Assessing Reservoir Depositional Environments to Develop and Quantify Improvements in CO_2 Storage Efficiency: A Reservoir Simulation Approach

Project Number: DE-FE0009612

Roland Okwen, Scott Frailey, and Hannes Leetaru

Illinois State Geological Survey

U.S. Department of Energy
National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and Infrastructure for CCS
August 20−22, 2013

Acknowledgments

- The Midwest Geological Sequestration Consortium (MGSC) is funded by the U.S. Department of Energy through the National Energy Technology Laboratory (NETL) via the Regional Carbon Sequestration Partnership Program (contract number DE-FC26-05NT42588) and by a cost share agreement with the Illinois Department of Commerce and Economic Opportunity, Office of Coal Development through the Illinois Clean Coal Institute.
- Through a university grant program, Landmark Software was used for the reservoir and geologic modeling.

Presentation Outline

- Project benefit to CO_2 program
- Project goals and objectives
- Project approach
- Expected outcome
- Accomplishments to date
- Summary

Benefit to the Program

Carbon Storage Program Major Goals

- Support industry's ability to predict CO_2 storage capacity in geologic formations to within ±30 percent.
- Develop and validate technologies to ensure 99 percent storage permanence.
- Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness.

Benefits Statement

This project will address Area of Interest 3, Field Methods to Optimize Capacity and Ensure Storage Containment. The identification of field techniques to improve storage efficiency above the baseline CO_2 storage efficiency in specific geologic formation classes of different depositional environments identified by DOE as promising storage formations will provide better regional assessment estimates and site screening criteria. The research will contribute to the program's effort of estimating CO_2 storage capacity in geologic formations.

Project Overview: Goals

- Quantify storage efficiency (*E*) of different depositional environment (formation classes);
  - DOE's "High" and "Medium" storage potential ratings
- Identify methods that can be used to
  - Improve *E*;
  - Manage CO_2 plume

Project Overview: Objectives

- Select study areas that represent different depositional systems
- Develop rigorous geologic and geostatistical models of selected formations
- Conduct numerical simulations to
  - Estimate baseline *E*
  - Depict CO_2 plume distribution within formation flow units
  - Determine injection well orientation and completion for improving *E*

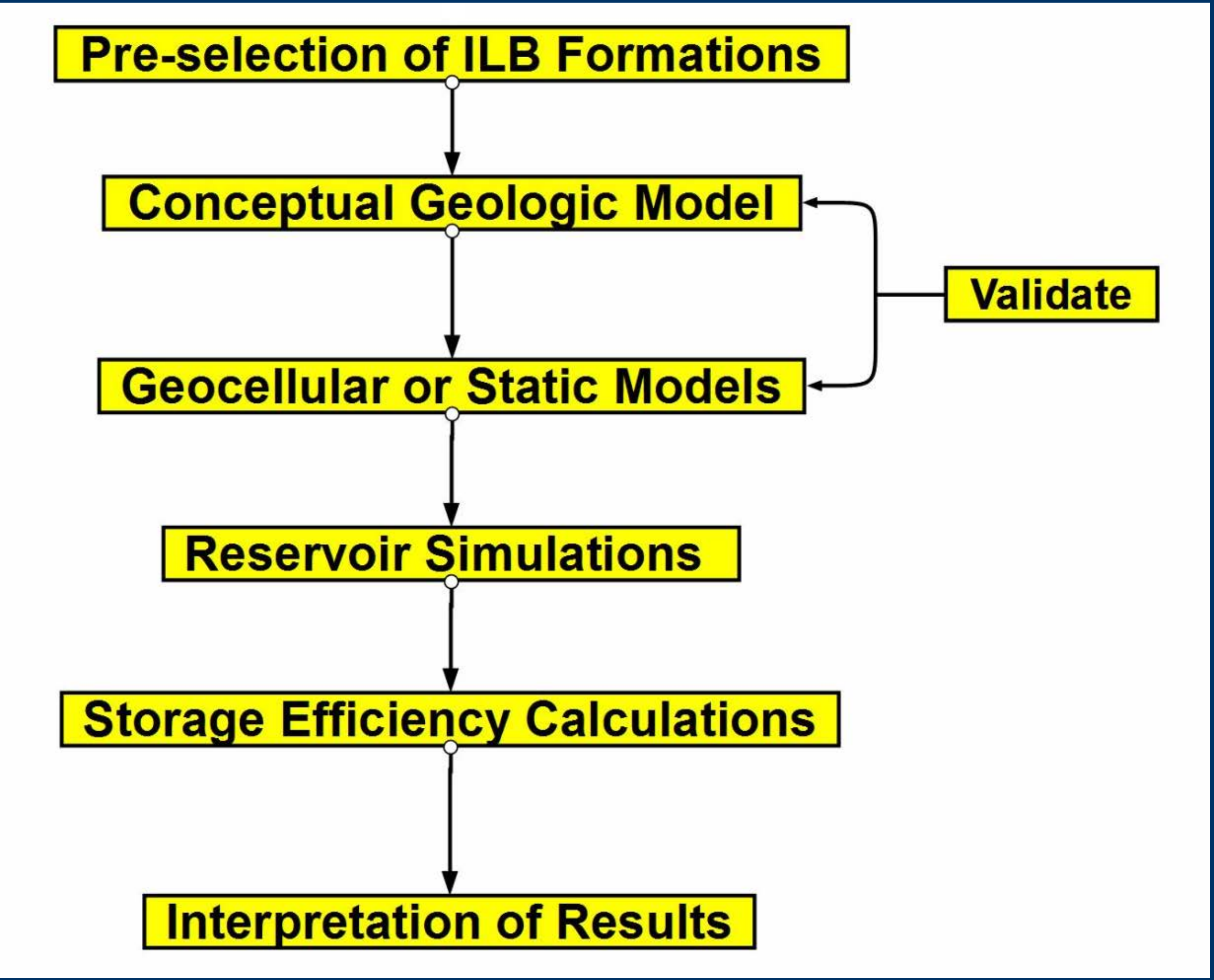
Background

- CO_2 storage potential Matrix (NETL, 2010)
- Large Scale, Small Scale and Characterization are DOE defined groups

Matrix of Field Activities in Different Formation Classes

Geologic Formation Classes	High Potential					Medium Potential				Low or Unknown Potential	
	Deltaic	Shelf Clastic	Shelf Carbonate	Strandplain	Reef	Fluvial Deltaic	Eolian	Fluvial & Alluvial	Turbidite	Coal	Basalt (LIP)
Large Scale	–	1	–	–	1	3	–	1	–	–	–
Small Scale	3	2	4	1	2	–	–	2	–	5	1
Characterization	1	–	8	6	–	3	3	2	2	–	1

Approach


Pre-selection of ILB Formations
Conceptual Geologic Model
Validate
Geocellular or Static Models
Reservoir Simulations
Storage Efficiency Calculations
Interpretation of Results

Pre-selection of Depositional Environments

- Take inventory of
  - All existing ILB geologic studies
  - Available geologic and reservoir data
- Review existing
  - Geologic and geocellular models
  - Reservoir characterization studies
- Select suitable formations

Selected Formations and Classes

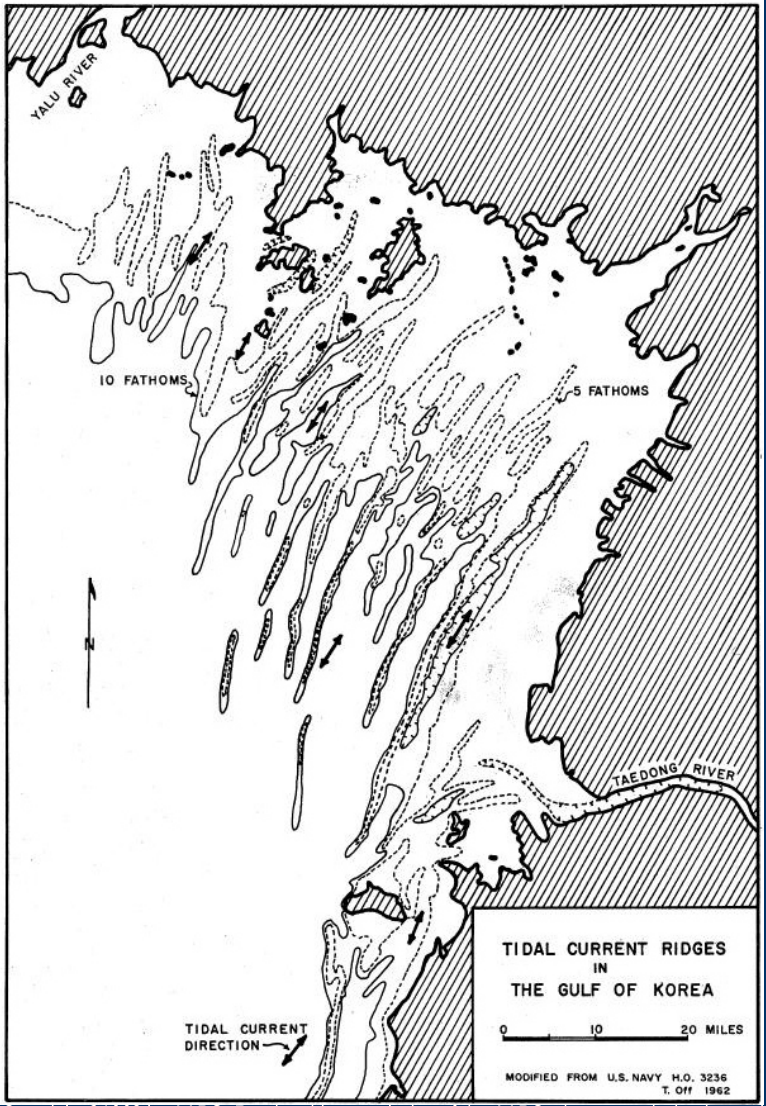
Formation Class	Storage Potential (DOE's Rating)	Illinois Basin Reservoir	Formation	Lithology
Deltaic	High	Iola Consolidated	Benoist	Sandstone
		Lawrence	Bridgeport	Sandstone
Shelf Clastic	High	Lawrence	Cypress	Sandstone
Shelf Carbonate	High	Johnsonville Consolidated	Ste. Genevieve	Limestone
		Miletus	Geneva	Dolomite
		Forsyth	Racine	Dolomite
Strandplain	High	Manlove	Upper Mt. Simon	Sandstone
Reef	High	Tilden	Racine	Dolomite
Fluvial Deltaic	Medium	Lawrence	Bridgeport	Sandstone
Fluvial & Alluvial	Medium	Illinois Basin Decatur project	Lower Mt. Simon	Sandstone
Turbidite	Medium	St. James	Carper	Sandstone

Conceptual Geologic Model

- Use available data to construct
  - Lithology
  - Correlate tops and bottoms
  - Cross sections
  - Isopach maps
  - Structure maps
- Determine depositional environment
  - Require validation by ISGS and contract geologists

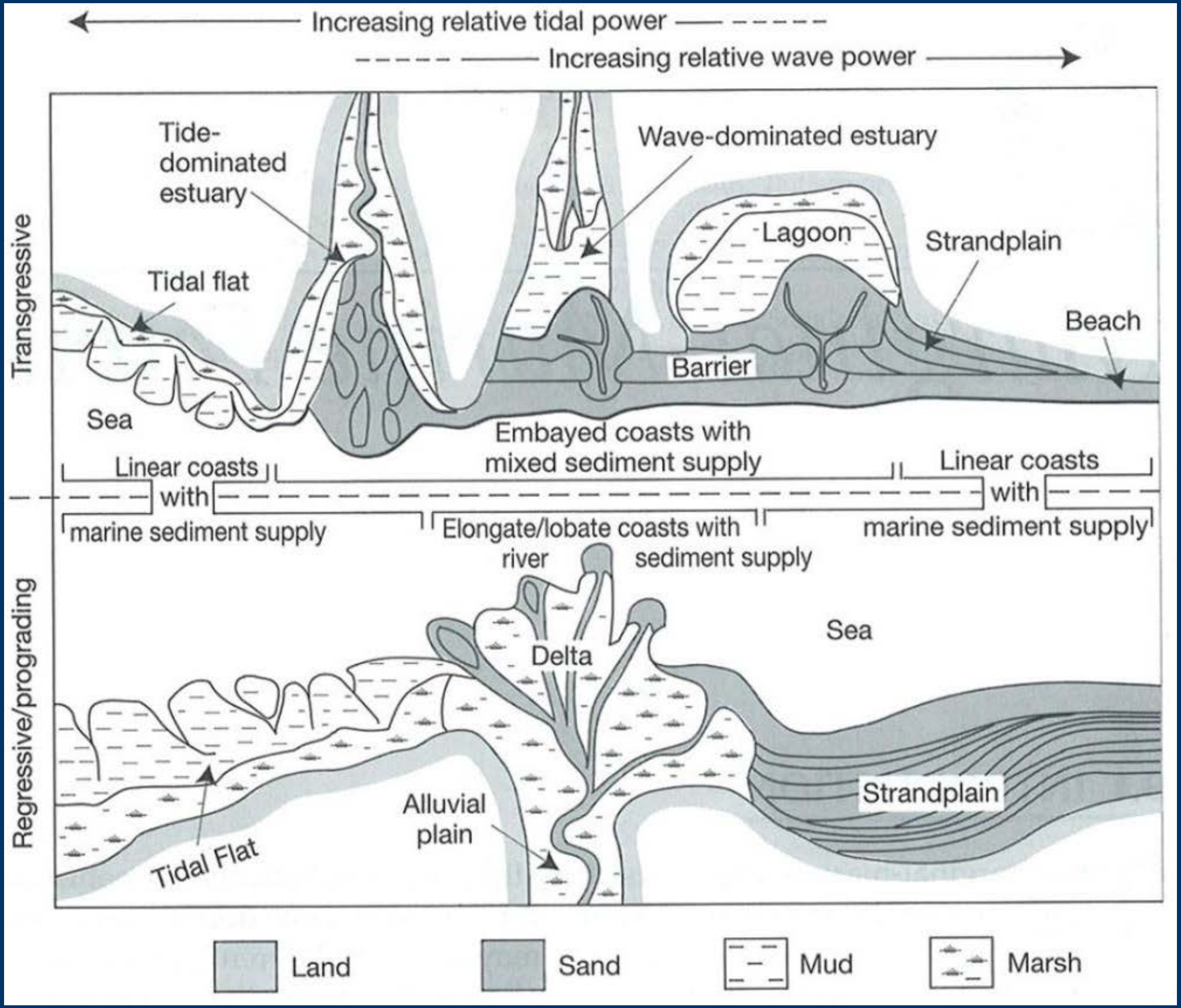
- Software: Geographix

Example: Shelf Clastic



- General conceptual model (Off, 1963)

Example: Deltaic

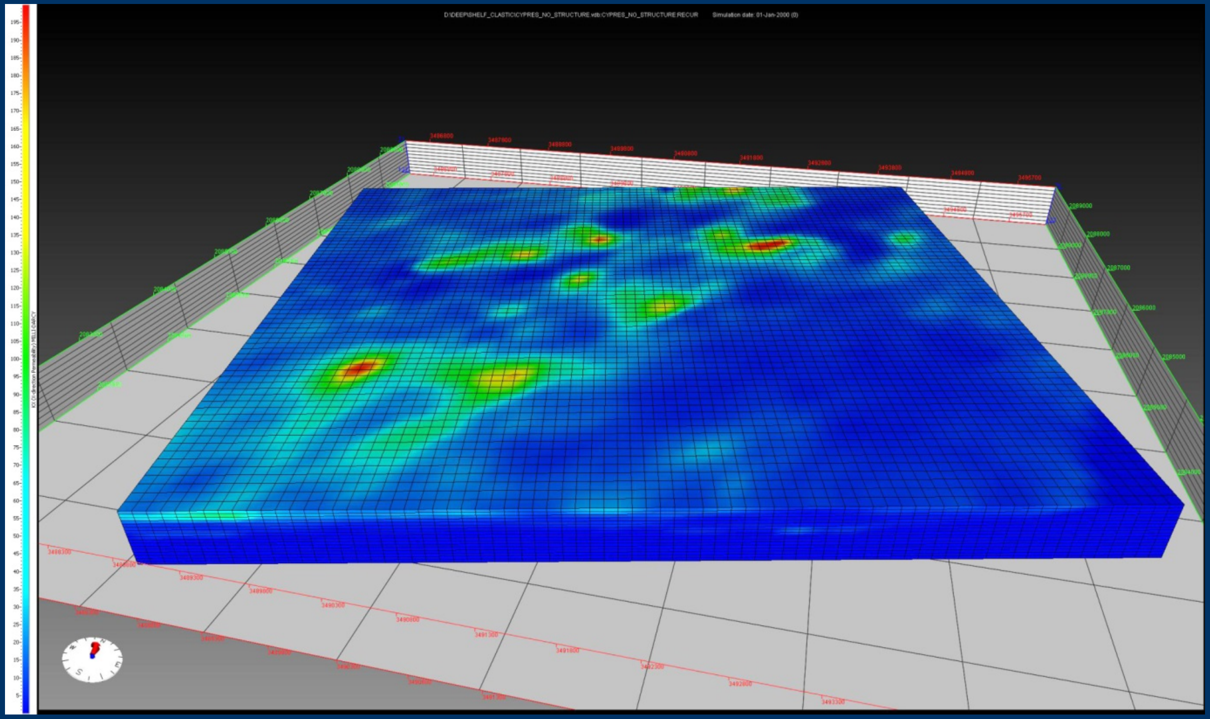


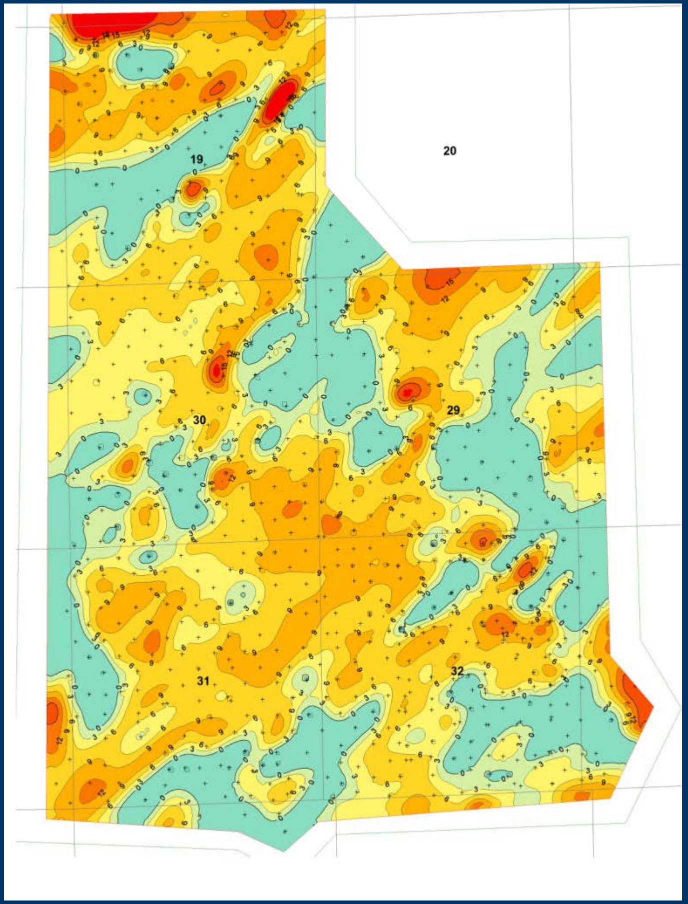
- General conceptual model (Boyd et al., 1992)

Geocellular Modeling

- Conduct geostatistical analyses using
  - Conceptual geologic model
  - Digitized logs
  - Core data
  - Surface maps
- Build geocellular model (4 distributions)
  - Porosity
  - Permeability
  - Thickness
  - Facies
- Flat, no structure
  - Accounts for effect of depositional environment only
- Software: Isatis

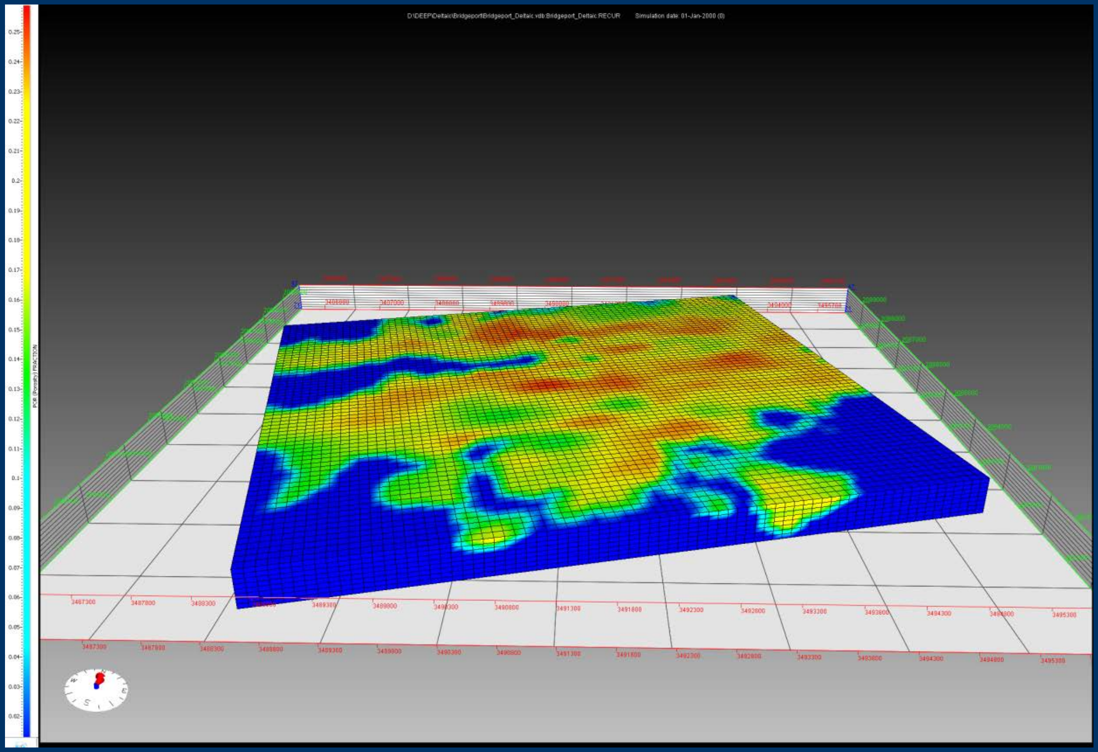
Example: Shelf Clastic

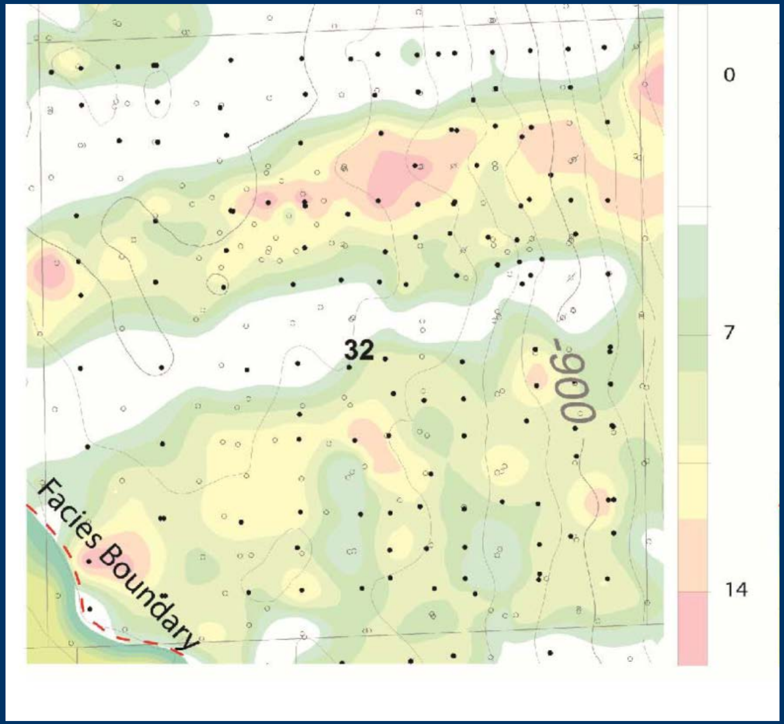




- Model Permeability distribution (10−300 mD)
- Model area covers section 32 (bottom right) of figure (Seyler et al., 2012)

Example: Deltaic Formation

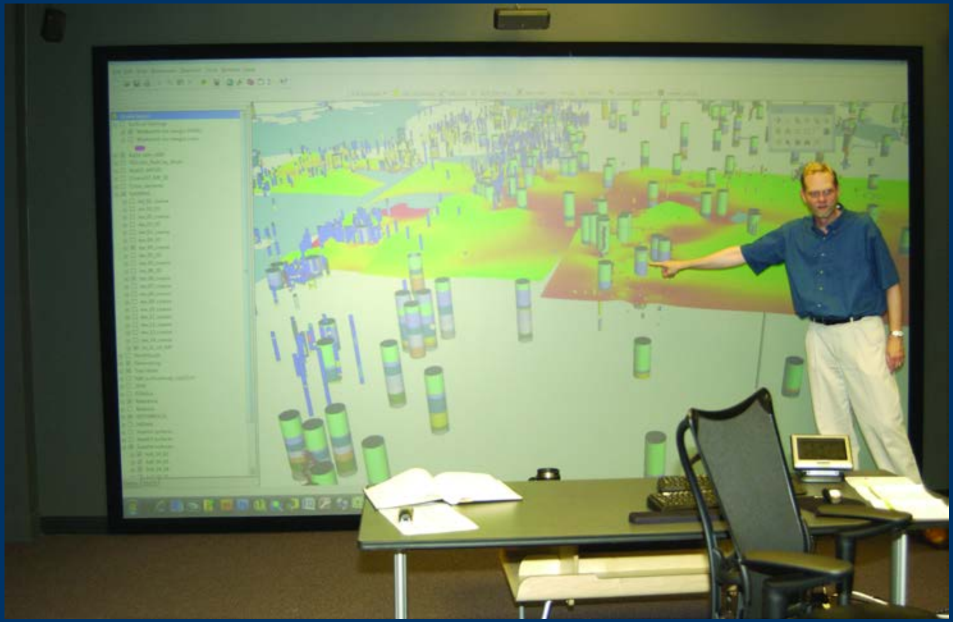




- Permeability distribution (5−300 mD)
- Model area covers isopach map (Seyler et al., 2012)

Model Validation

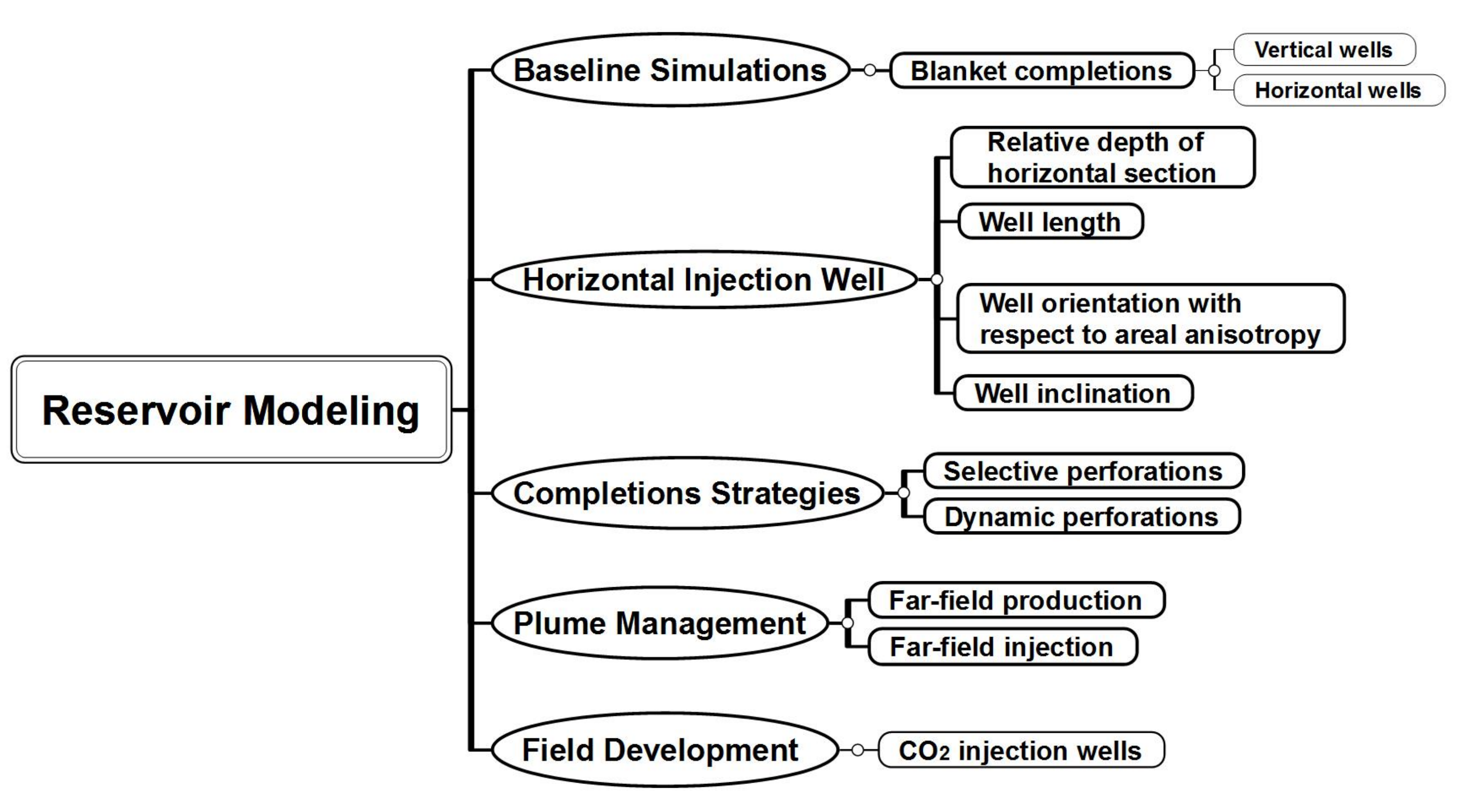
- Goal:
  - Obtain a geocellular model representing a depositional environment of interest
- Compare geocellular and conceptual models
  - Ensure match between both models
  - Validated by ISGS and contract geologists



Reservoir Simulations

- Input
  - Geocellular model
  - Reservoir and PVT properties
  - End-point saturations and relative permeabilities
  - Initial conditions
  - Brine saturate formation
  - $P_{init} > P_{crit,CO2}$, $T_{res} > T_{crit,CO2}$
- Conduct numerical simulations of CO_2 injection wells
  - Vertical
  - Horizontal
- Software: Landmark Nexus

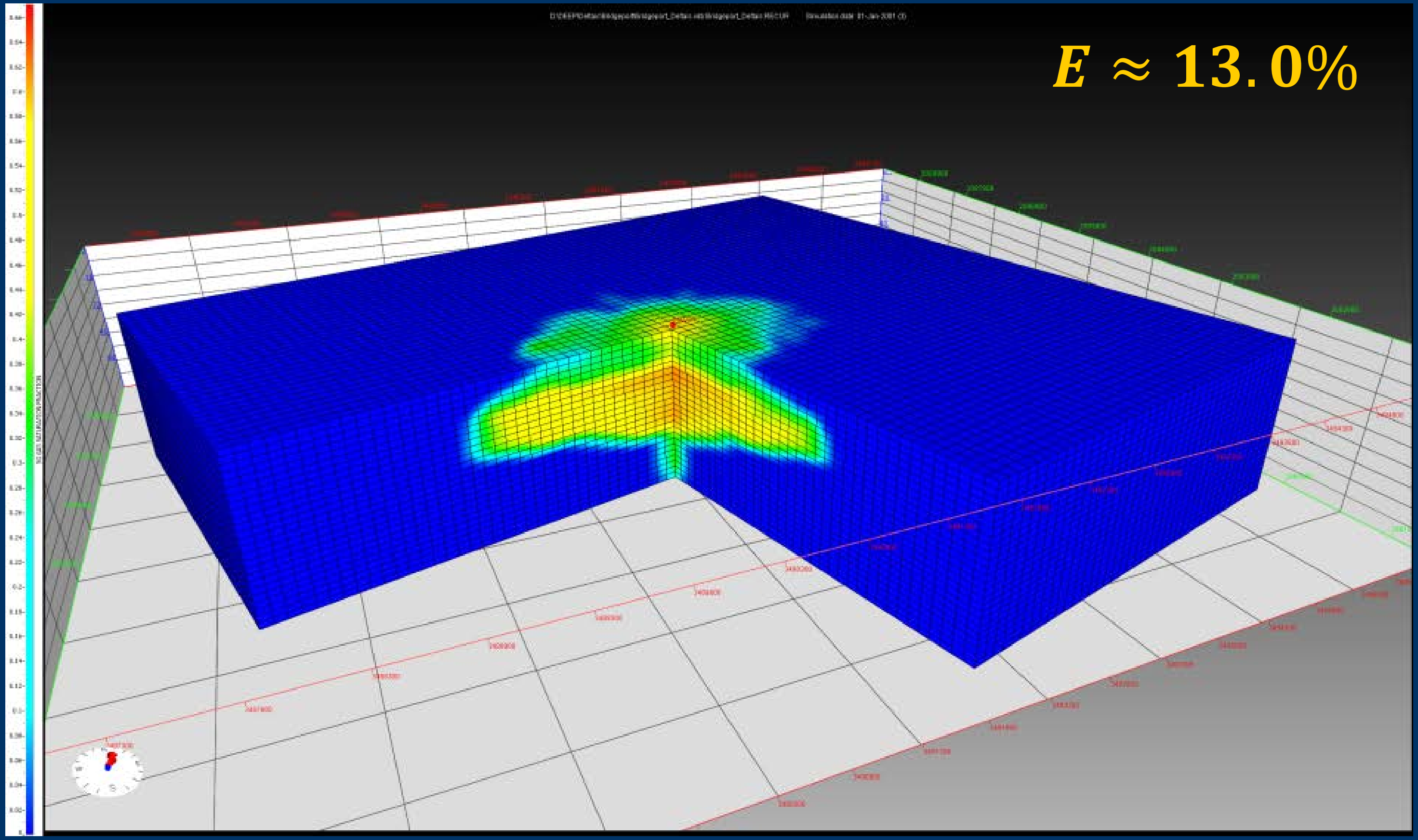
Reservoir Simulations, cont.



Example: Deltaic

- Preliminary reservoir model
- Cells: 127,500
- Vertical injection well

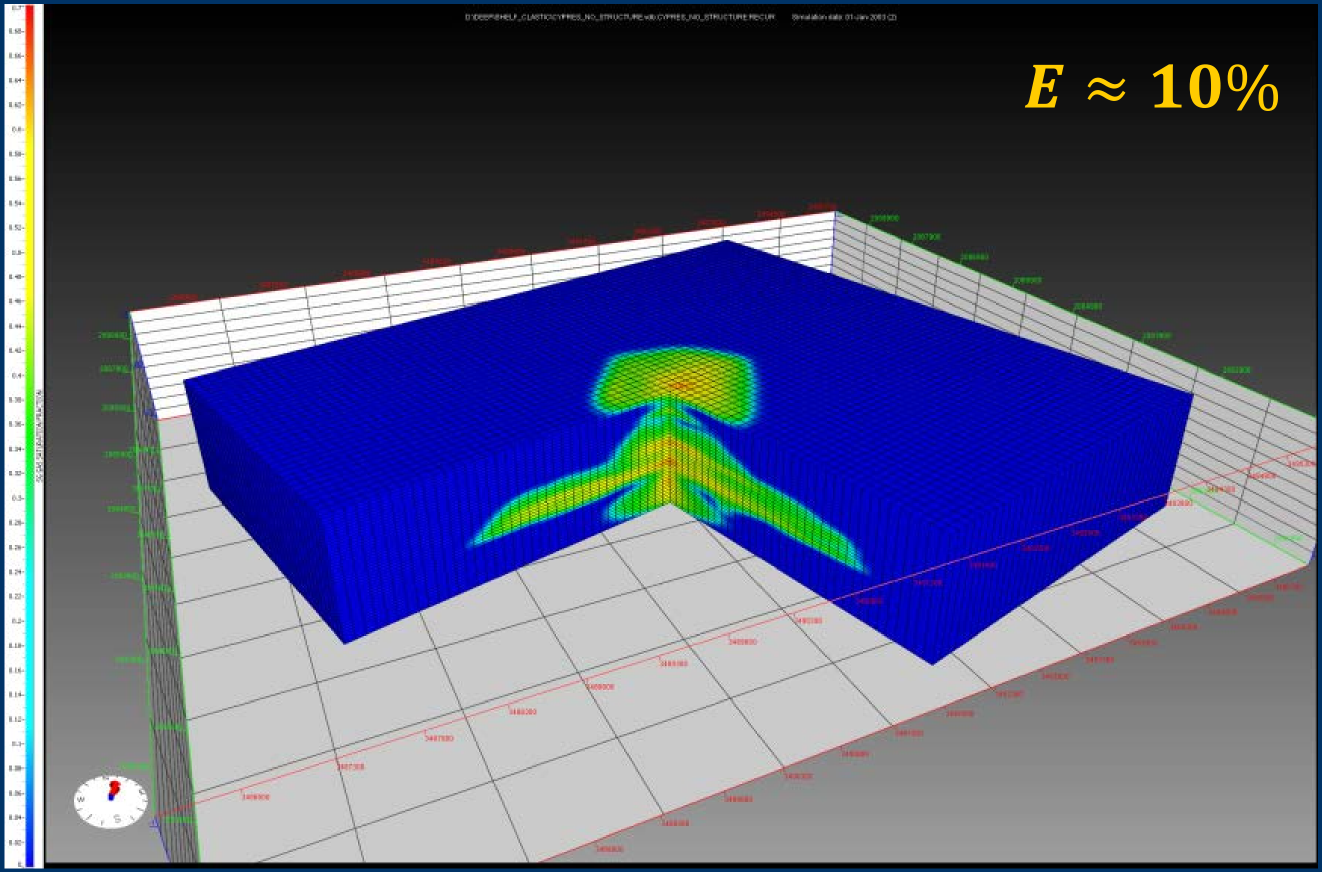
CO_2 plume distribution (1 year)



Example: Shelf Clastic

- Preliminary reservoir model
- Cells: 127,500
- Vertical injection well

CO_2 plume distribution (3 years)



Expected Outcome

Formation Class	Storage Potential (DOE's Rating)	Lithology	Baseline Storage Efficiency
			Without geologic structure
Deltaic	High	Sandstone	? — ? %
Shelf Clastic	High	Sandstone	? — ? %
Shelf Carbonate	High	Limestone	? — ? %
		Dolomite	? — ? %
Strandplain	High	Sandstone	? — ? %
Reef	High	Dolomite	? — ? %
Fluvial Deltaic	Medium	Sandstone	? — ? %
Fluvial & Alluvial	Medium	Sandstone	? — ? %
Turbidite	Medium	Sandstone	? — ? %

Geologic Modeling Status

Formation Class	ILB Oil or Gas Storage Field	Formation	Lithology	Conceptual Model	Geocellular Model	Reservoir Model
Deltaic	Iola Consolidated	Benoist	Sandstone	Completed	Completed	In progress
	Lawrence Field	Bridgeport	Sandstone	Completed	Completed	In progress
Shelf Clastic	Lawrence Field	Cypress	Sandstone	Completed	Completed	In progress
Shelf Carbonate	Johnsonville Consolidated	Ste. Genevieve	Limestone	In progress	Pending	Pending
	Miletus Field	Geneva	Dolomite	In progress	Pending	Pending
	Forsyth Field	Racine	Dolomite	Completed	In progress	Pending
Strandplain	Manlove Field	Upper Mt. Simon	Sandstone	Completed	Completed	In progress
Reef	Tilden Field	Racine	Dolomite	In progress	Pending	Pending
Fluvial Deltaic	Lawrence Field	Bridgeport	Sandstone	Completed	Completed	In progress
Fluvial & Alluvial	Illinois Basin Decatur Project	Lower Mt. Simon	Sandstone	Completed	Completed	In progress
Turbidite	St. James Field	Carper	Sandstone	Completed	In progress	Pending

- 8 out of 11 geologic conceptual models completed
- 7 out of 11 geocellular models completed
- 6 geocellular models validated

Summary

- Key Findings
  - ILB formations studied exhibit a mixture of depositional environments with one having a dominating presence
- Lessons Learned
  - Depositional environment based storage efficiency requires “structure-free” models
- Future Plans
  - Compare ILB formations to similar formations in other US basins
  - Complete construction of conceptual and geocellular models of the remaining ILB formations
  - Complete reservoir simulation scenarios of selected ILB formations

ISGS Staff

- Reservoir Engineers:
  - Roland Okwen
  - Scott Frailey
- Sub-contractor (Schlumberger) :
  - John Grube
  - Beverly Seyler
- Database specialist
  - Damon Garner
- Geologists:
  - Hannes Leetaru
  - Yaghoob Lasemi
  - Nathan Webb
  - James Damico
  - Charles Monson
- Editor:
  - Dan Klen

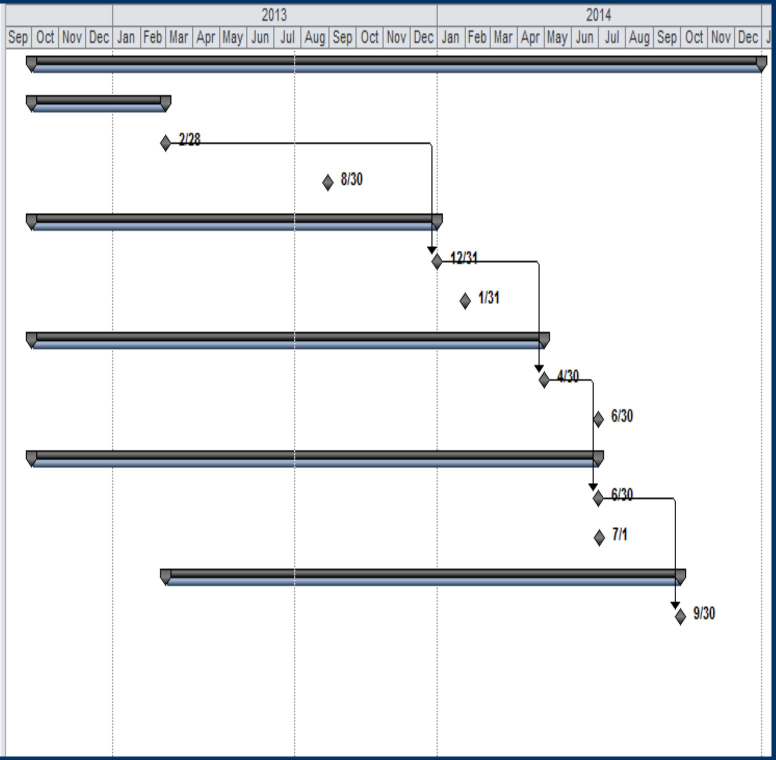
Midwest Geological Sequestration Consortium
www.sequestration.org

Appendix

- Gantt Chart
- Bibliography

Gantt Chart

	Task Name	Start	Finish	% Complete
1	**Task 1 – Project Management, Planning, and Reporting**	Mon 10/1/12	Wed 12/31/14	55%
43	**Task 2 – Geologic Formation Screening**	Mon 10/1/12	Thu 2/28/13	100%
53	Milestone: Formation List to NETL Capacity Team for Review	Thu 2/28/13	Thu 2/28/13	100%
54	Deliverable: Task 2 Report	Fri 8/30/13	Fri 8/30/13	100%
55	**Task 3 - Geology and Geologic Modeling**	Mon 10/1/12	Tue 12/31/13	80%
67	Milestone: Complete contruction og geologic models	Tue 12/31/13	Tue 12/31/13	0%
68	Deliverable: Task 3 Report	Fri 1/31/14	Fri 1/31/14	0%
69	**Task 4 – Geostatistical Analyses and Geocellular Modeling**	Mon 10/1/12	Wed 4/30/14	60%
81	Milestone: Complete constuction of geocellular models	Wed 4/30/14	Wed 4/30/14	0%
82	Deliverable: Task 4 Report	Mon 6/30/14	Mon 6/30/14	0%
83	**Task 5 – Reservoir Flow Modeling**	Mon 10/1/12	Mon 6/30/14	20%
110	Milestone: Complete reservoir simulations	Mon 6/30/14	Mon 6/30/14	0%
111	Deliverable : Task 5 Report	Tue 7/1/14	Tue 7/1/14	0%
112	**Task 6 – Interpretation and Analyses of Modeling Results**	Fri 3/1/13	Tue 9/30/14	10%
115	Milestone: Finalize estimates of storage efficiency by geologic classification	Tue 9/30/14	Tue 9/30/14	0%



Bibliography

1. Boyd, R., R. Dalrymple, and B. A. Zaitlin. 1992. "Classification of clastic coastal depositional environments." *Sedimentary Geology* 80 (3–4): 139–150.
2. Off, T. 1963. "Rhythmic linear sand bodies caused by tidal currents." *AAPG Bulletin* 47 (2): 324–341.
3. Seyler, B., J. Grube, B. Huff, N. Webb, J. Damico, C. Blakley, V. Madhavan, P. Johanek, and S. Frailey. 2012. *Reservoir Characterization of Bridgeport and Cypress Sandstones in Lawrence Field Illinois to Improve Petroleum Recovery by Alkaline-Surfactant-Polymer Flood*. DOE Contract DE-NT0005664 (Issued December 21, 2012.).