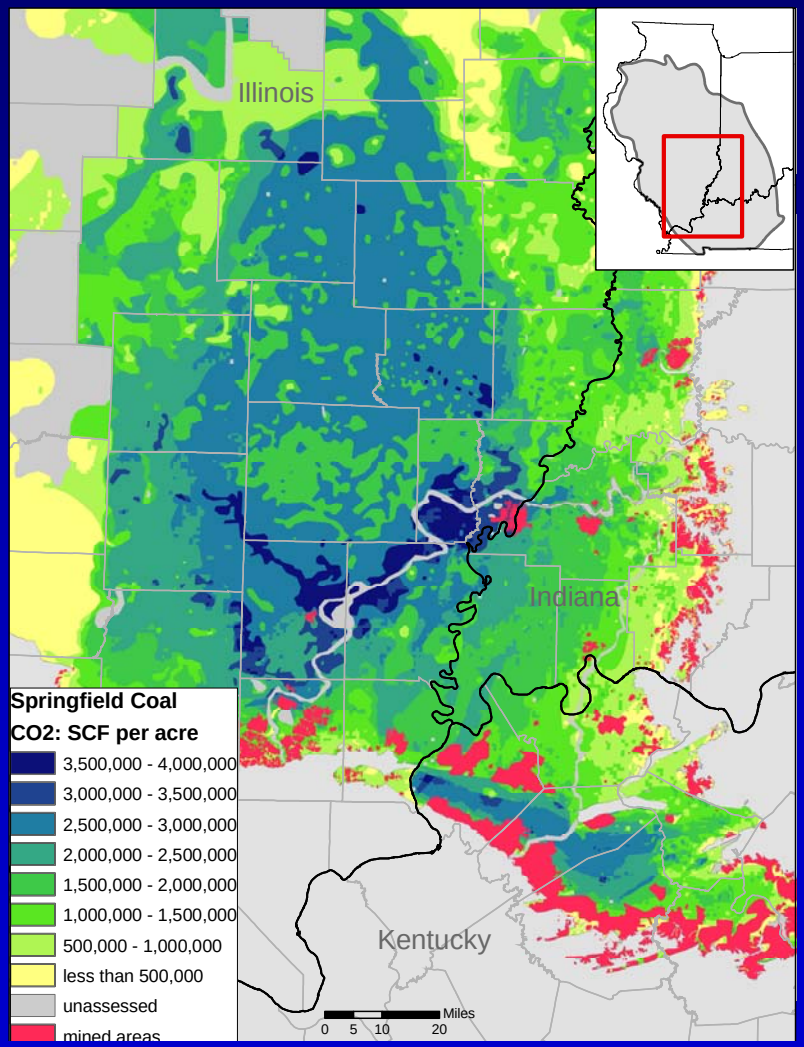


GIS Calculation of CO_2 Storage

- Combine GIS layers of coal properties using CSCV equation for each coal seam
- Sum CSCV for all coal seams
- Contour map of CSCV for Basin
- Similar approach for ECBM



Final Product
CO_2 ECBM and CSCV Estimates



Zone	CSCV Mtonne	ECBM Tscf
Springfield	*110-330*	*0.70-2.1*
Herrin	*b*	*x*
Seelyville	*c*	*y*
Davis	*d*	*z*

10-30% E_V; 33% C1/CO_2 (Allison)

Maps and tables for ECBM and CSCV

Project Task 5

Oil: CO_2 Storage Assessment

MGSC Project Team

B. Seyler, R. Knepp, D. Keefer, S. Frailey, C. Korose, D. Garner, B. Huff, J. Grube and S. Gustison, ISGS

J. Rupp, IGS and B. Nuttall, KGS

S. Rittenhouse, ISU

Oil Reservoir Objectives

- Oil Sequestered CO_2 Volume (OSCV)
- CO_2 Enhanced Oil Recovery (EOR)
- CO_2 EOR injection rate
- OSCV and EOR distribution

Oil: OSCV Equations

$$19.76\,\rho_{CO2}hA\phi S_g$$

- Mobile, Free Phase CO_2 (replaces hydrocarbon gas)

$$19.76\,\rho_{CO2}hA\phi S_o E_V$$

- Mobile, Free Phase CO_2 (replaces EOR)

$$3.519\,\rho_{CO2std}R_{sCO2/oil}hA\phi S_{or}E_V$$

- CO_2 Saturated Residual Oil

$$3.519\,\rho_{CO2std}R_{sCO2/w}hA\phi S_w E_V$$

- CO_2 Saturated Water

Oil CO_2 Storage: Parameters Required

- Original oil in place (OOIP) combines
  - area, thickness and porosity (pore volume)
  - initial oil, gas, and water saturation
- CO_2 solubility in reservoir water and oil
- Volumetric displacement efficiency

Original Oil In Place: Data

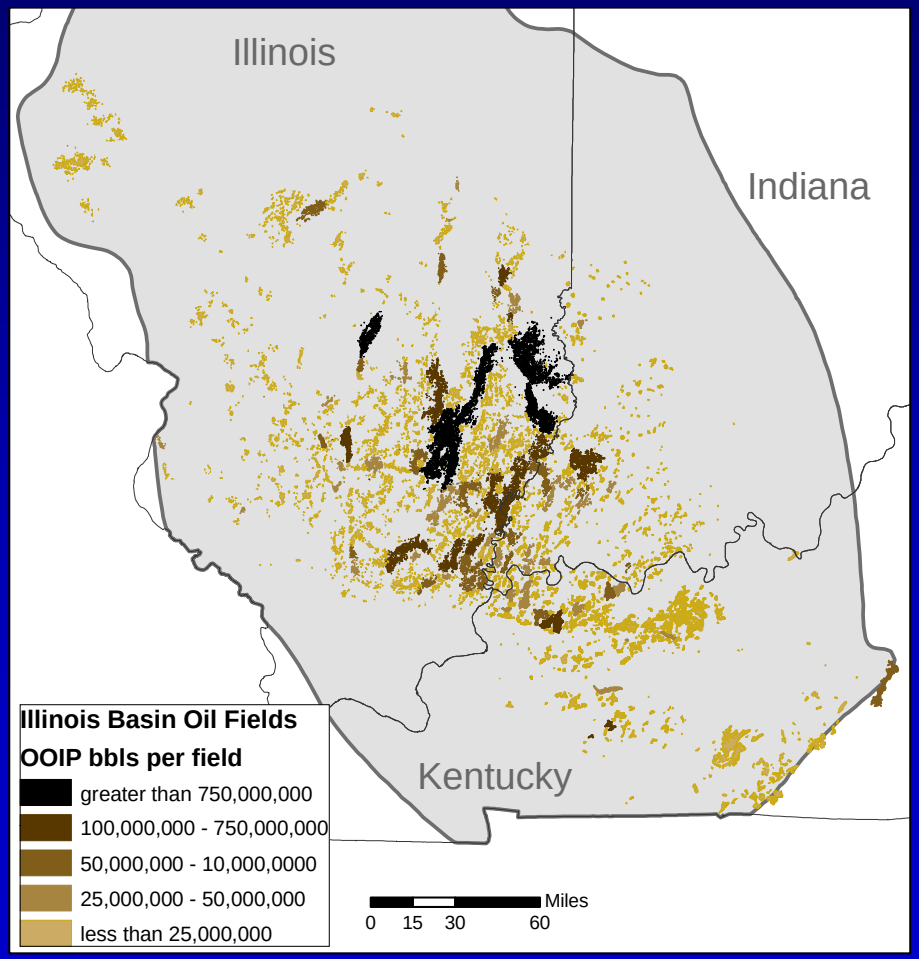
- OOIP (N) includes A, h, ϕ, S_o, S_g, and S_w

$$N = 7758\ Ah\phi(1-S_w)/B_o$$

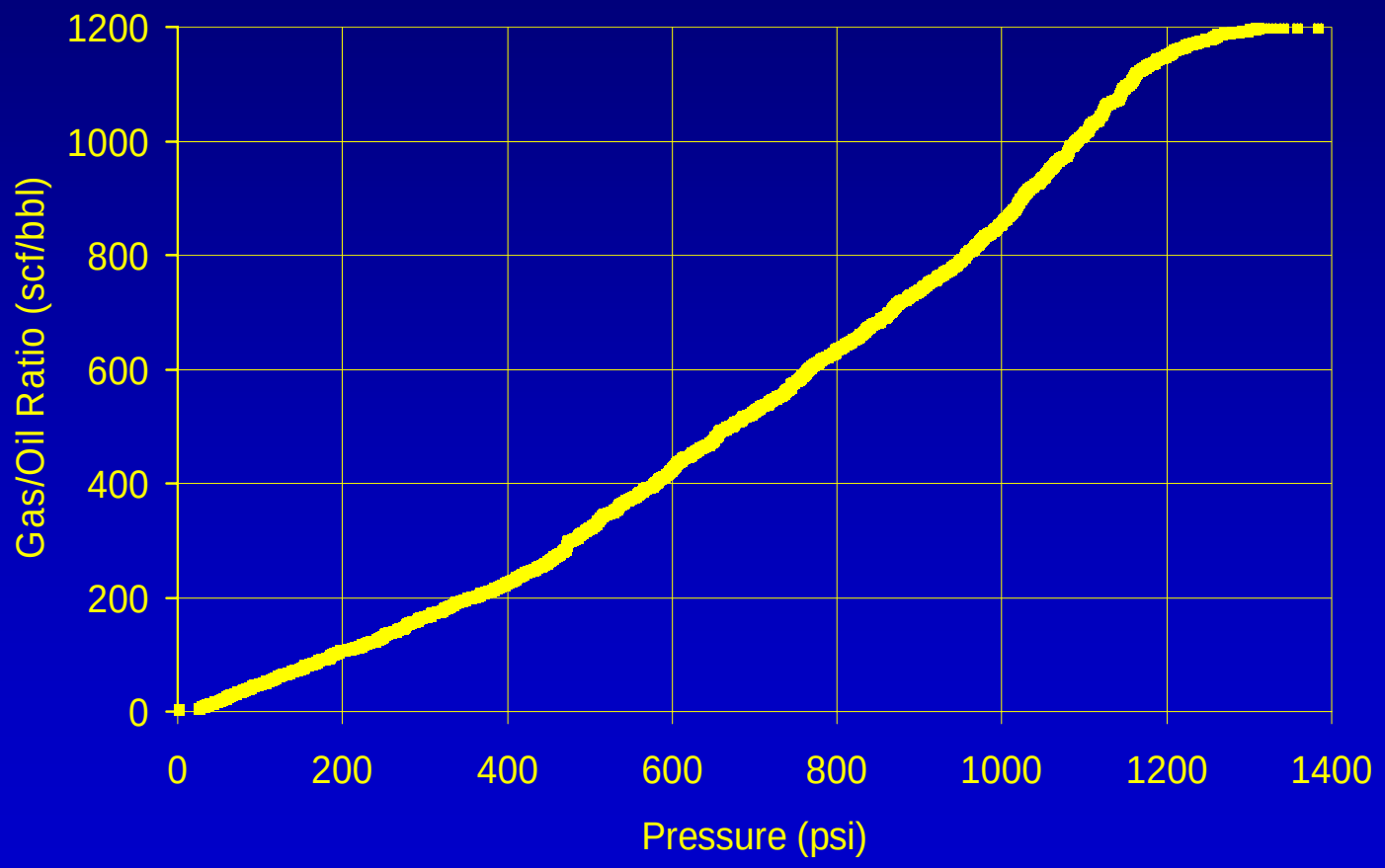
- Data available for most formations
- Statistics used to complete missing data
- Verification of top fields (80% N_p-67 fields)
  - thickness (waterflood unit reports)
  - GIS-based reservoir areas
  - decline curves

Original Oil In Place Map

OOIP MMstb	Number of Fields
>750	4
100-750	15
50-100	24
25-50	38
<25	>1000



CO_2 Solubility in Reservoir Oil



Temperature 98 °F

Dale Consolidated Field

Franklin County IP 140

Volumetric Displacement Efficiency

- *CO_2 Oil Recovery Factor* (E_R)

$$E_R = \frac{N_{pEOR}}{N}$$

- *CO_2 Sequestration Factor* (E_S)

$$E_S = \frac{G_{injCO2}}{N}$$

- E_R and E_S functions of OOIP (N)

Estimating Oil Recovery (E_R) and CO_2 Sequestration (E_S) Factors

- Landmark software (Geographix and VIP)
- Recovery factors based on most prolific Illinois Basin oil producing formations
  - Aux Vases
  - St. Genevieve
  - Cypress
- Structure and isopach: Deterministic
- Porosity and permeability: Statistical

Oil Recovery and CO_2 Sequestration Factors

- Miscible/immiscible: pressure and temp (phase behavior)
- Geologic formations: flow heterogeneity and depositional environment
- Separate table for E_S Factors

CO_2 Oil Recovery Factors

Miscible Conditions

Zone	I	N	M
A-V	*5-8*	*5-15*	*10-15*
St.G	*4-8*	*4-16*	*13-16*
Cyp	*5-10*	*5-19*	*14-19*

This table is an example only

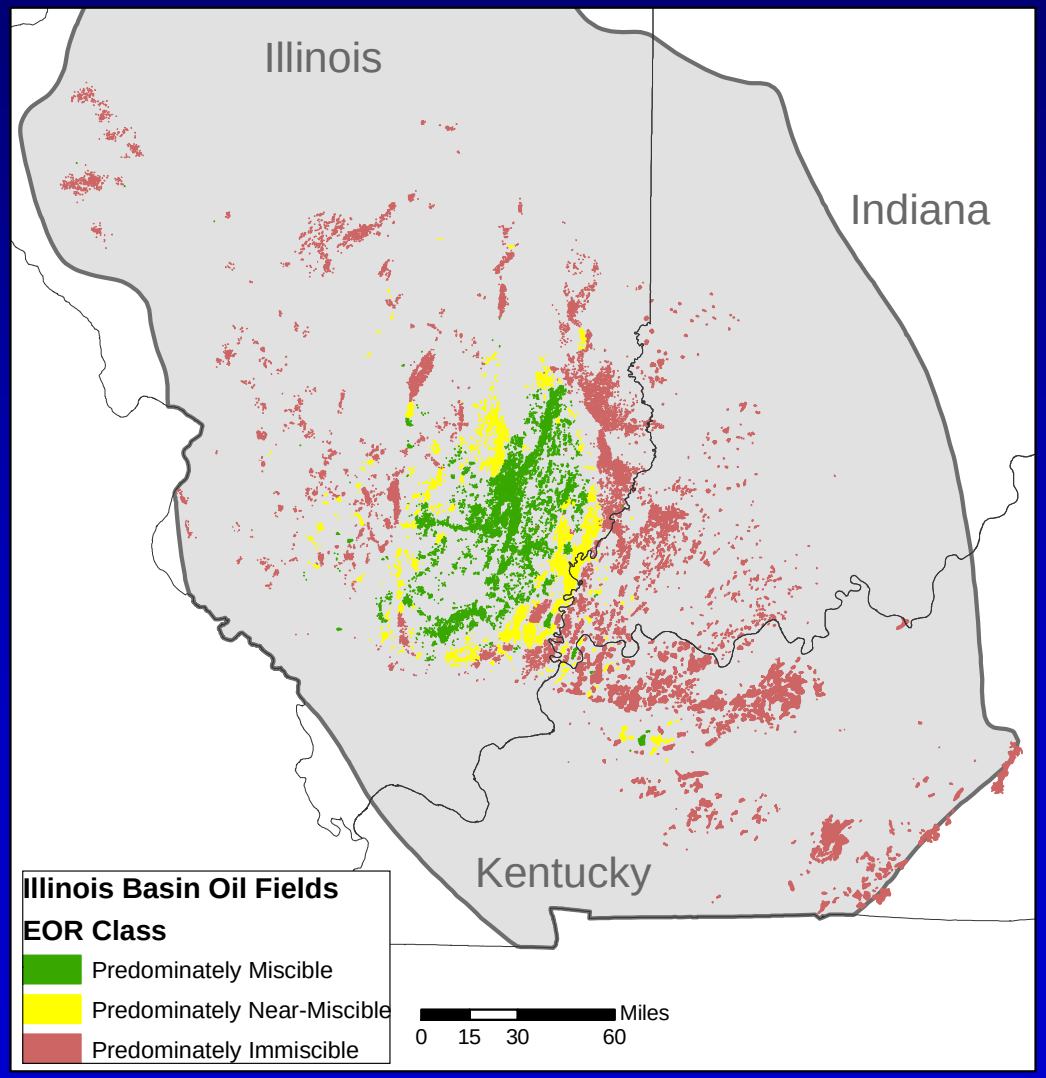
Miscible, Near Miscible and Immiscible Map

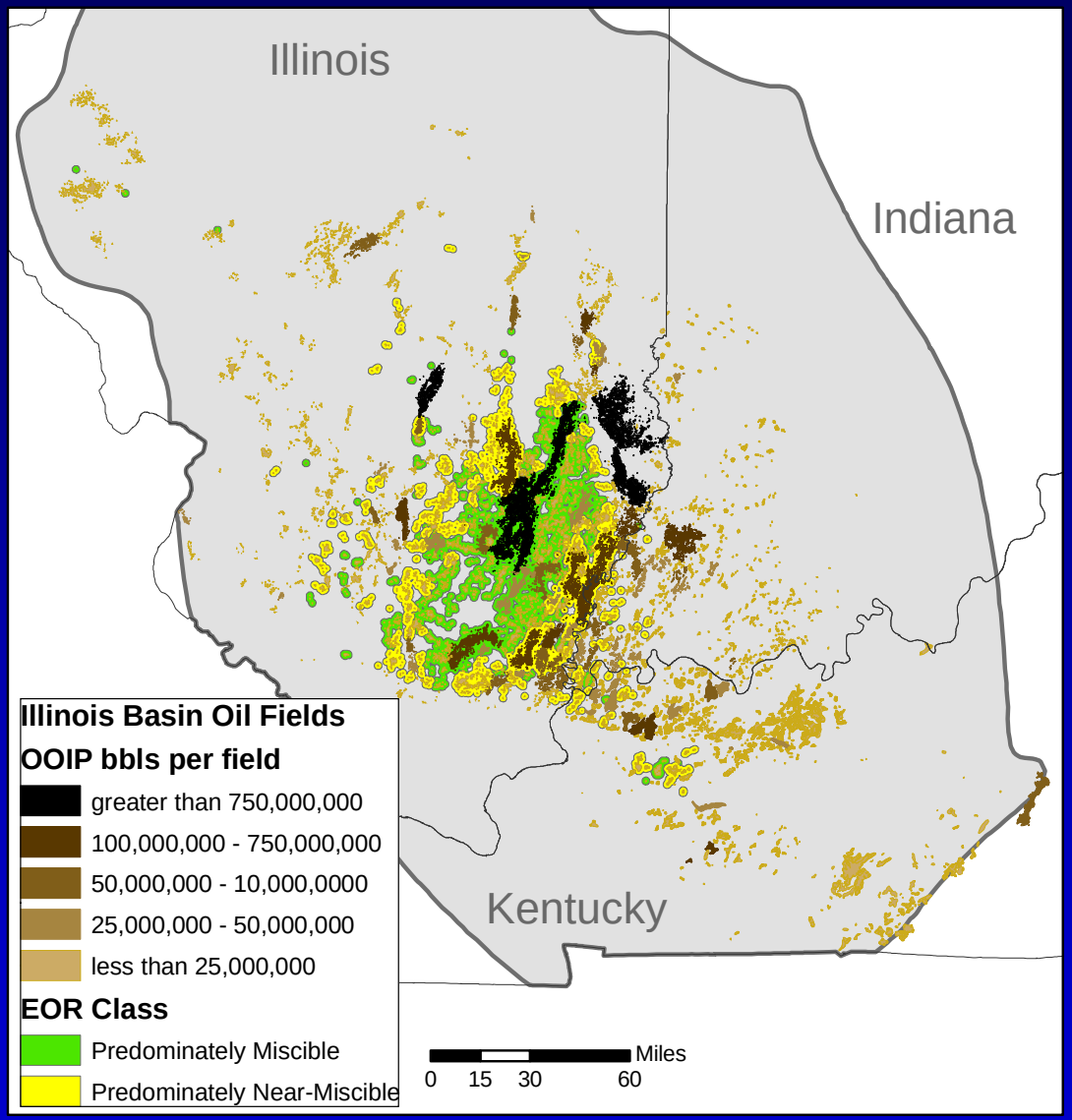
Classification based on anticipated pressure and temperature using gradients observed in the Basin

Field depth: bulk volume weighted by formation

Pressure: 0.433-1.0 psi/ft

Temperature: 1.0-1.2 F/100 ft

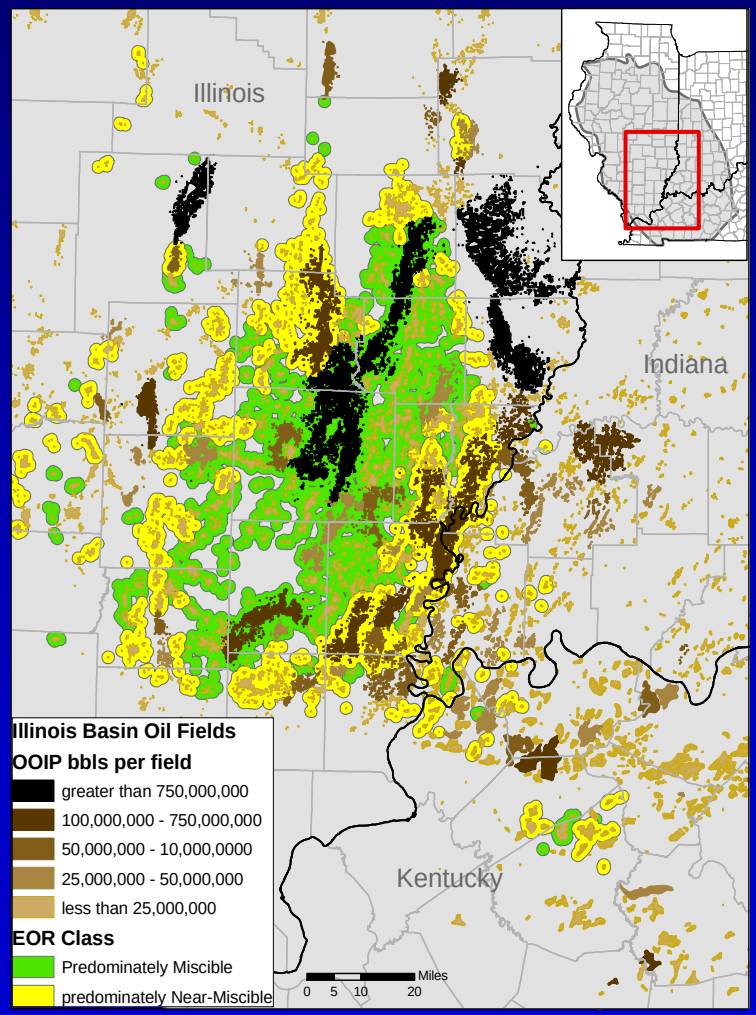




GIS Analysis: OOIP & Miscibility Map

Miscibility Condition	OOIP Bstb
Miscible	*2-2.5*
Near	*2-2.5*
Immiscible	*8-10.5*

Final Product
CO_2 EOR and SCV Maps



Condition	CO_2 Mtonne	EOR Bstb
Miscible	*40-220*	*0.15-0.40*
Near	*30-160*	*0.10-0.30*
Immiscible	*90-550*	*0.30-1.0*
Total	*160-930*	*0.55-1.7*

Maps and tables for EOR and OSCV

West Texas CO_2 EOR Rules-of-Thumb

Task 6

Saline Reservoirs In the Illinois Basin

Hannes Leetaru, David Morse,
Scott Frailey, Don Keefer, and
Edward Mehnert (Illinois State Geological Survey)

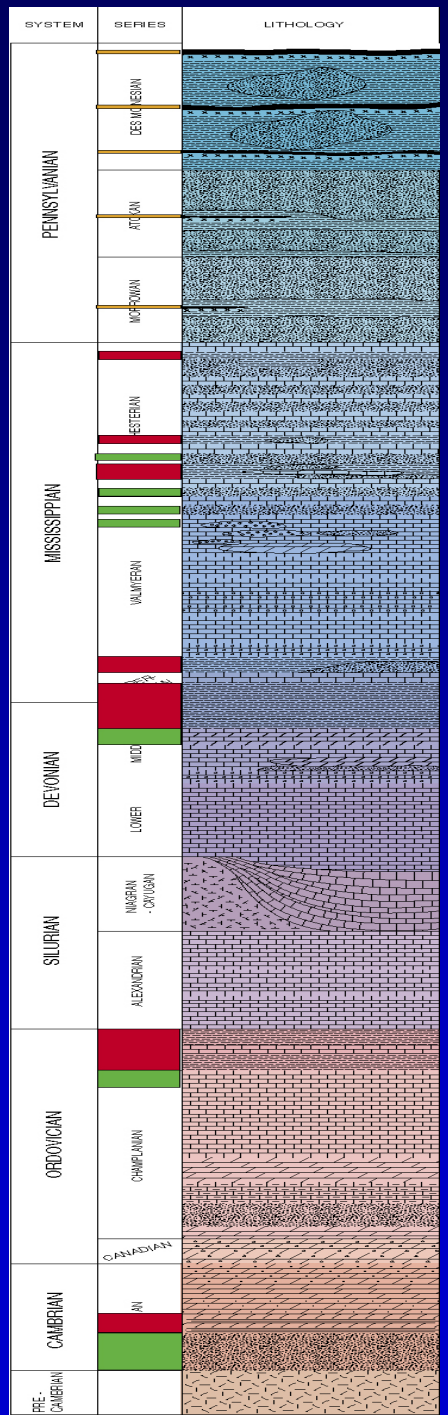
James Drahovzal and Steve Fisher (Kentucky Geological Survey)

Sarah Rittenhouse (Illinois State University)

John McBride (Brigham Young University)

Midwest Geological
Sequestration Consortium

Illinois Basin Stratigraphic Column



Mississippian

New Albany

Maquoketa

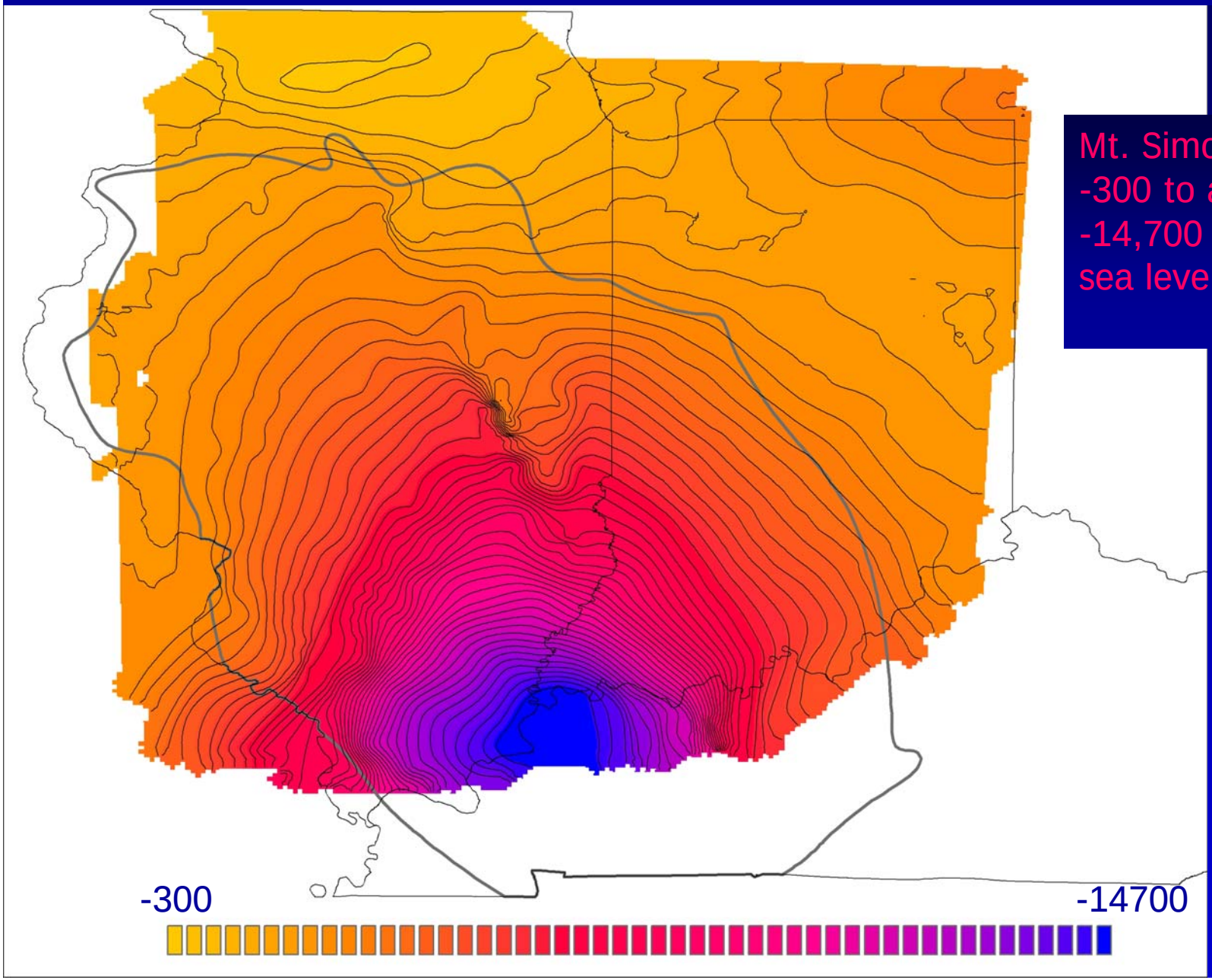
St. Peter

Eau Claire (Seal)

Mt. Simon (Sink)

- Potential Seal
- Potential Sink
- Coal Bed Potential Sink and Seal

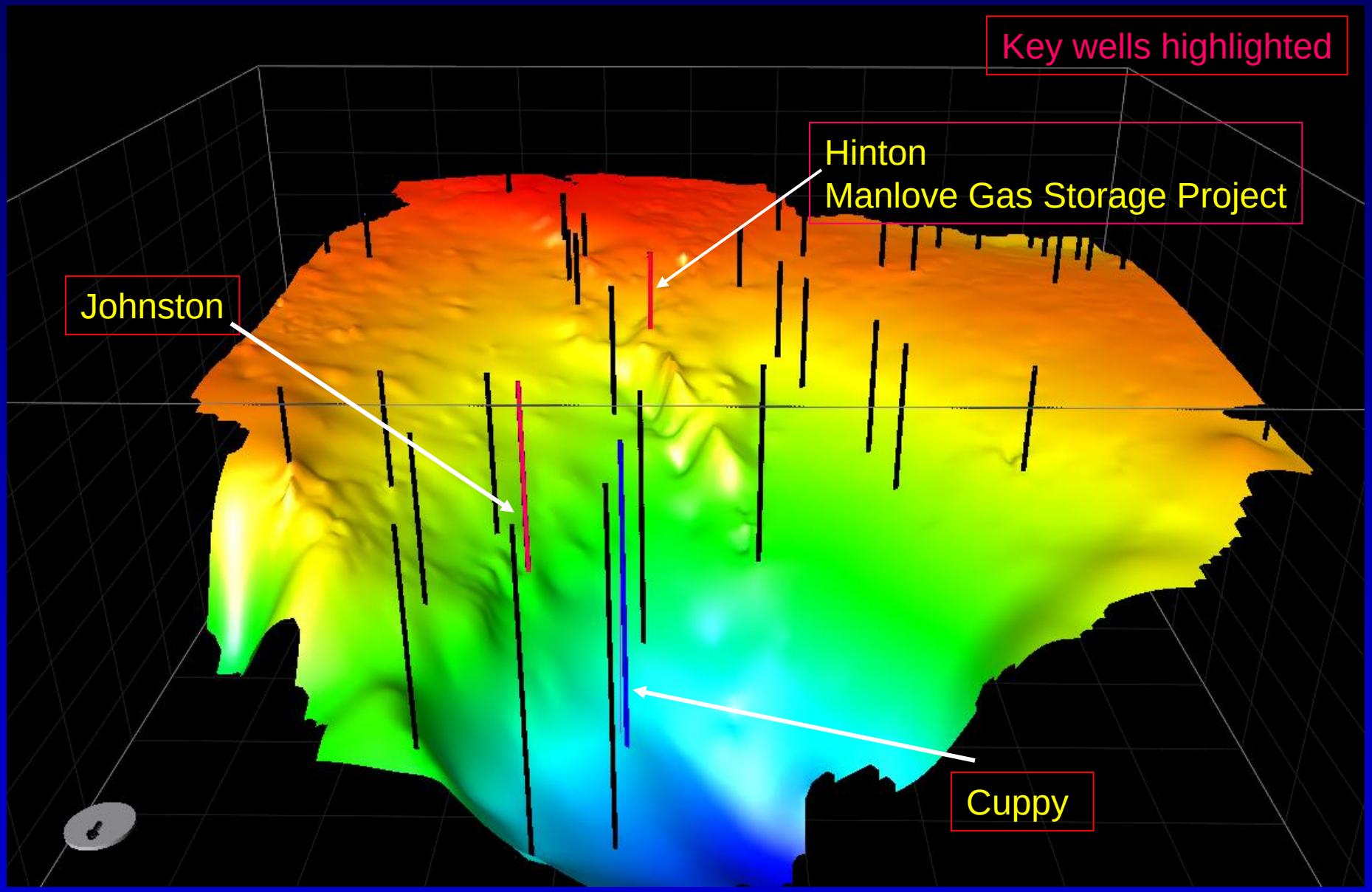
Structure: Top of Mt. Simon



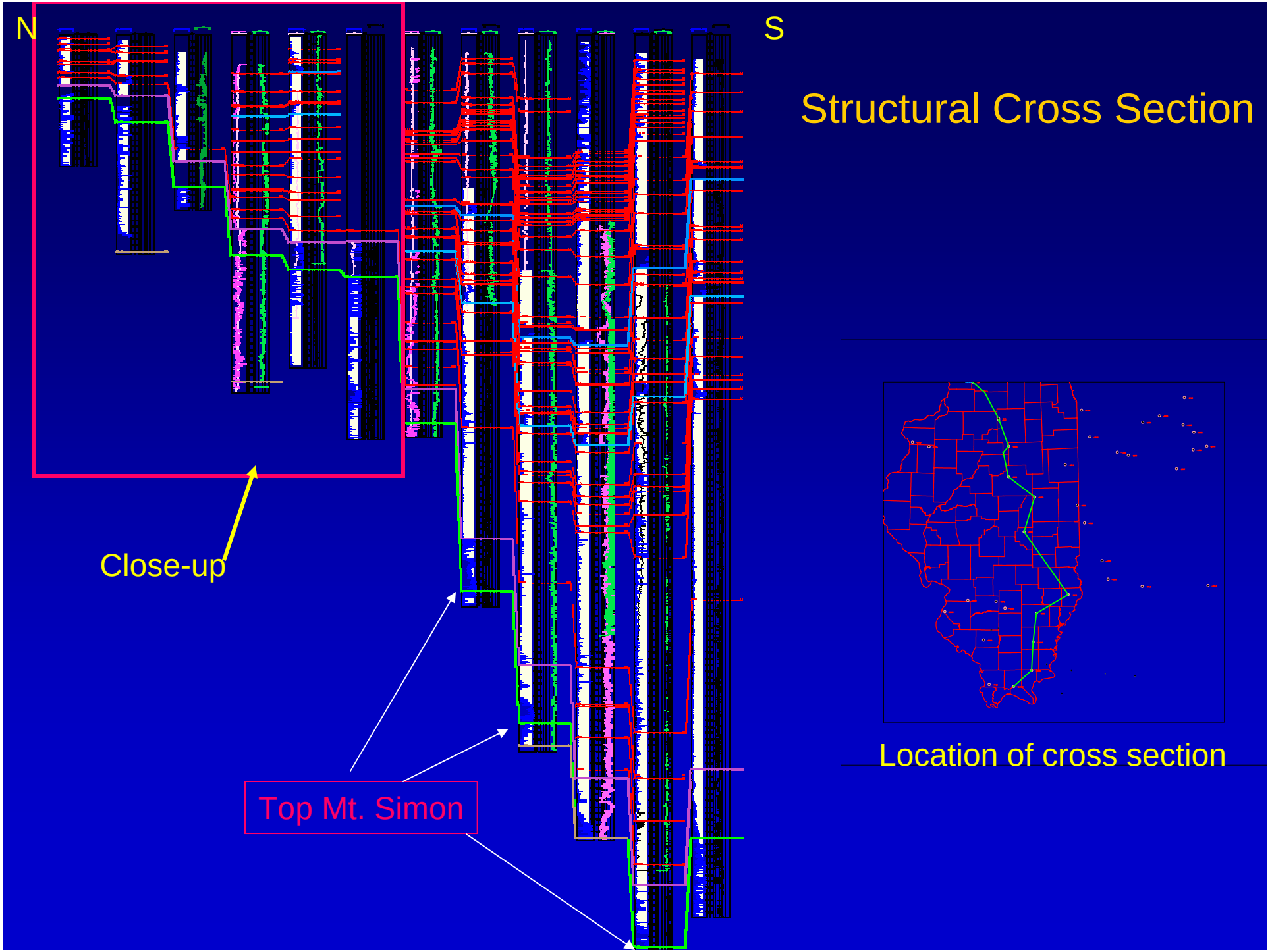
Mt. Simon ranges from -300 to a projected -14,700 feet below sea level

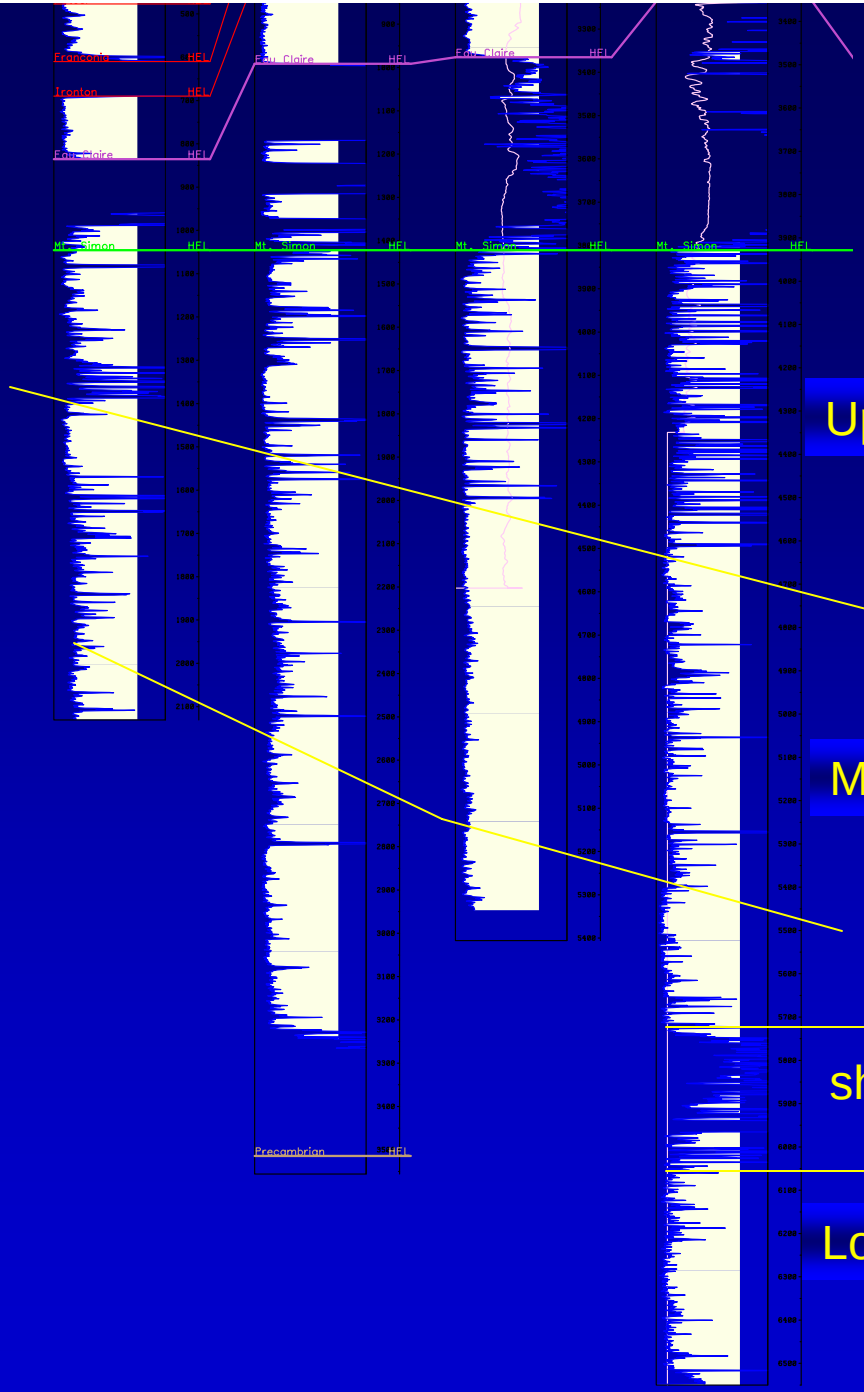
CI: 300 ft

Model of Mt. Simon Structure



Structural Cross Section





Top: Eau Claire

Top: Mt. Simon

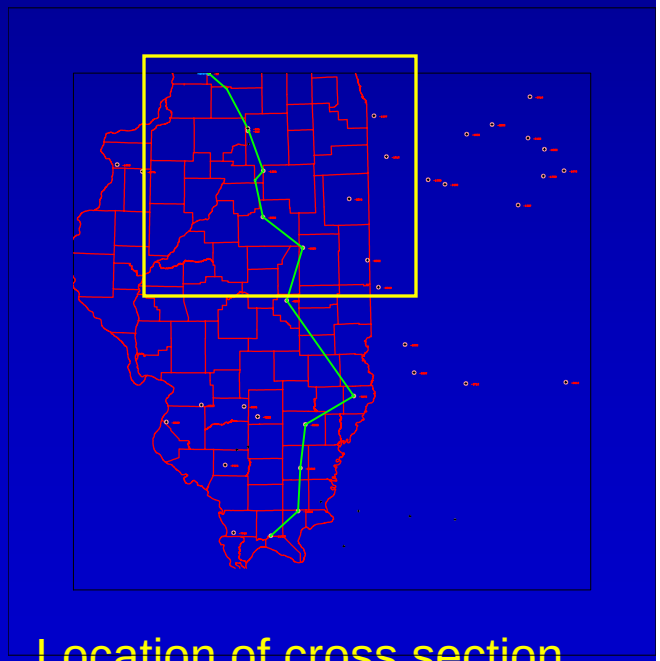
Datum: Top of Mt. Simon Sandstone

Upper

Middle

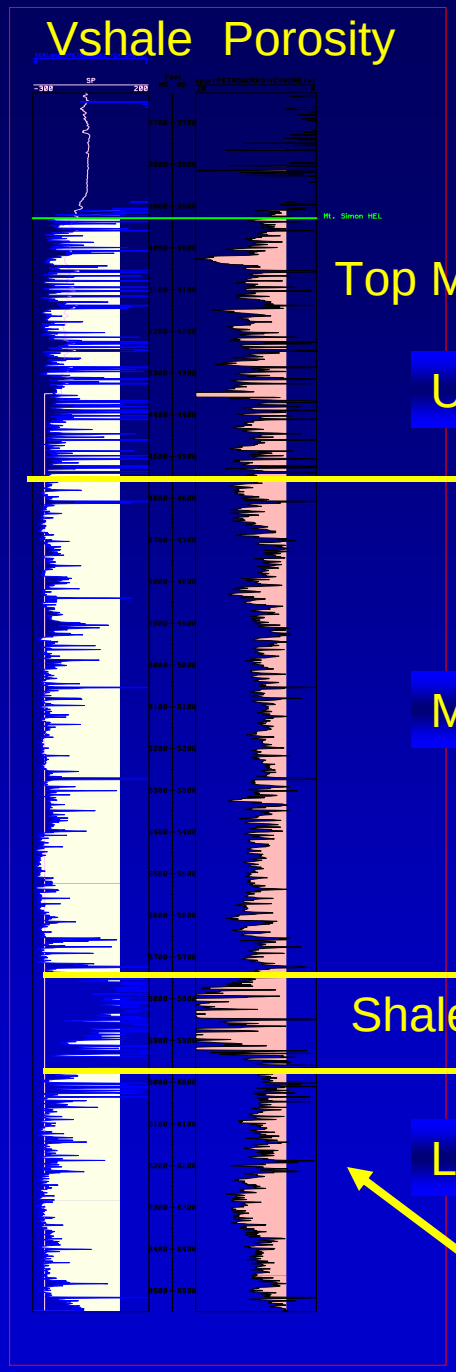
shale

Lower



Location of cross section

Hinton # 7 in Manlove Field



Top Mt. Simon

Upper

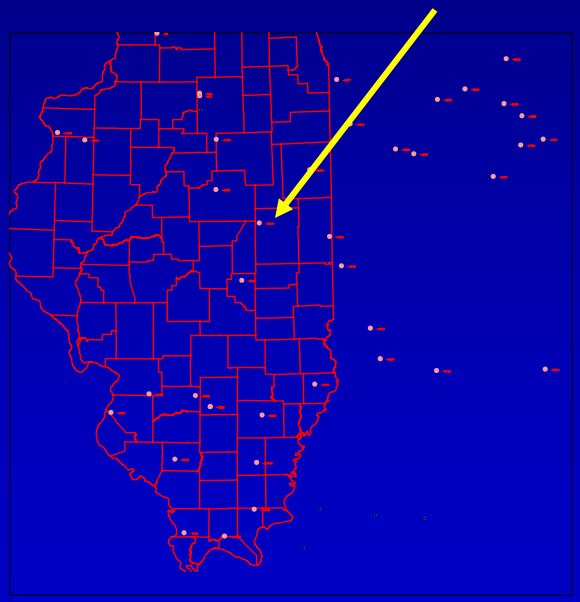
Middle

Shale

Lower

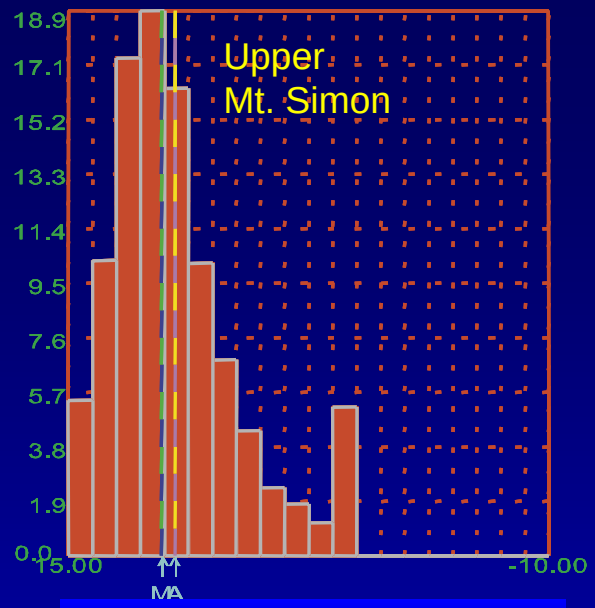
5% cut off for porosity

No significant loss of porosity in 2000 feet of Mt. Simon strata

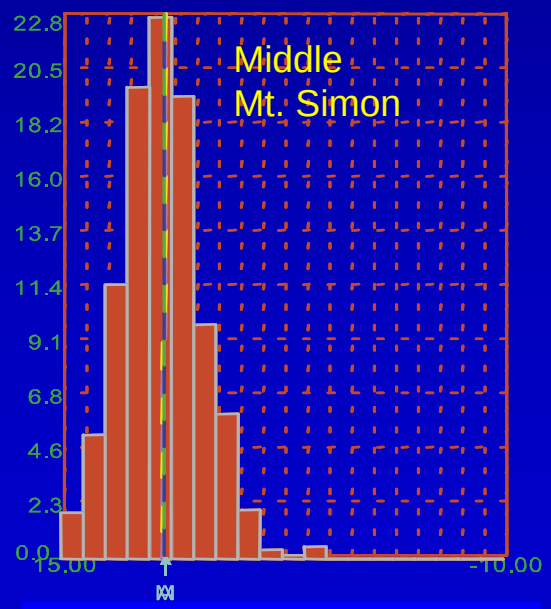


Location of Hinton #7

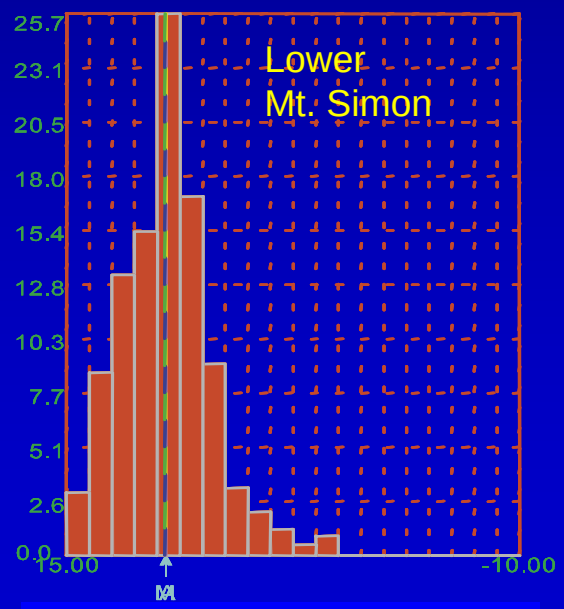
Distribution of porosity in the Hinton No. 7 Manlove Gas Storage Project



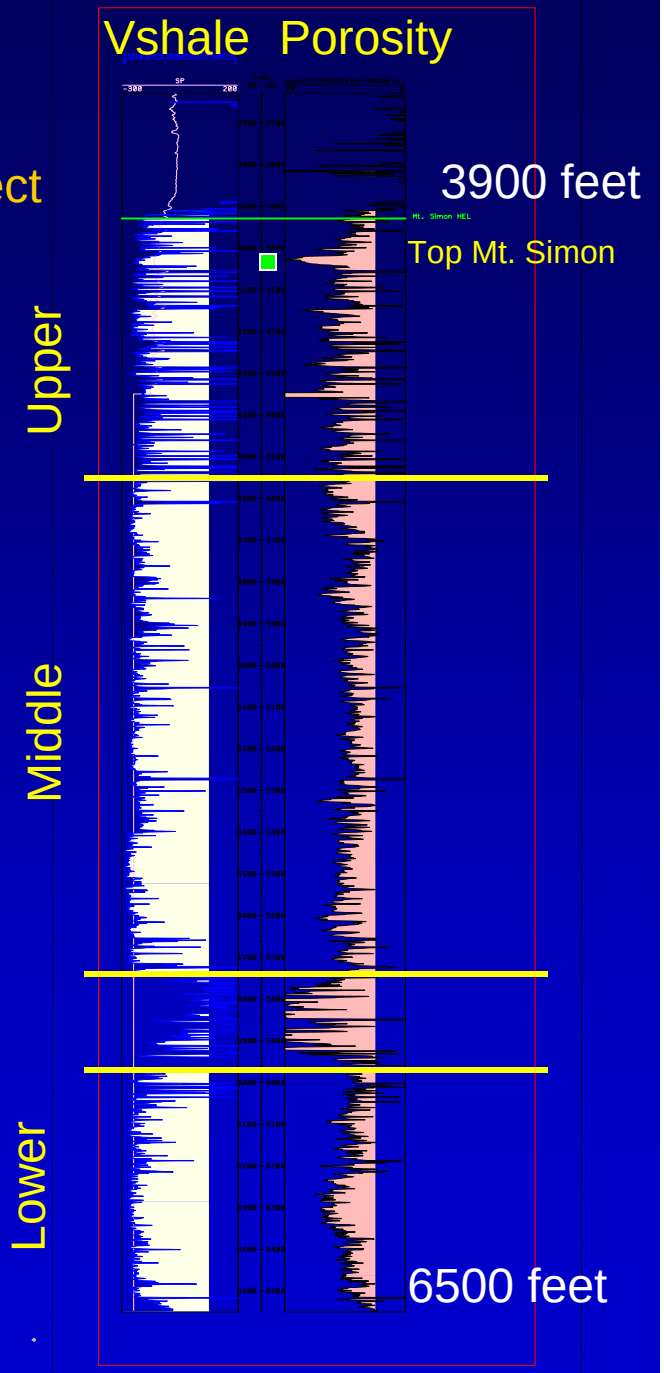
Median Porosity: 10%



Median Porosity: 9.3%

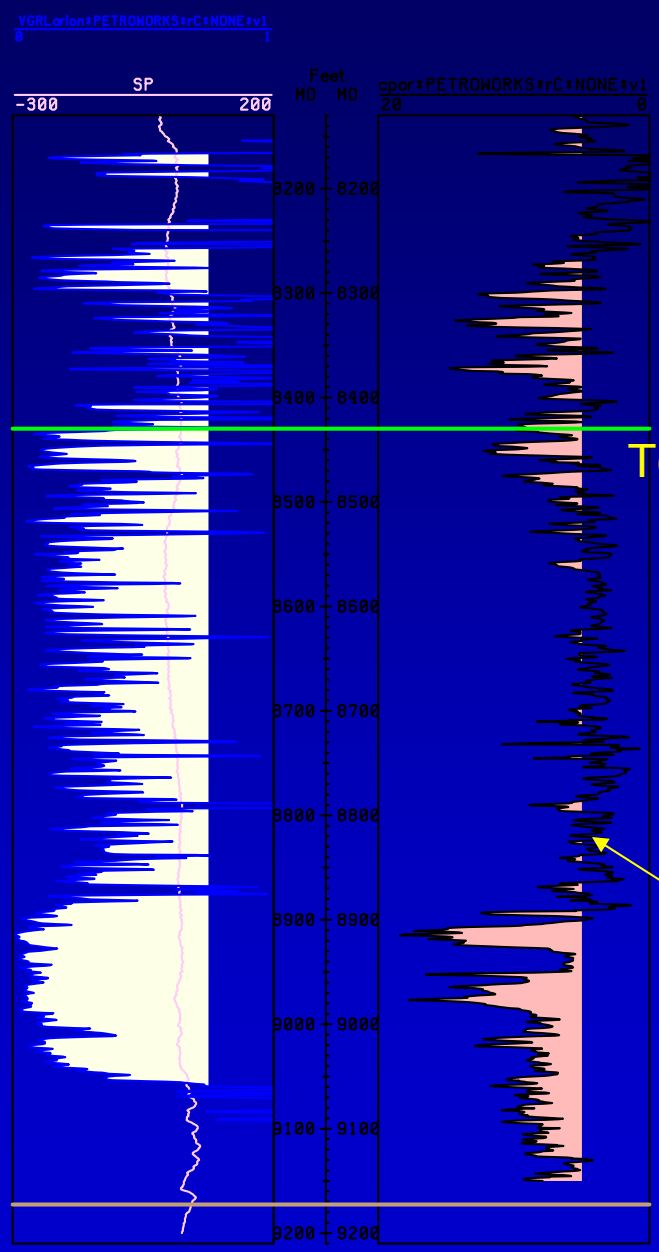


Median Porosity: 9.5%



Vshale

Porosity (from Sonic)



8400 feet

Mt. Simon HEL

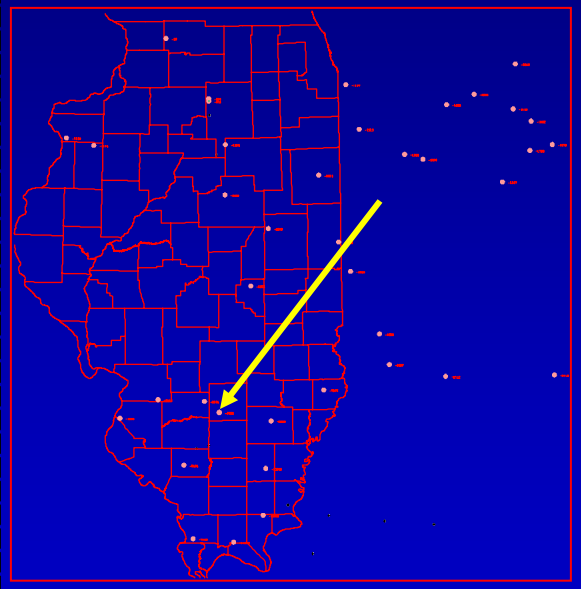
Top Mt. Simon

Precambrian HEL

9200 feet

5% cut off for porosity

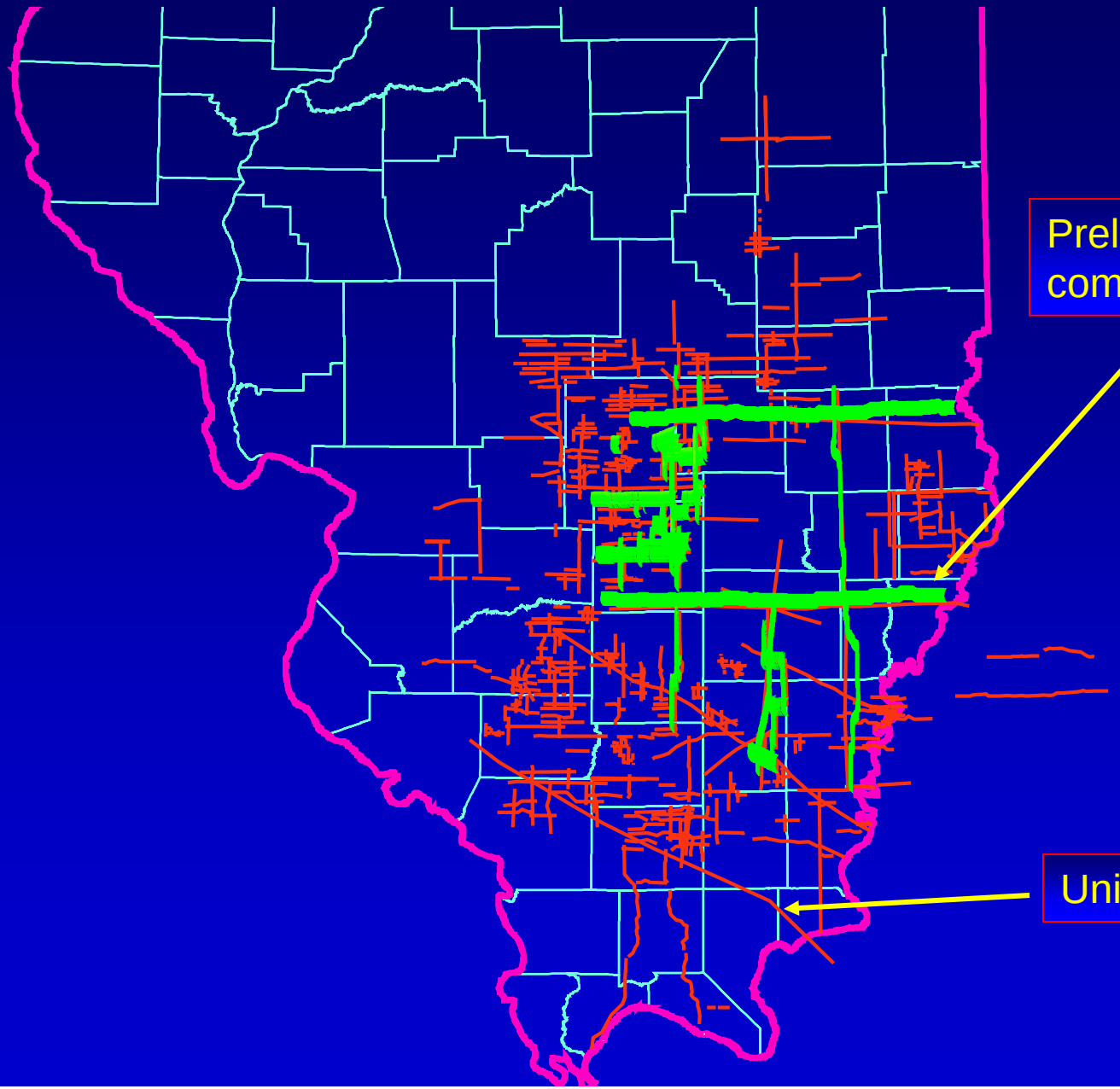
Wireline log of the
R.S. Johnson No. 1
Salem Field



Reflection Seismic Interpretation

- Over 5000 miles of proprietary seismic donated to Illinois State Geological Survey
- Only a portion is commercially available

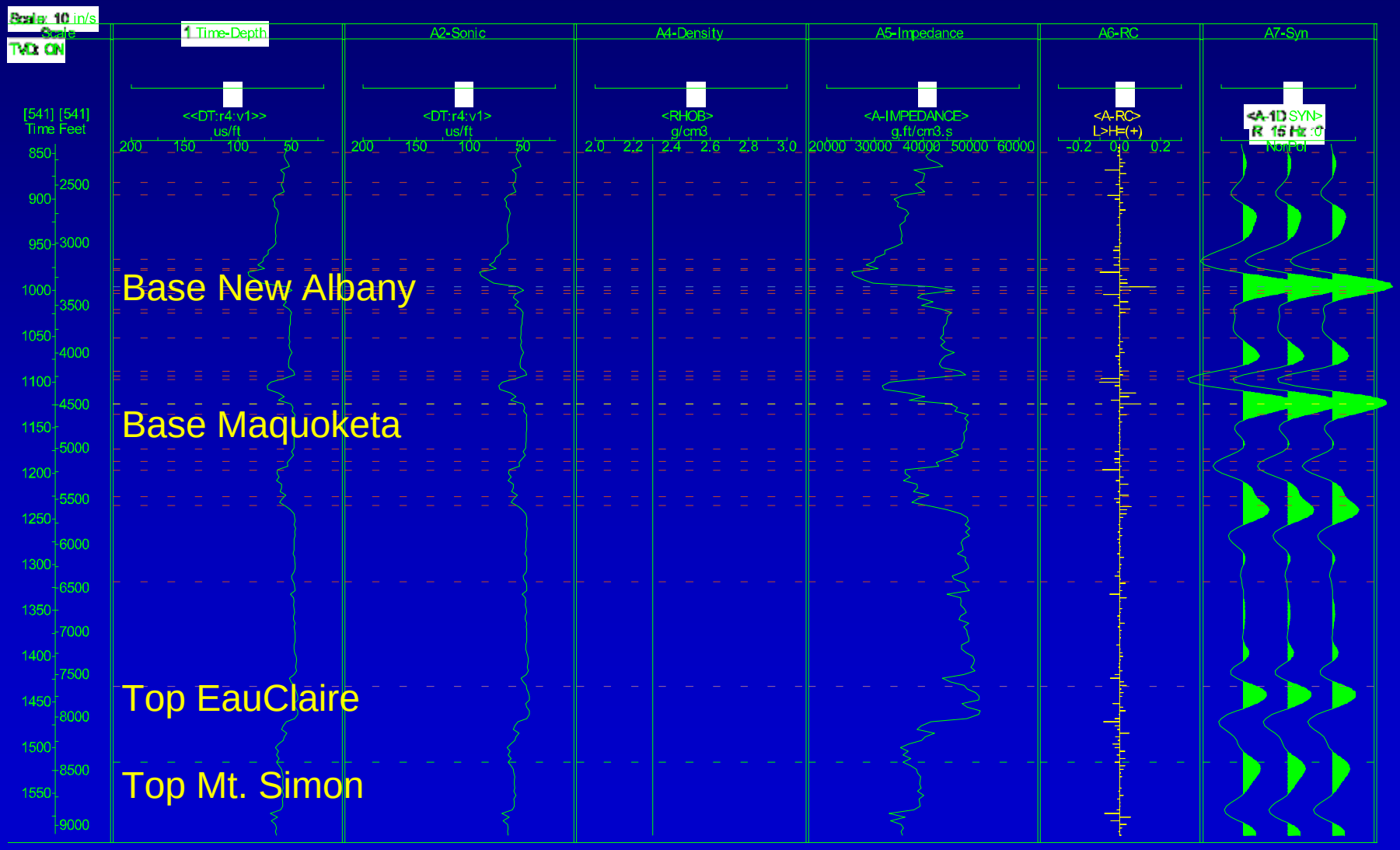
Seismic Control in Illinois



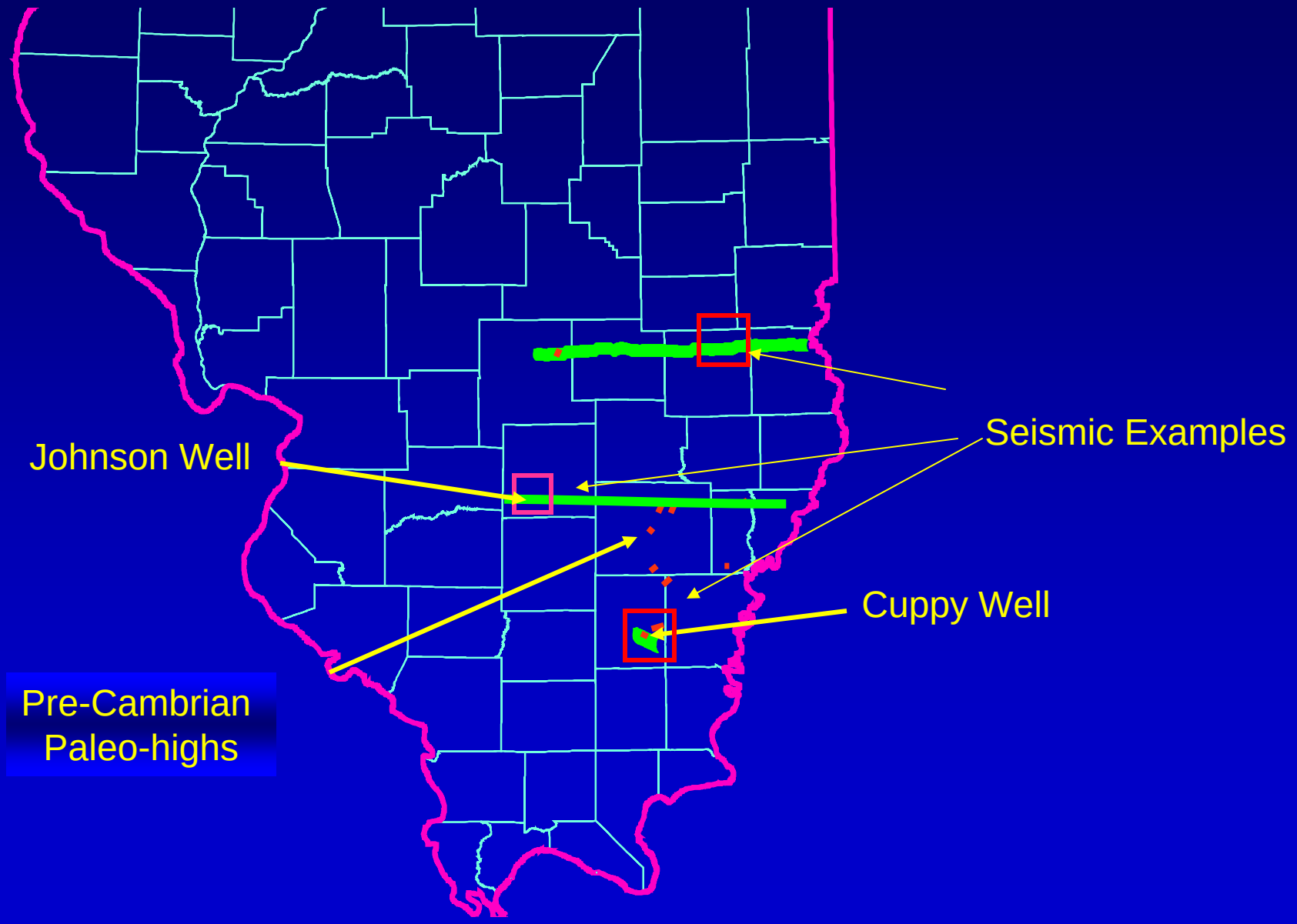
Preliminary interpretation completed

Uninterpreted Seismic

Synthetic Seismogram for Correlating Wells with Seismic Reflection Data

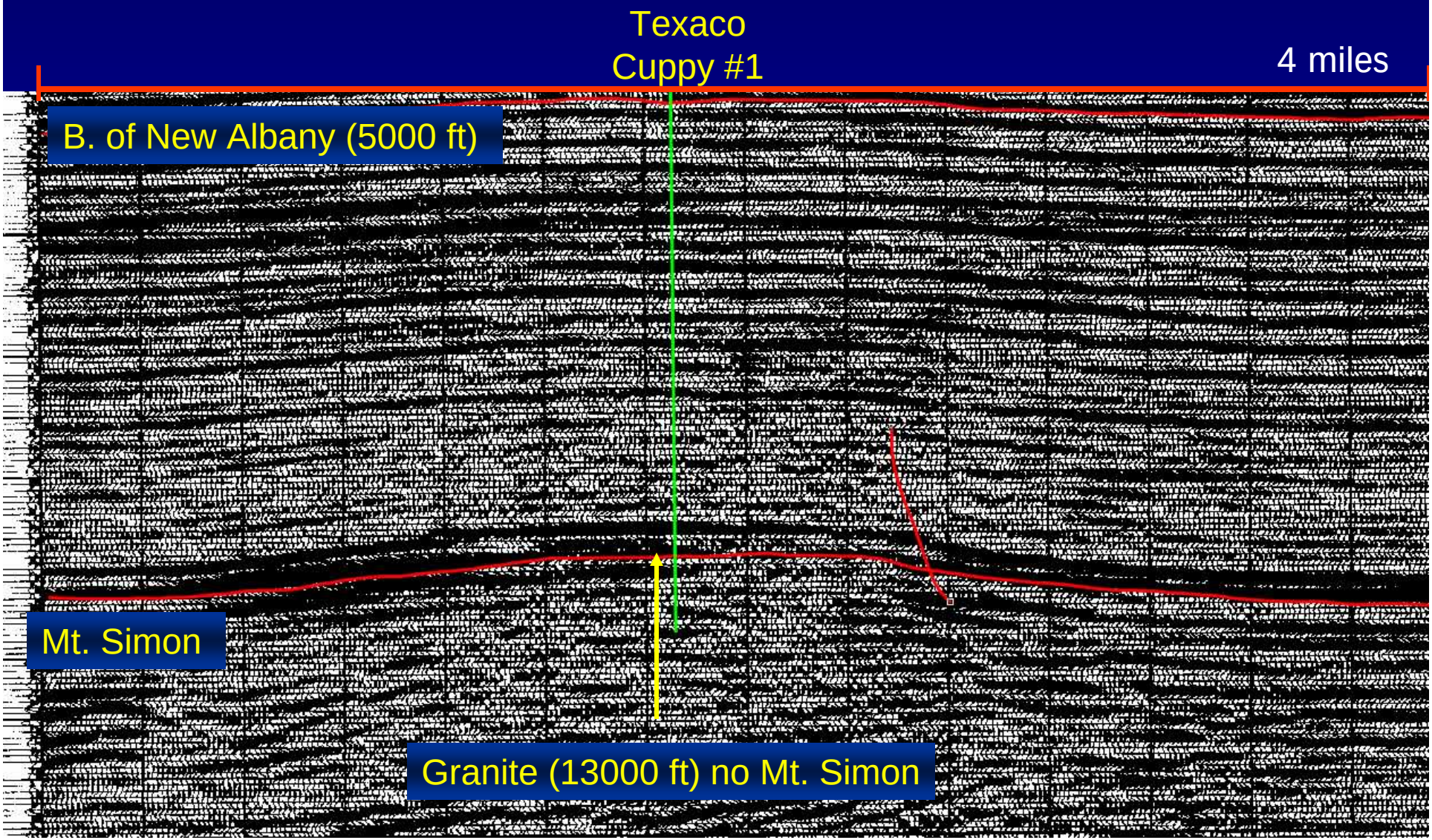


Seismic Reflection Data Interpretation



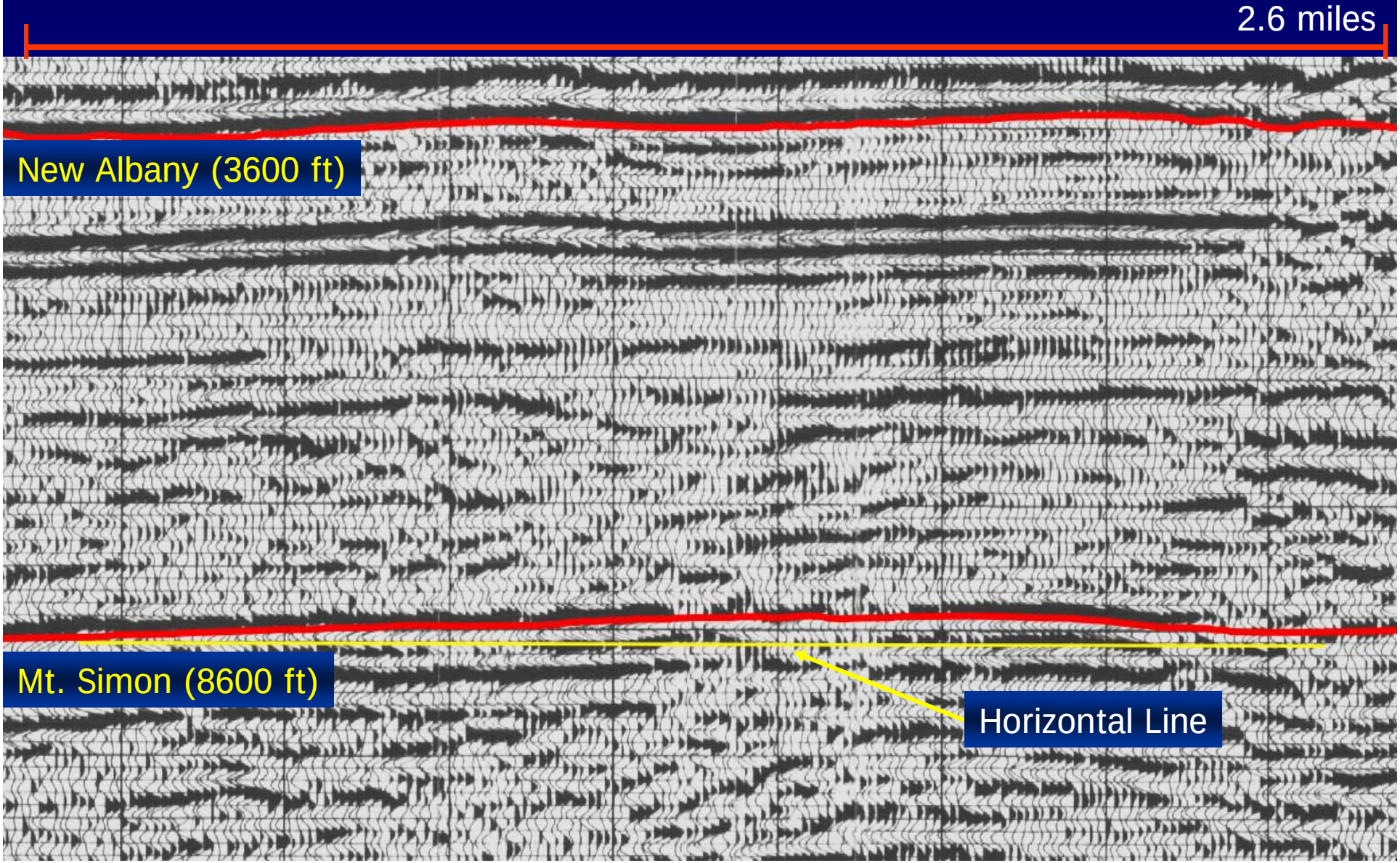
Pre-Cambrian Paleo-High

The Mt. Simon is missing in this well

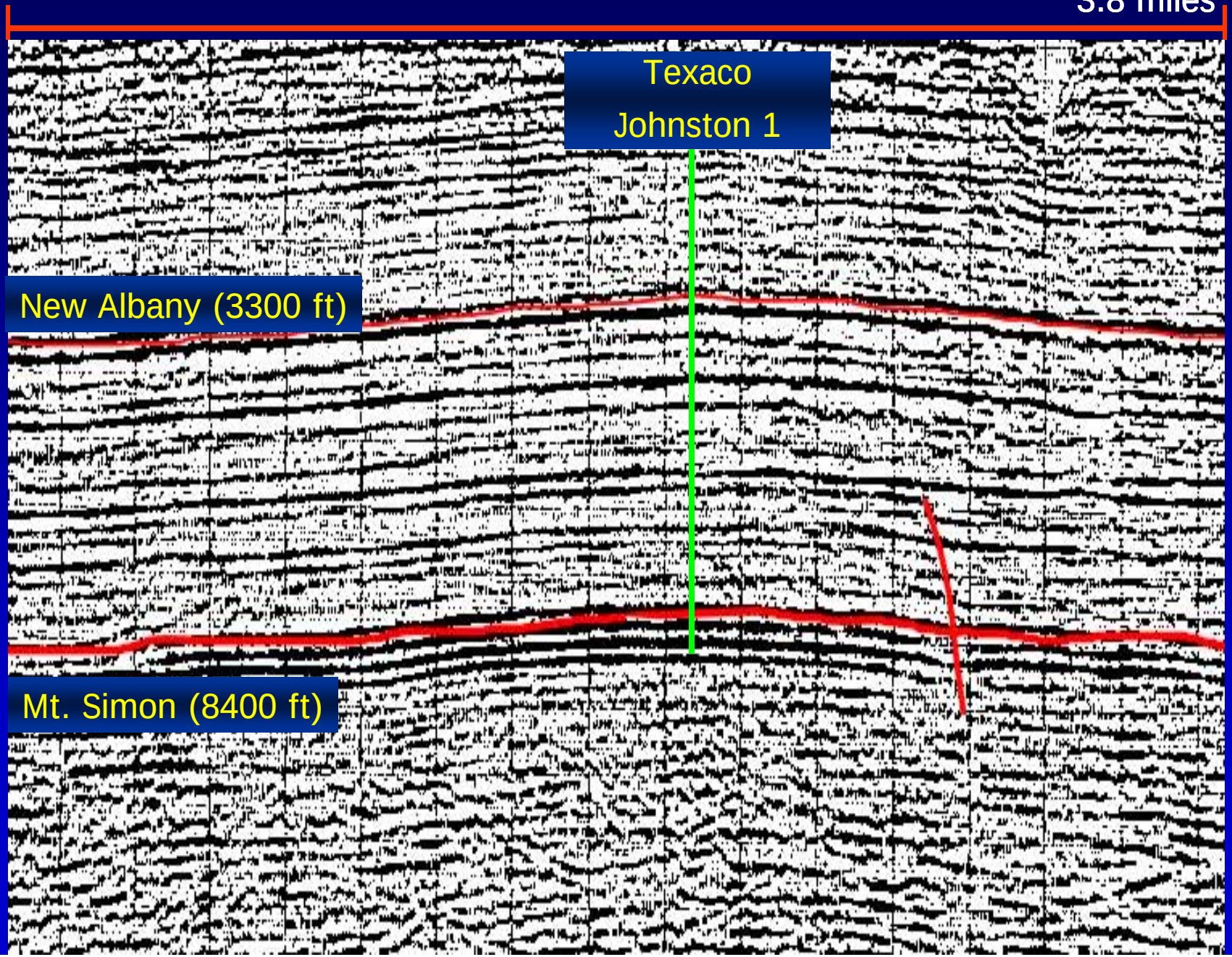


Northern Part of Jasper County

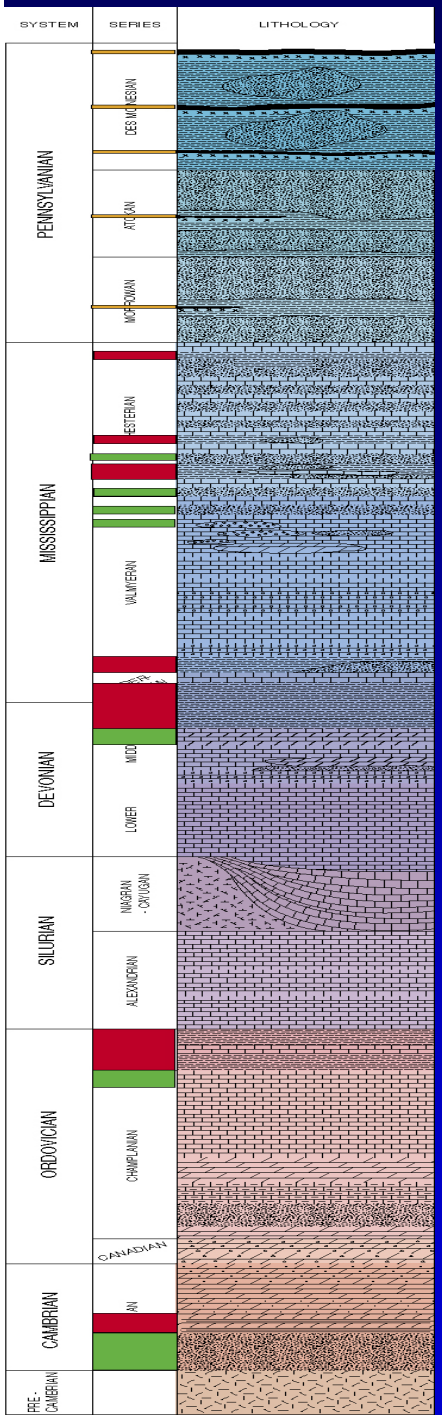
Clay City Consolidated



Salem Field


3.8 miles
Texaco
Johnston 1
New Albany (3300 ft)
Mt. Simon (8400 ft)

Seals



Mississippian (Seals)

New Albany (Seal)

Maquoketa (Seal)

Eau Claire (Seal)

Mt. Simon (Sink)

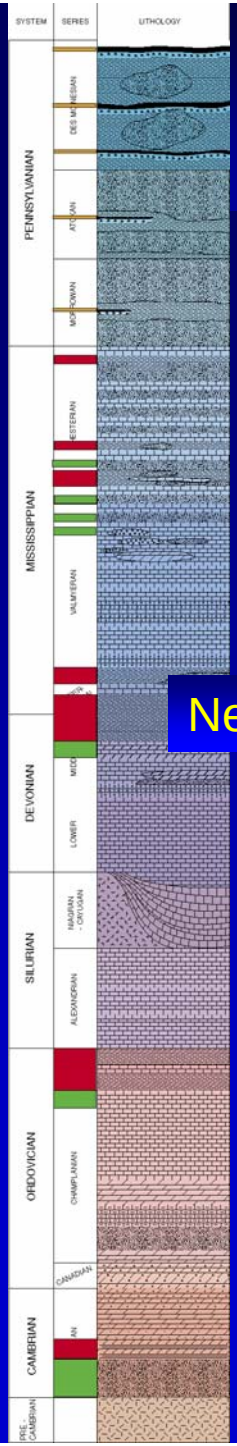
- New Albany Group
  - Silurian and Devonian
- Maquoketa Group
  - Ordovician
- Eau Claire Formation
  - Mt. Simon areas

Potential Seal

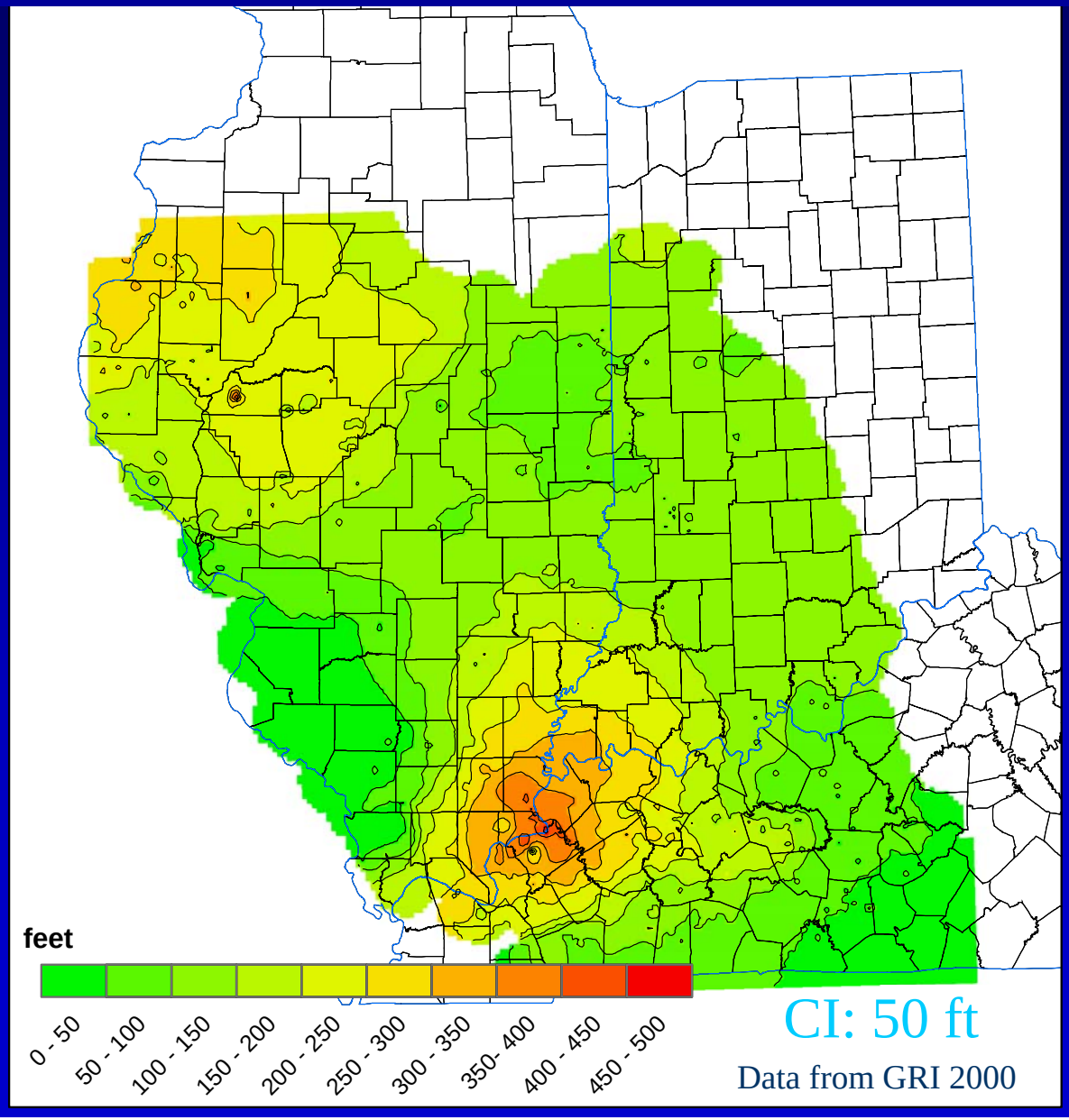
Potential Sink

Coal Bed Potential Sink and Seal

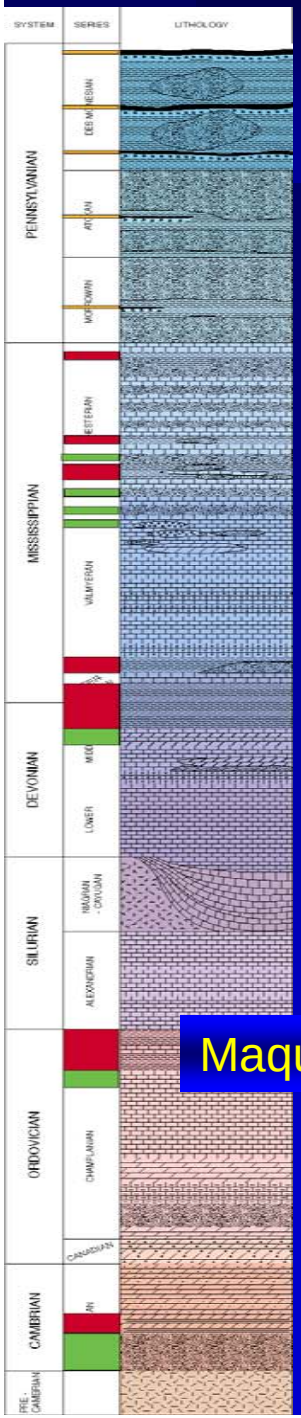
Thickness: New Albany Shale

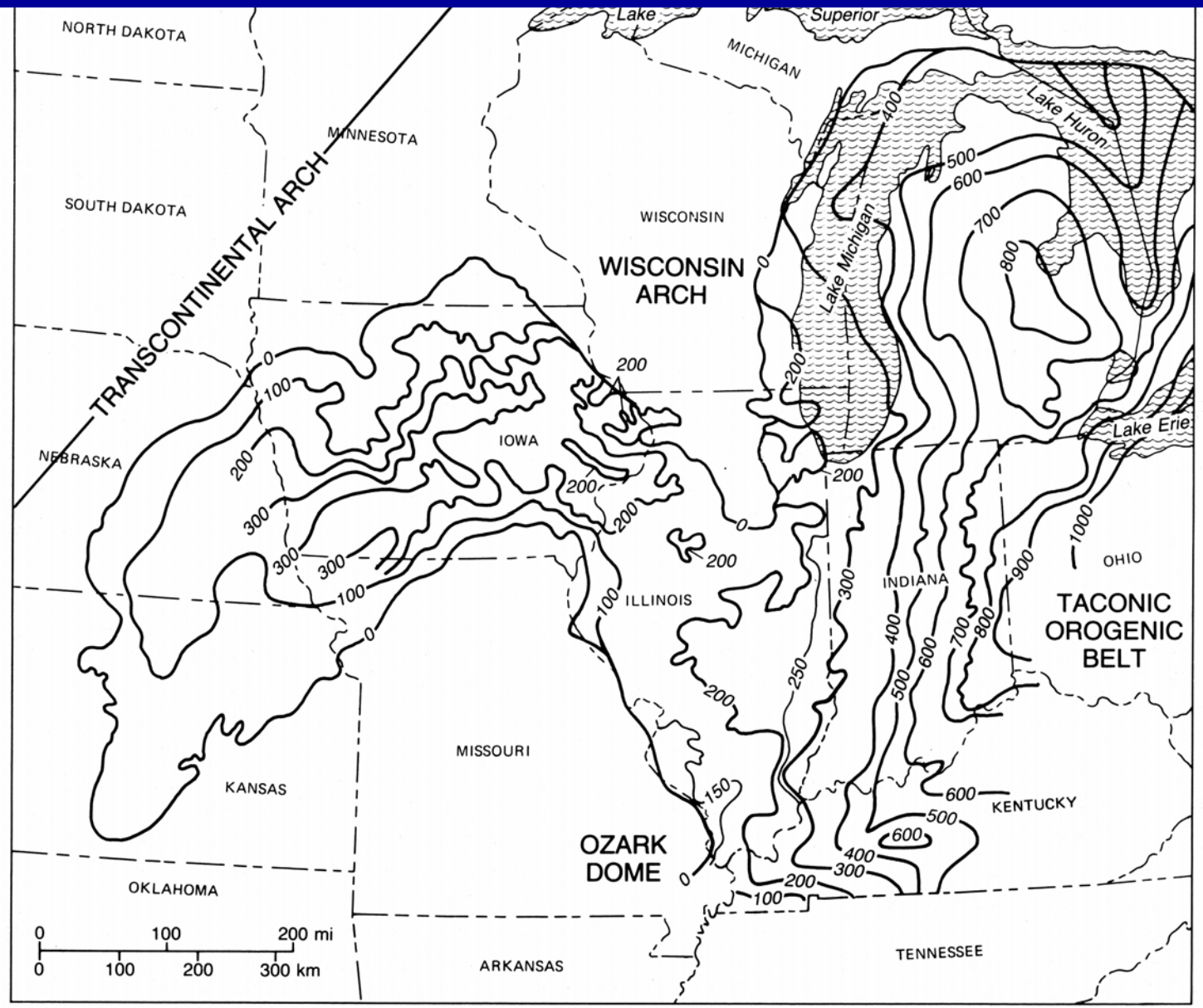


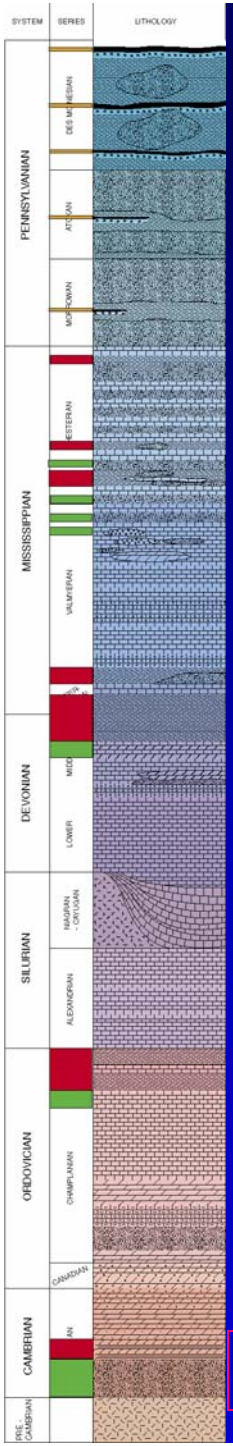
New Albany



Thickness of Maquoketa







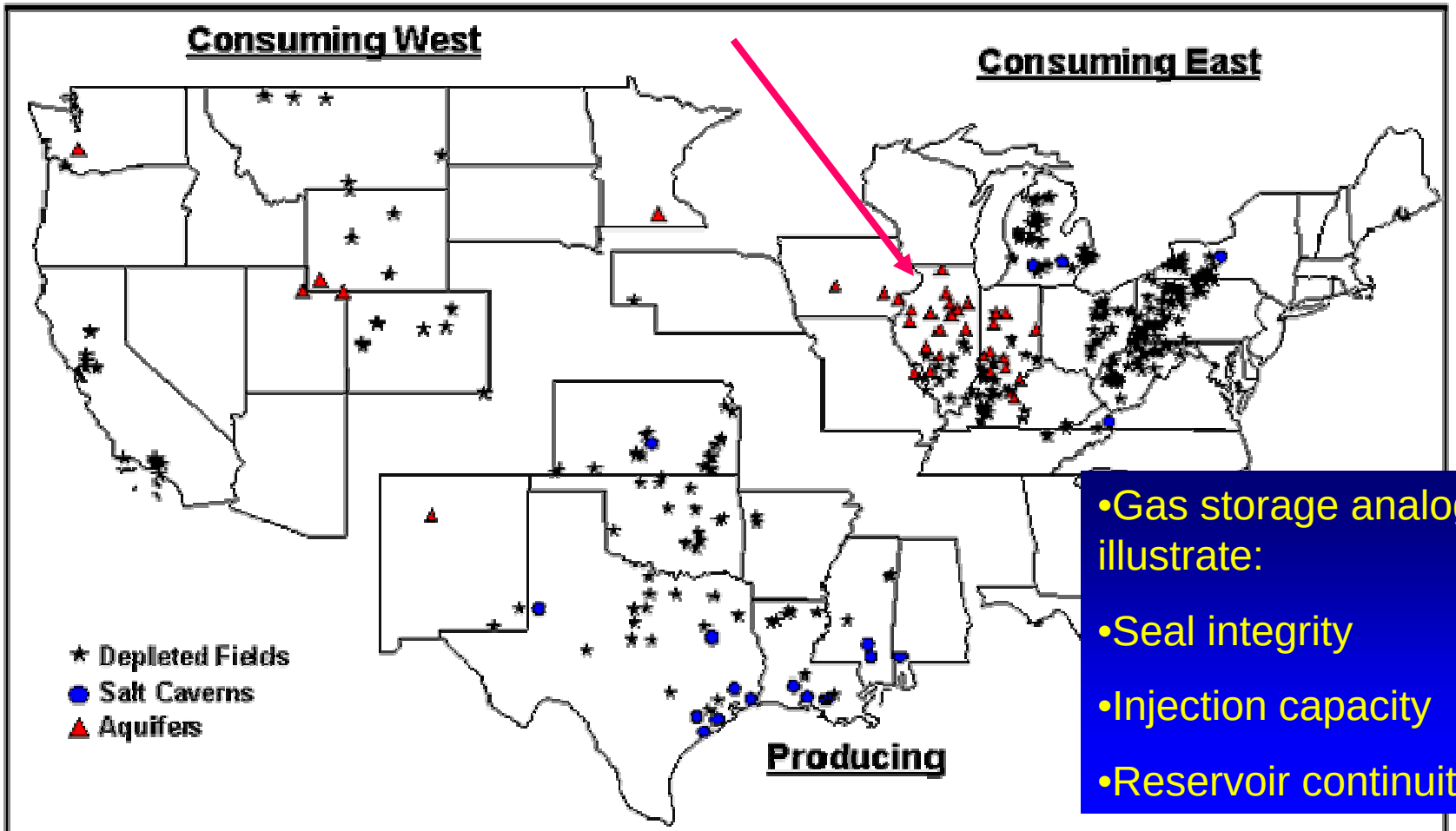
Eau Claire as a Seal
UIC Wells

- Caprock horizontal and vertical perm
  - Eau Claire median vertical permeability of <0.0001 mD
- Flow model studies
  - 10,000 year liquid migration
  - less than 5 miles
- Tracer tests
  - injection profiles
  - effective thickness

Eau Claire (Seal)

Illinois Basin has the Largest Concentration of Saline (Gas Storage) Reservoirs in the US

Figure 2. Underground Natural Gas Storage Facilities in the Lower 48 States



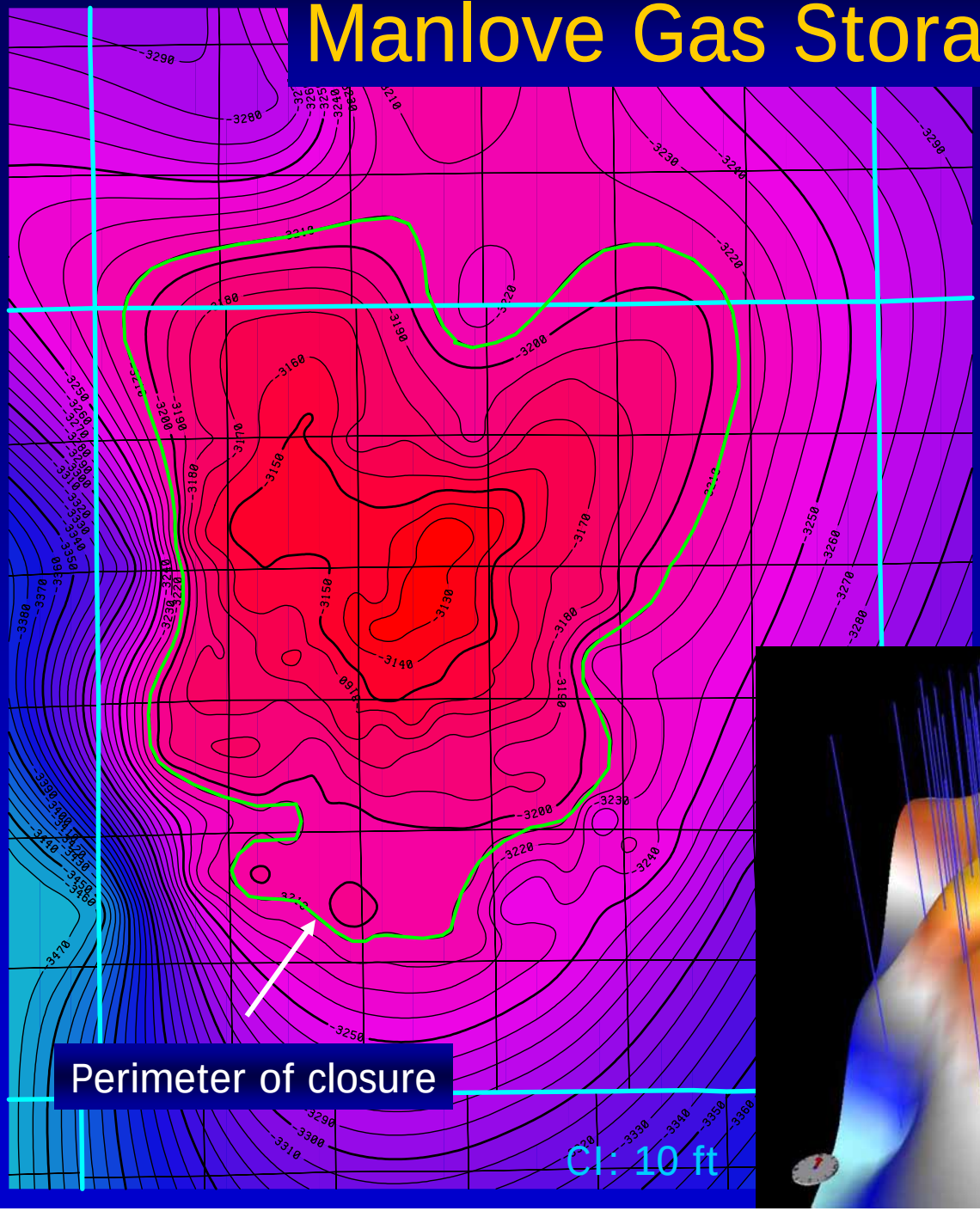
Source: Energy Information Administration, EIAGIS-NG Geographic Information System, Underground Storage Database, as of June 2002.

- Gas storage analogs illustrate:
- Seal integrity
- Injection capacity
- Reservoir continuity

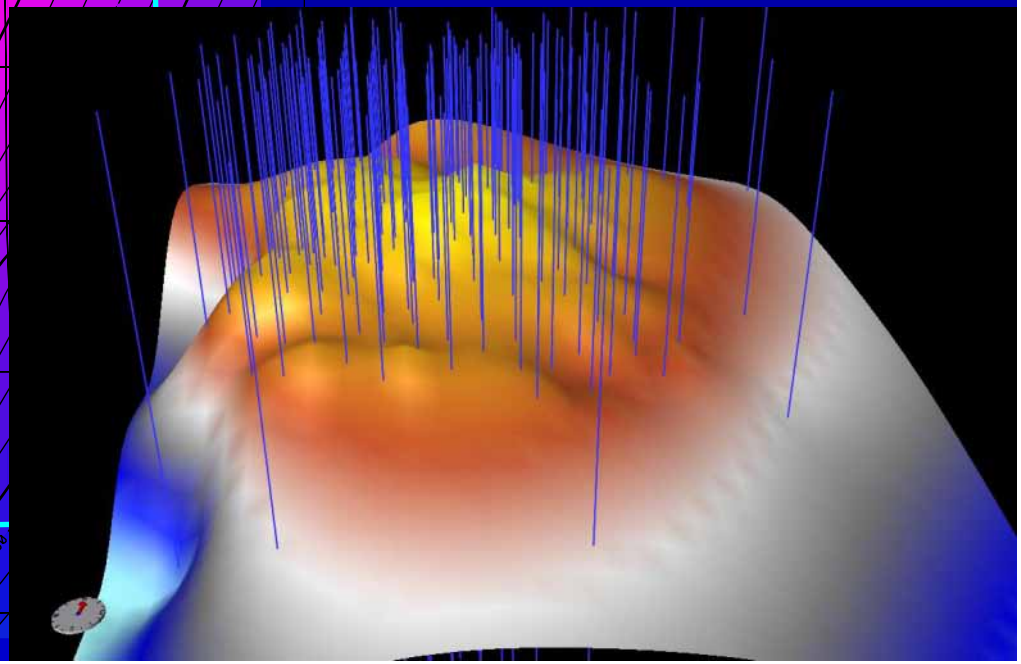
Gas Storage Projects
What have we learned?

- Manlove Gas Storage Project
  - Discontinuous low permeability layers behave as baffles
  - Some are laterally continuous across most of reservoir
  - Porous zones can be lenticular
- Other gas storage projects in Illinois Basin
  - Mt. Simon has good seal (Eau Claire)
  - Other saline formations have good reservoir quality but some leakage has been documented

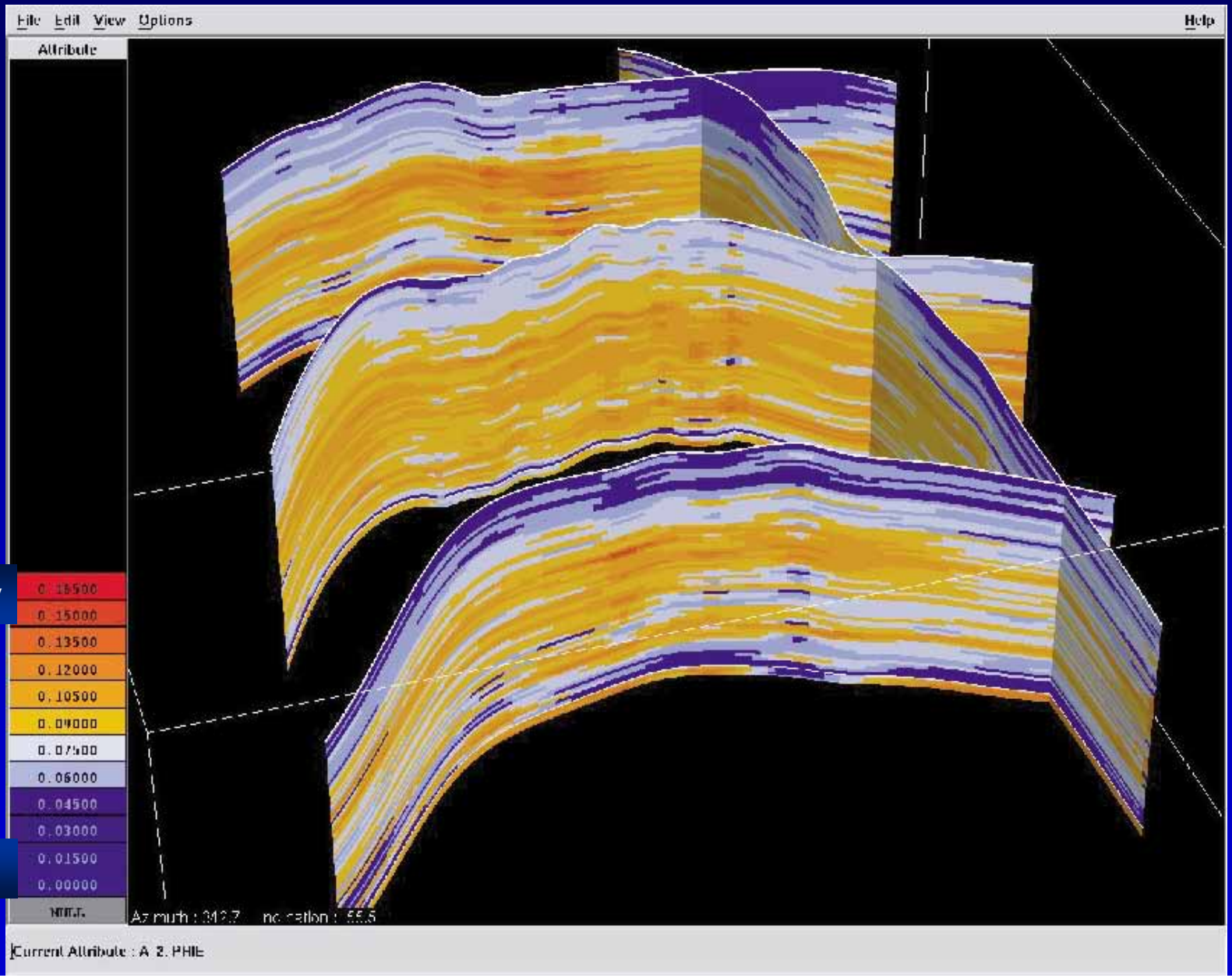
Manlove Gas Storage Project



The Manlove Project has
90 feet of closure,
is 5 miles long and 4 miles wide



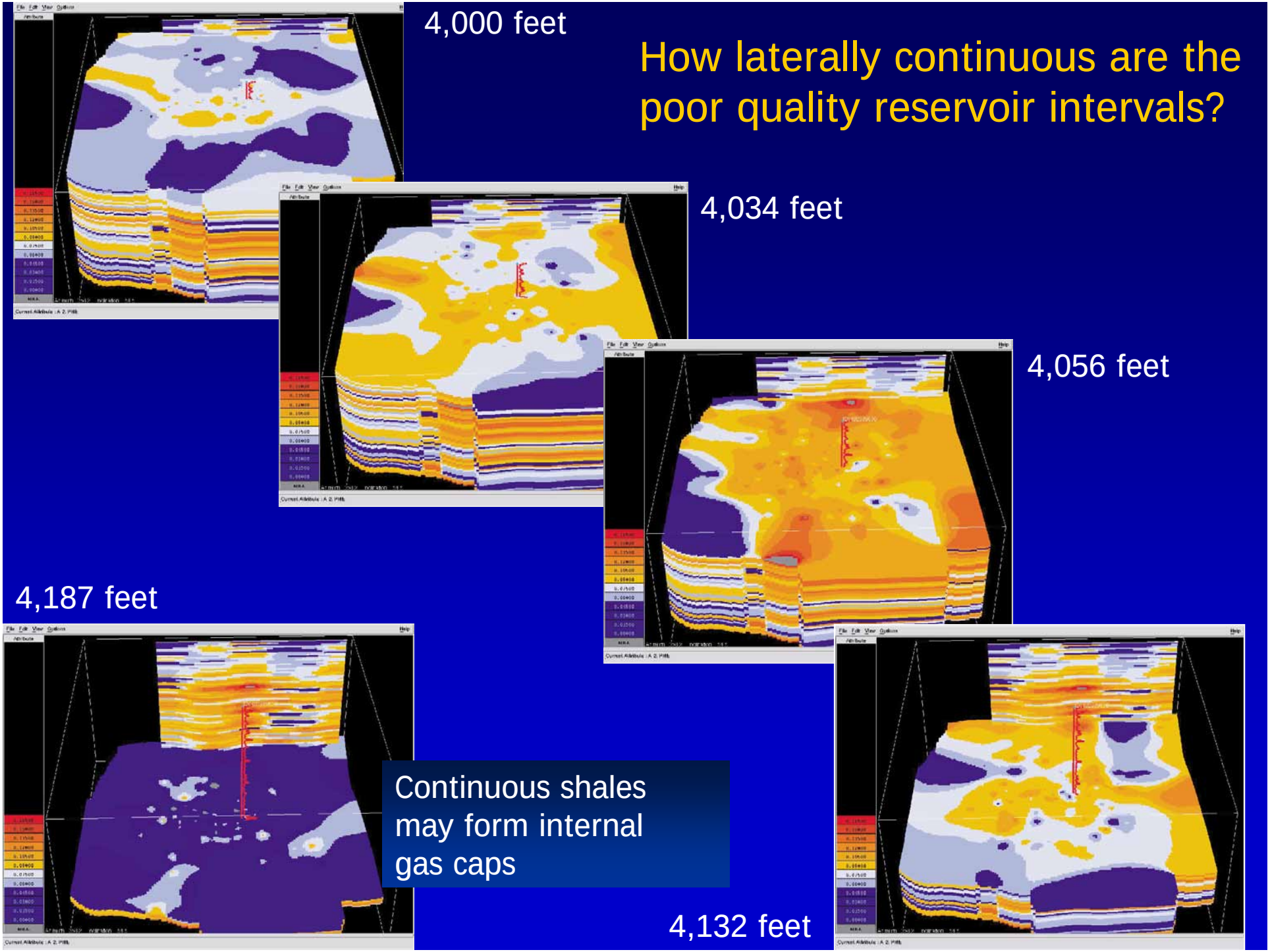
Porosity Variation in Manlove



High Porosity

Low Porosity

How laterally continuous are the poor quality reservoir intervals?



Continuous shales may form internal gas caps

Saline: Storage Capacity Equations

$$19.76\,Ah\phi\rho_{CO2}(1-S_{wirr})E_{Vm}$$

- Mobile, Free Phase (*Structurally Trapped*)

$$3.519\,Ah\phi\rho_{CO2std}R_{sCO2/w}S_{wirr}E_{Vm}$$

- CO_2 Saturated Brine, Swept to S_{wirr}

$$19.76\,Ah\phi\rho_{CO2}S_{CO2irr}E_{Virr}$$

- Immobile, Free Phase (*Capillary Bound*)

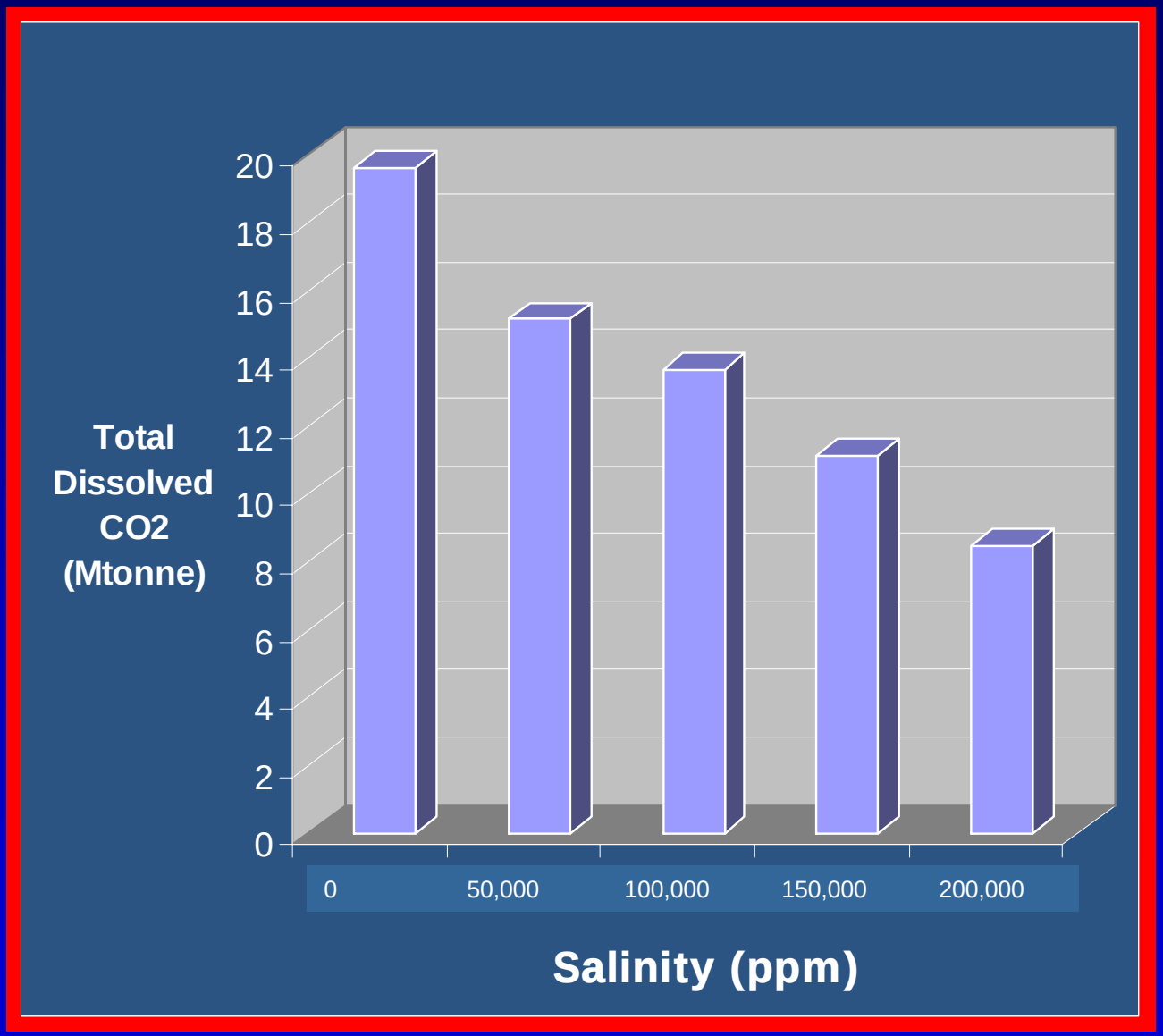
$$3.519\,Ah\phi\rho_{CO2std}R_{sCO2/w}(1-S_{CO2irr})E_{Virr}$$

- CO_2 Saturated Brine, Swept to $1\text{-}S_{co2irr}$

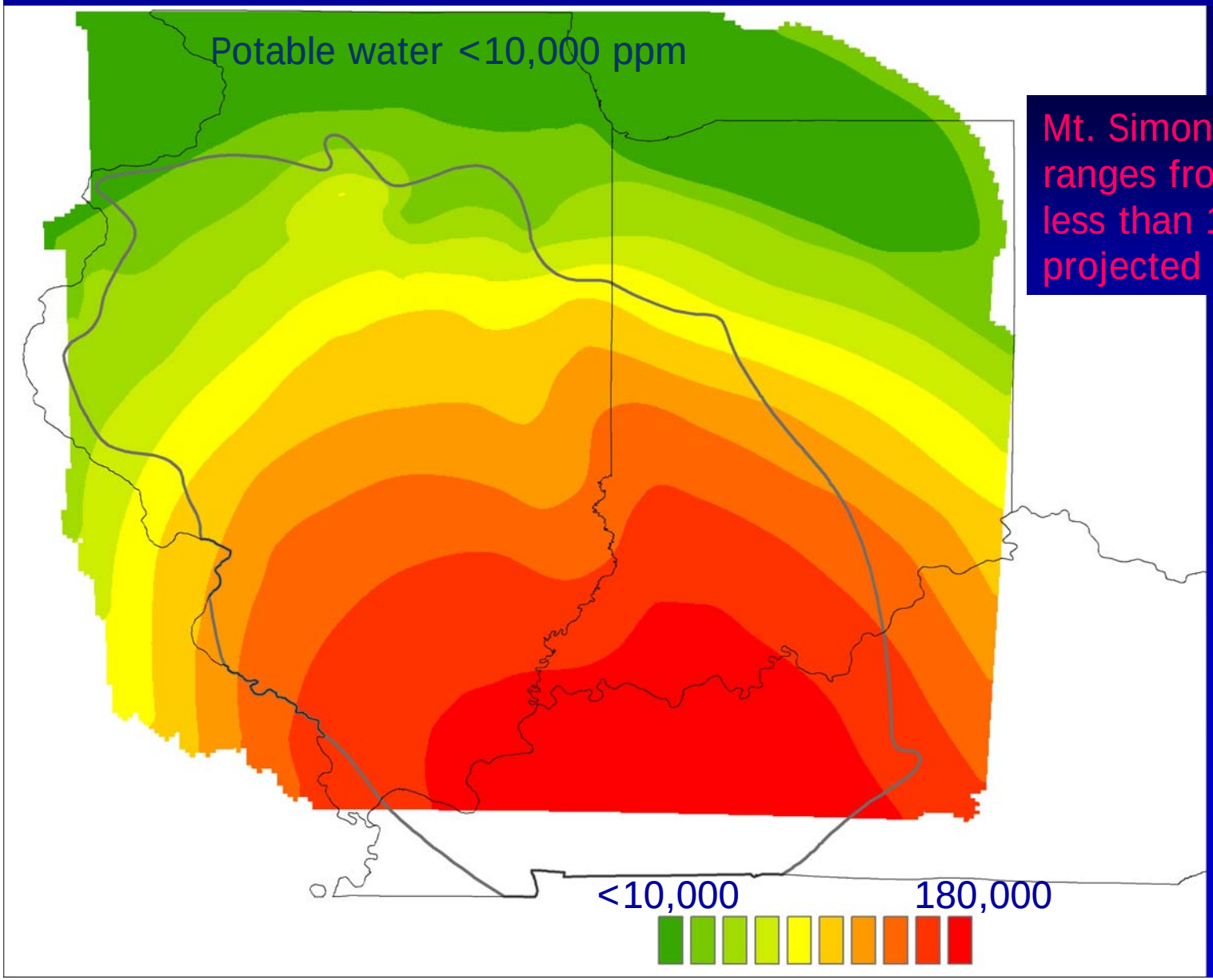
$$3.519\,Ah\phi\rho_{CO2std}R_{sCO2/w}(1-E_{vm}-E_{virr})$$

- CO_2 Saturated Brine, Unswept

Solubility of CO_2 with Salinity



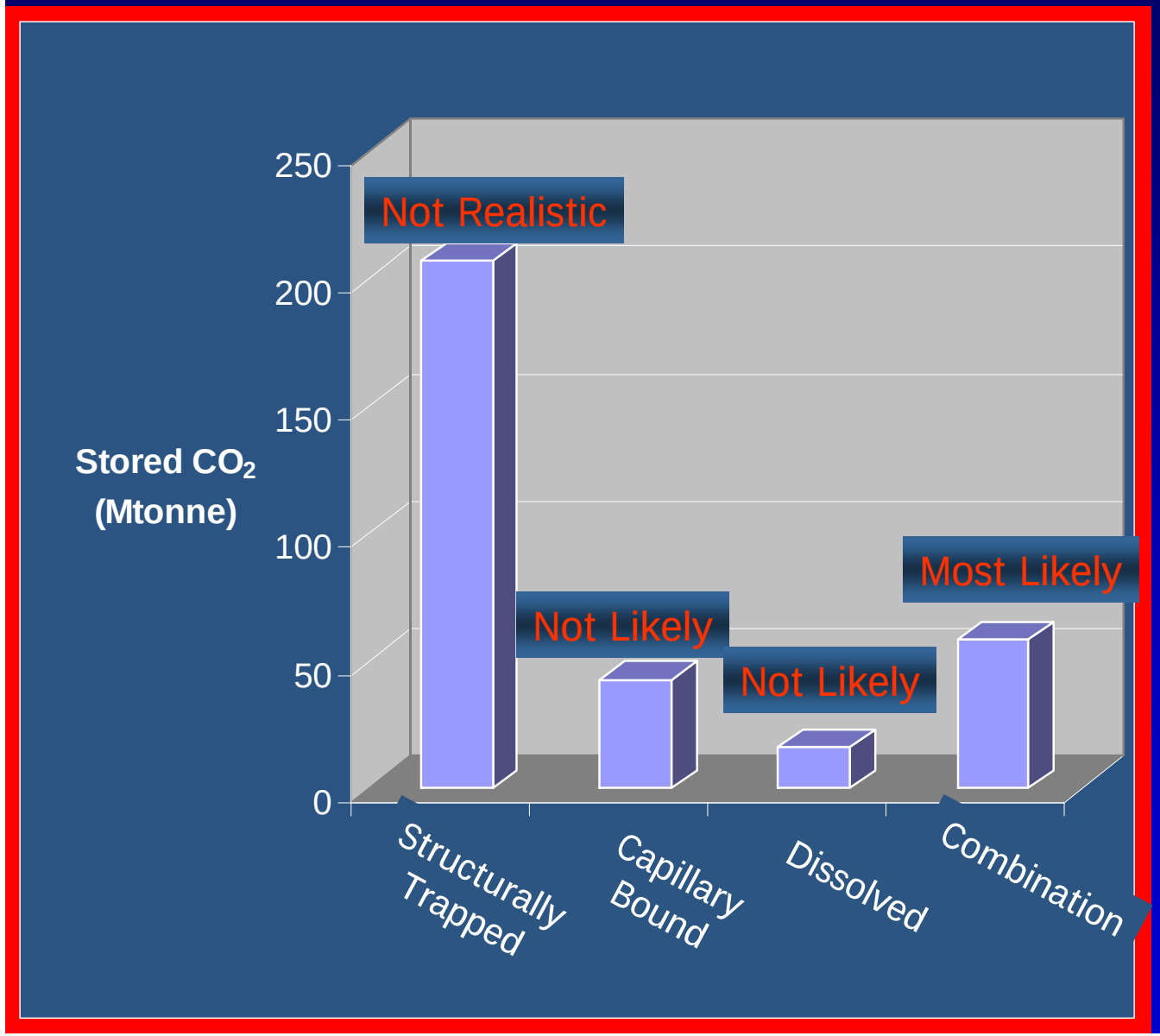
Total Dissolved Solids in Mt. Simon



Mt. Simon water quality ranges from
less than 10,000 ppm to a projected 180,000 ppm

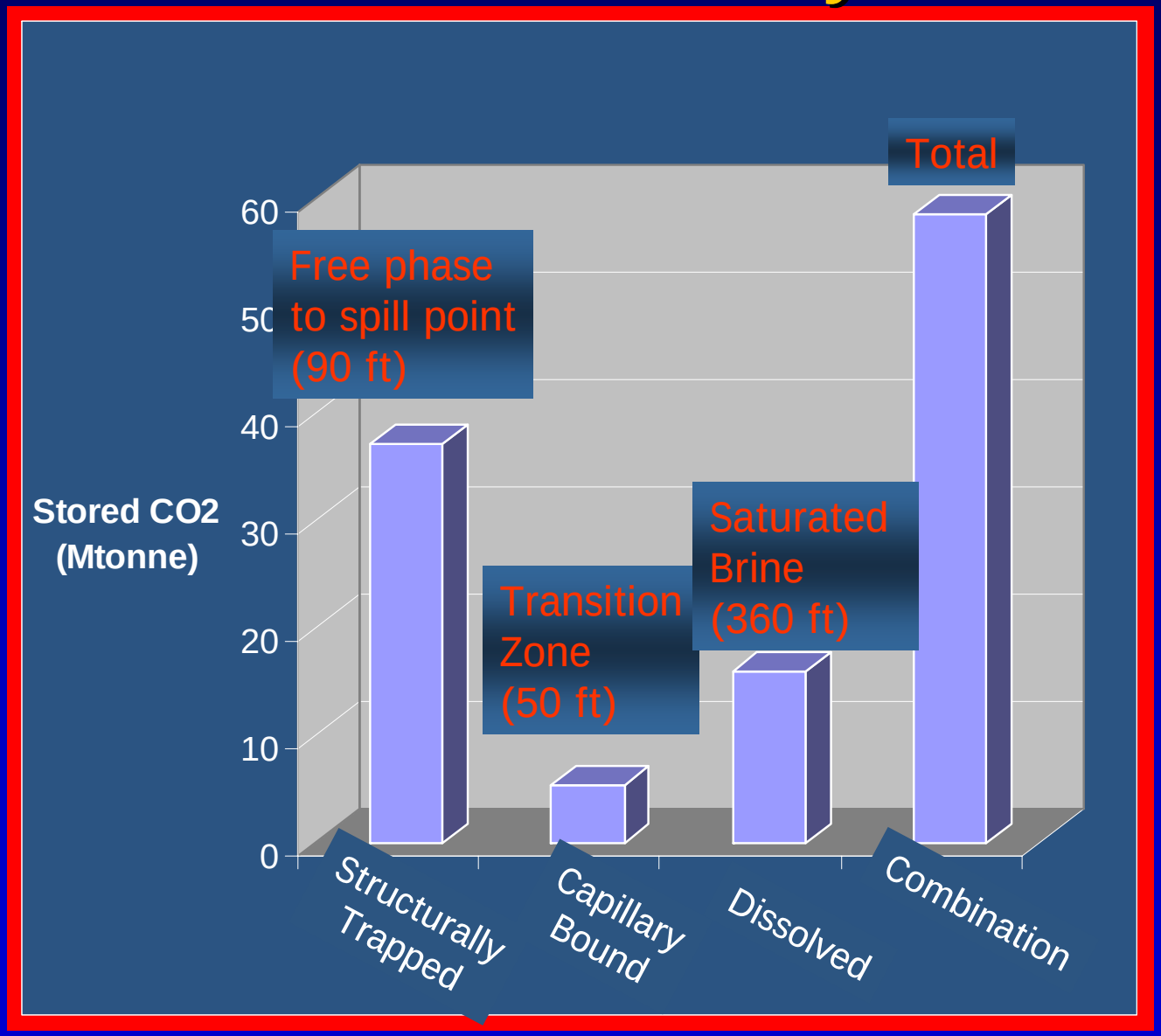
CI: 20,000 ppm

Volumetric Comparison of Manlove



Assume 500 feet of water column

Components of Manlove Most Likely Model



A Manlove analog should hold up to 58 Mtonnes of Carbon Dioxide

Summary of Task 6 Progress

- Preliminary screening of all saline reservoirs (completed)
- Regional Mt. Simon cross sections (completed)
- Regional Mt. Simon stratigraphy (completed)
- Seismic interpretation of reflection seismic (partially completed)
- Chemical interaction modeling (partially completed)
- Earthquake assessment (partially completed)
- Stochastic modeling of Mt. Simon (partially completed)

Summary of Year One Activities

Robert J. Finley

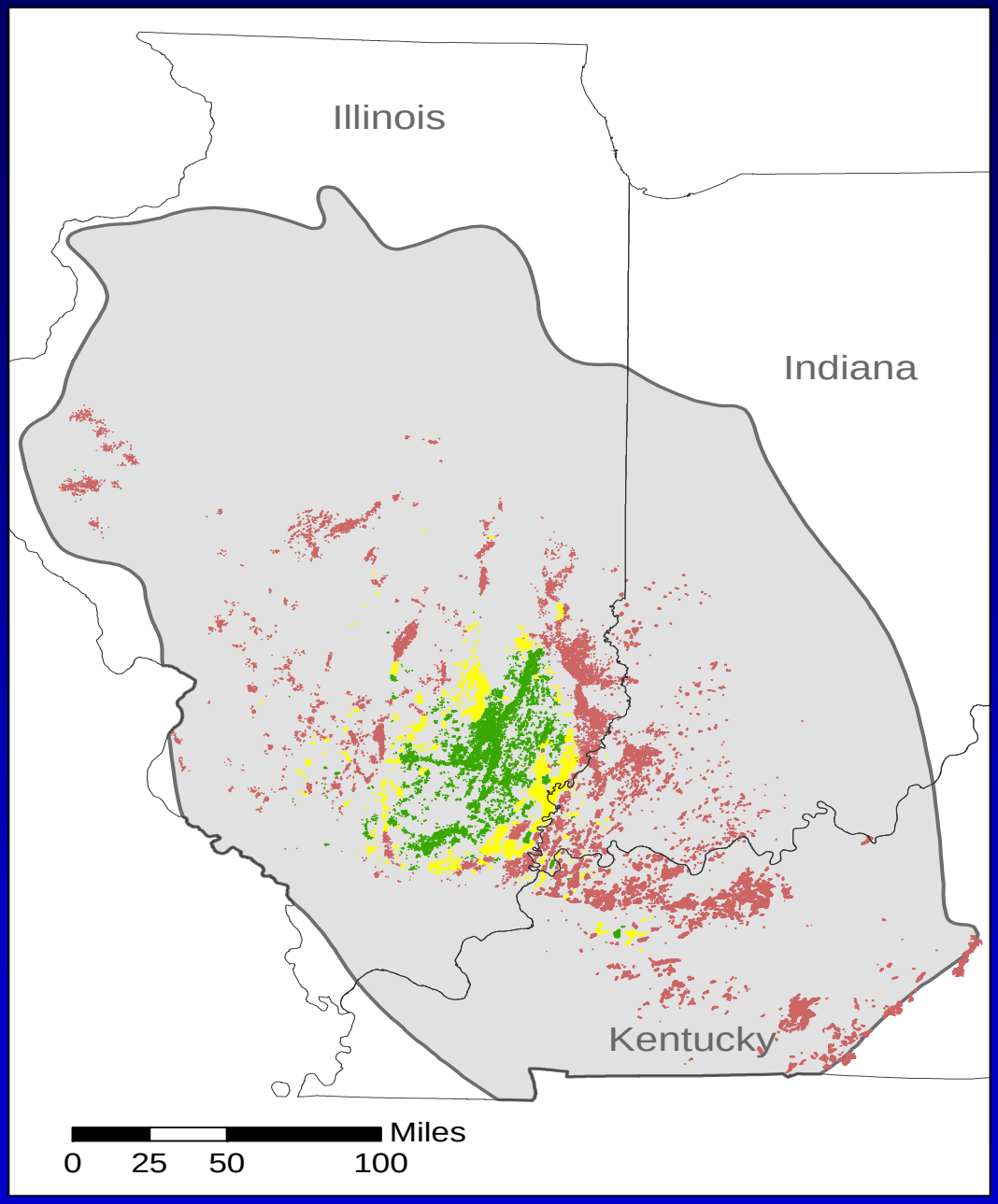
Illinois State Geological Survey

Midwest Geological
Sequestration Consortium
www.sequestration.org

Year One Illinois Basin Outcomes

- Capture and transportation options ready to be linked with geological characterization to define scenarios for small-scale regional validation field tests
- Rate of technical presentations and publications increasing, web site established, and preparation for more public outreach
- Geological characterization advanced to point of determining “sequestration fairway” with desirable reservoir characteristics for field tests

Oil Field Classification for Assessing EOR Potential

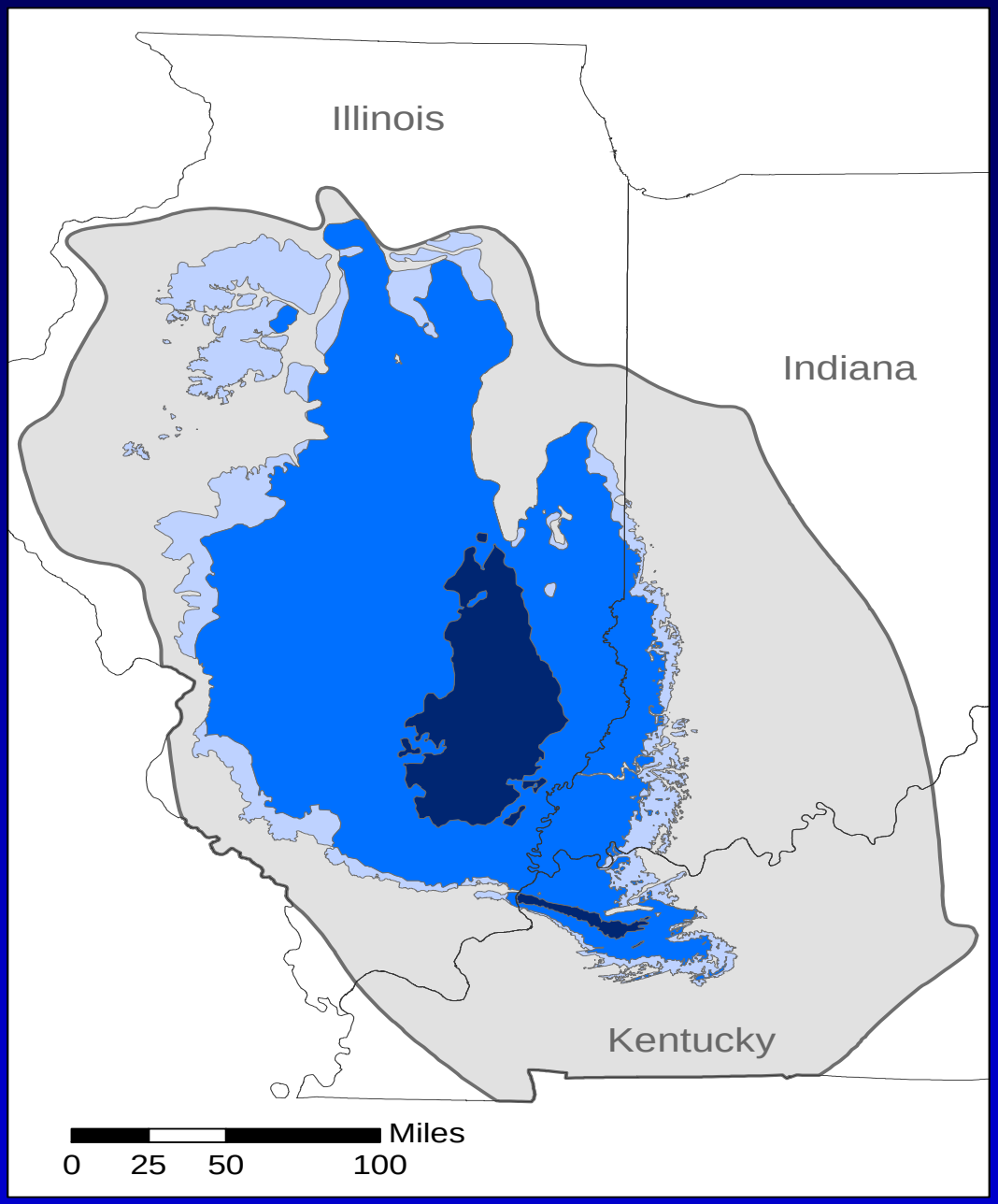


Illinois Basin Oil Fields

EOR Class

- Predominately Miscible
- Predominately Near-Miscible
- Predominately Immiscible

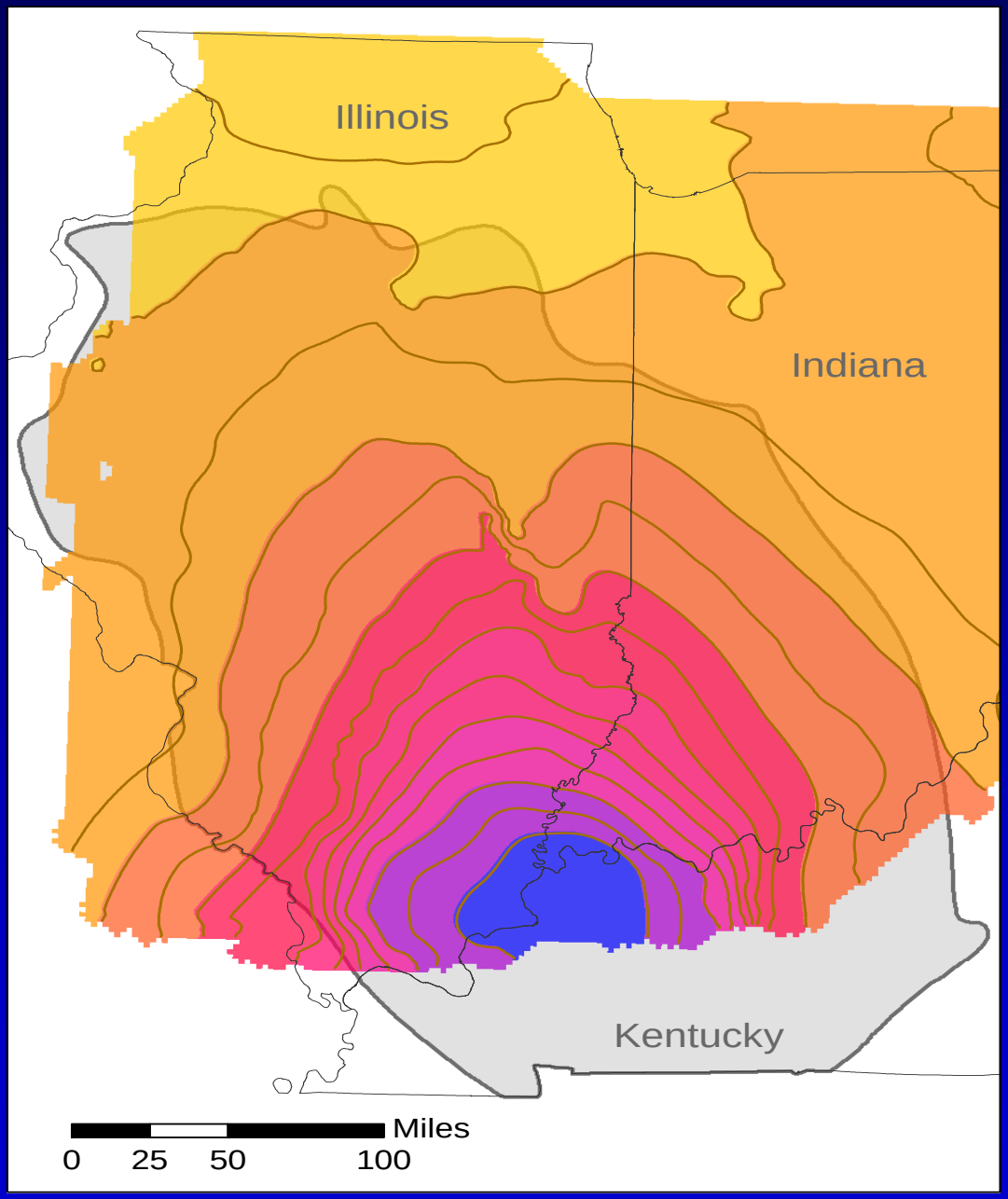
Deep Coal Least Likely to be Mined



Springfield Coal Depth

- 0 to 200 feet
- 200 to 1,000 feet
- greater than 1,000 feet

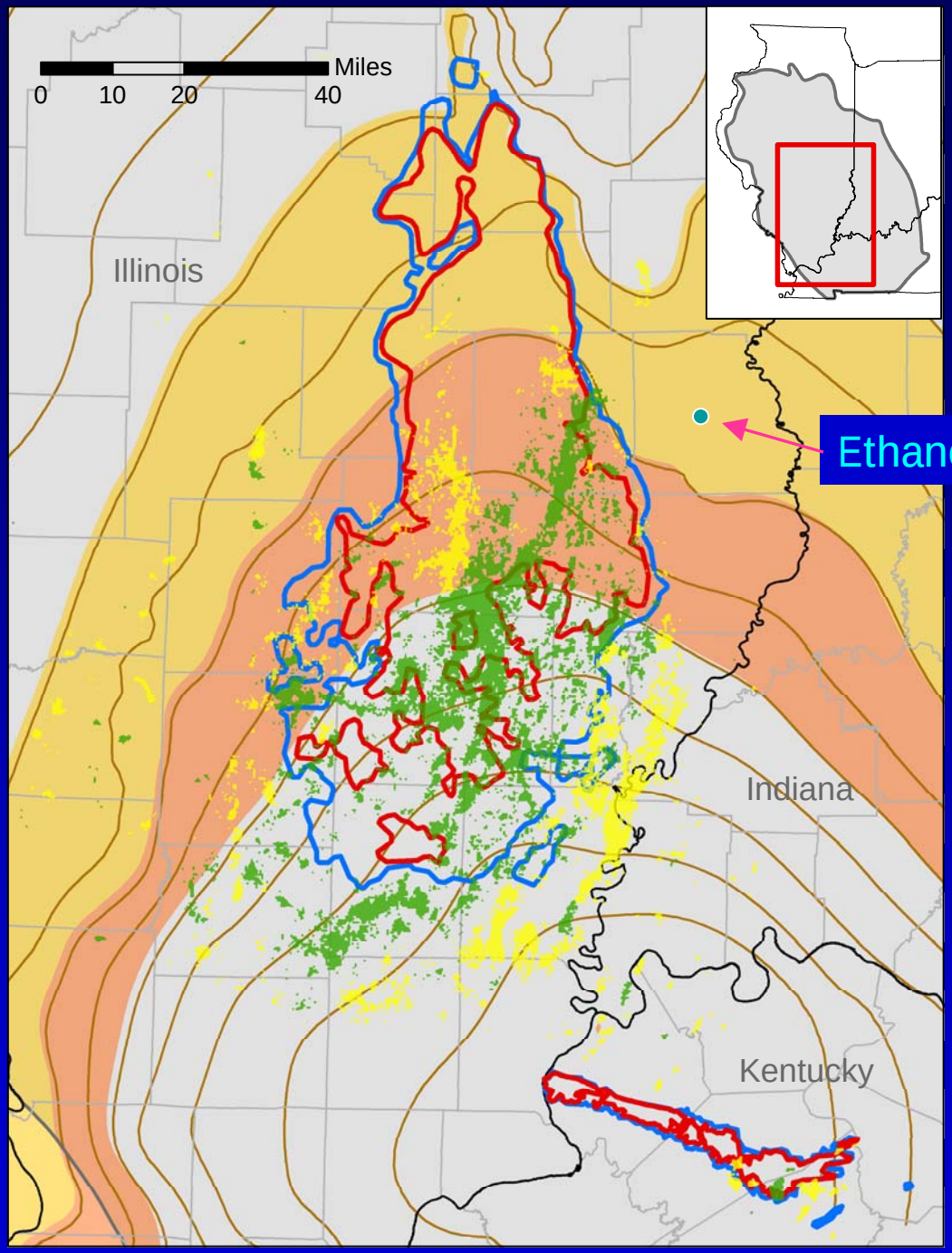
Mt. Simon Readily Accessible at 6-10,000 ft



Mt. Simon Elevation (msl in feet)

- 0 to -2,000
- -2,000 to -4,000
- -4,000 to -6,000
- -6,000 to -8,000
- -8,000 to -10,000
- -10,000 to -12,000
- -12,000 to -14,000
- > 14,000
- 1,000 foot contours

Central Illinois Basin Sequestration Fairway Emerges



Oil Fields EOR Class

- Predominately Miscible
- Predominately Near-Miscible

Coal Depth

- Herrin greater than 1,000 feet
- Springfield greater than 1,000 feet

Mt. Simon elevation (msl)

- -6,000 to -8,000 feet
- -8,000 to -10,000 feet
- 1,000 foot contours

Developing Future Collaboration

- Ameren, a member utility of the MGSC, collaborating with CBM test drilling planned in December
- Dialogue underway with four oil field operators in areas of MGSC interest, fifth operator identified
- New ethanol plant began operating July 04 on east edge of fairway

Outreach

- Thirteen presentations to date at:
  - American Council of Engineering Companies
  - Clearwater Coal Conference
  - DOE Ann. Conf. on Carbon Capture and Sequestration
  - ESRI Annual Users Conference
  - Illinois Oil & Gas Association
  - Illinois Geological Society
  - Illinois State University
  - Independent Oil Producers Association-Tri State
  - Indiana University
  - Geological Society of America Annual Meeting
  - GHGT-7 Vancouver
  - Society of Petroleum Engineers-EOR Conference

Midwest Geological Carbon Sequestration Consortium - Microsoft Internet Explorer

File Edit View Favorites Tools Help

Address http://sequestration.org/

Midwest Geological Sequestration Consortium - sequestration.org

Assessing Geological Carbon Sequestration Options in the Illinois Basin

The Midwest Geological Carbon Sequestration Consortium (MGSC) will assess the potential for geologic sequestration (storage) of carbon dioxide in the deeply buried unminable coal seams, depleting oil or gas reservoirs, and brine-filled rock formations found in the Illinois Basin. The Illinois Basin is a geologic depression underlying most of Illinois and extending into southwest Indiana and northwest Kentucky.

The MGSC was selected by the National Energy Technology Laboratory (NETL) of the United States Department of Energy (DOE) as one of seven regional partnerships charged with evaluating available technologies for capture and long-term storage of carbon dioxide. The program aims to ultimately reduce the emissions intensity of greenhouse gases within the Earth's atmosphere.

INTRODUCTION
- Carbon Dioxide Sequestration
- CO_2 in the News

GEOLOGY
- Illinois Basin
- Site Screening
- Stratigraphy

RESEARCH
- Activities
- Publications
- Program Links

CONSORTIUM
- Mission
- Partners
- Staff

Member Login

Done

Plans for Year Two

- Complete geological characterization by March 05, plus studies of CO_2 isotopes, rock fluid interactions, seismicity, stress and fractures
- Tasks 7 and 9: integrate storage options with likely sinks for field test and larger volumes
- Task 8: incorporate environmental and regulatory framework, IOGCC product
- Task 10 and 11: Compile results and expand outreach activities, including two regional conferences
- Task 12: Nominate and document five potential field test sites

Midwest Geological
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www.sequestration.org