OPTIMIZING AND QUANTIFYING CO_2 STORAGE RESOURCE IN SALINE FORMATIONS AND HYDROCARBON RESERVOIRS

DE-FE0009114

Mastering the Subsurface Through Technology Innovation & Collaboration:
Carbon Storage & Oil & Natural Gas Technologies Review Meeting

August 17, 2016

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Energy & Environmental Research Center

Critical Challenges. **Practical Solutions.**

PRESENTATION OUTLINE

- Benefit to the program
- Project overview
- Technical status
  - Task 2: Saline Formations
  - Task 3: Oil Reservoirs
- Accomplishments to date
- Synergy opportunities
- Summary

PARTNERS

BENEFIT TO THE PROGRAM

- Second, third, and fourth goals of Carbon Storage Program:
  - Improve reservoir storage efficiency while ensuring containment effectiveness.
  - Predict CO_2 storage capacity.
  - Develop best practices manuals (BPMs).
- CO_2 storage resource estimation methodologies will be evaluated and refined, if necessary, for saline and hydrocarbon reservoirs.
- Storage efficiency values will be available for various depositional environments.
- Lessons learned will be presented in a BPM.

PROJECT OVERVIEW

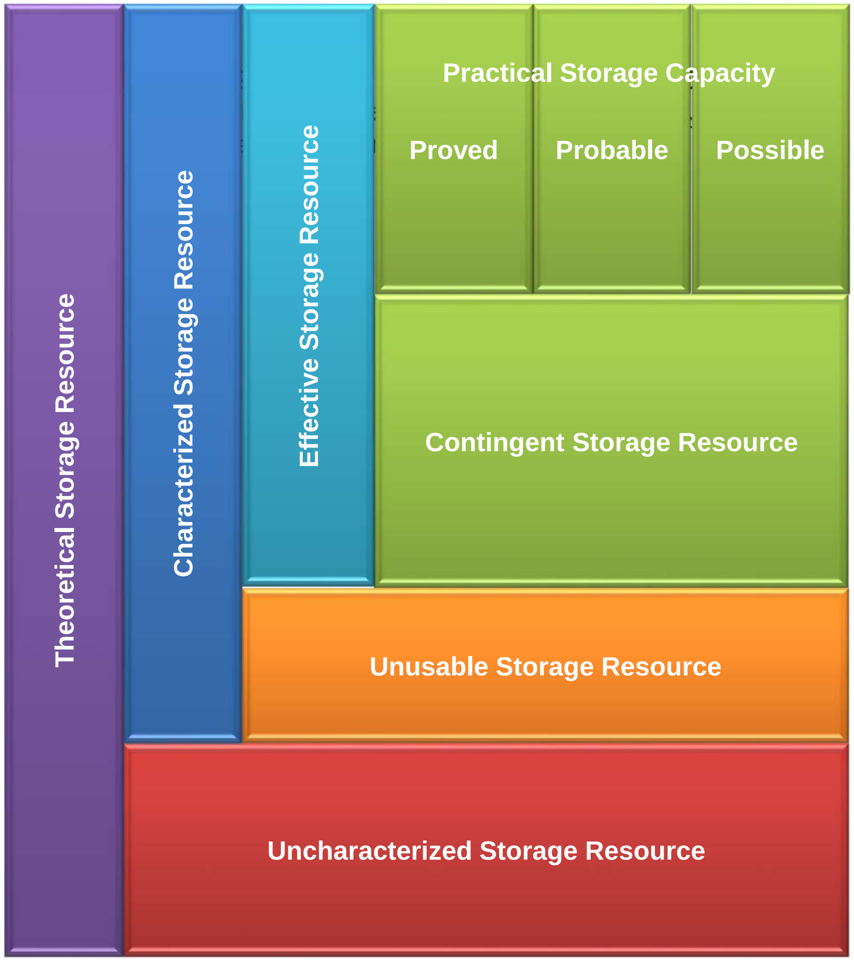
Goal

- To refine current methods and terms used to estimate CO_2 storage resource in saline formations and hydrocarbon reservoirs

Objectives

- Review literature and industry data
- Construct models, perform simulations
- Evaluate storage efficiency
  – Task 2: By depositional environment (saline formations)
  – Task 3: During CO_2 enhanced oil recovery (EOR)

CO_2 STORAGE RESOURCE/CAPACITY

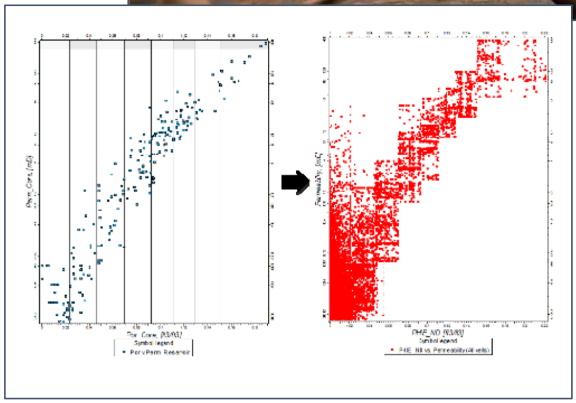


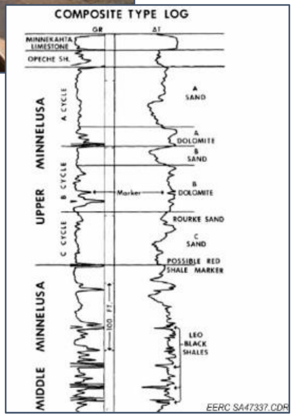
Adapted from IEA Greenhouse Gas R&D Programme, 2009, Development of storage coefficients for CO_2 storage in deep saline formations: 2009/12, October 2009.

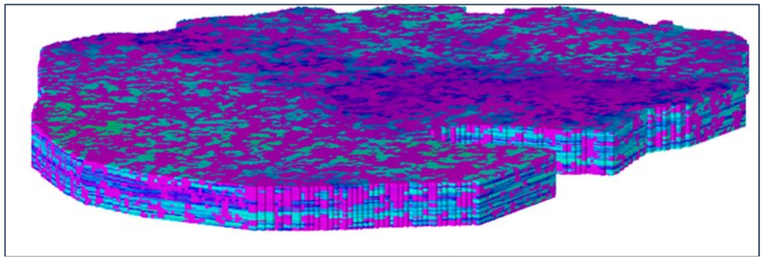
TASK 2: SALINE FORMATION MODELING

Approach

- Construct regional- to basin-scale geocellular models representing various depositional environments (primary and secondary).
- Use real saline formations as a guide and data source.
- Supplement petrophysical properties using the Average Global Database (AGD).
- Perform CO_2 injection simulations.







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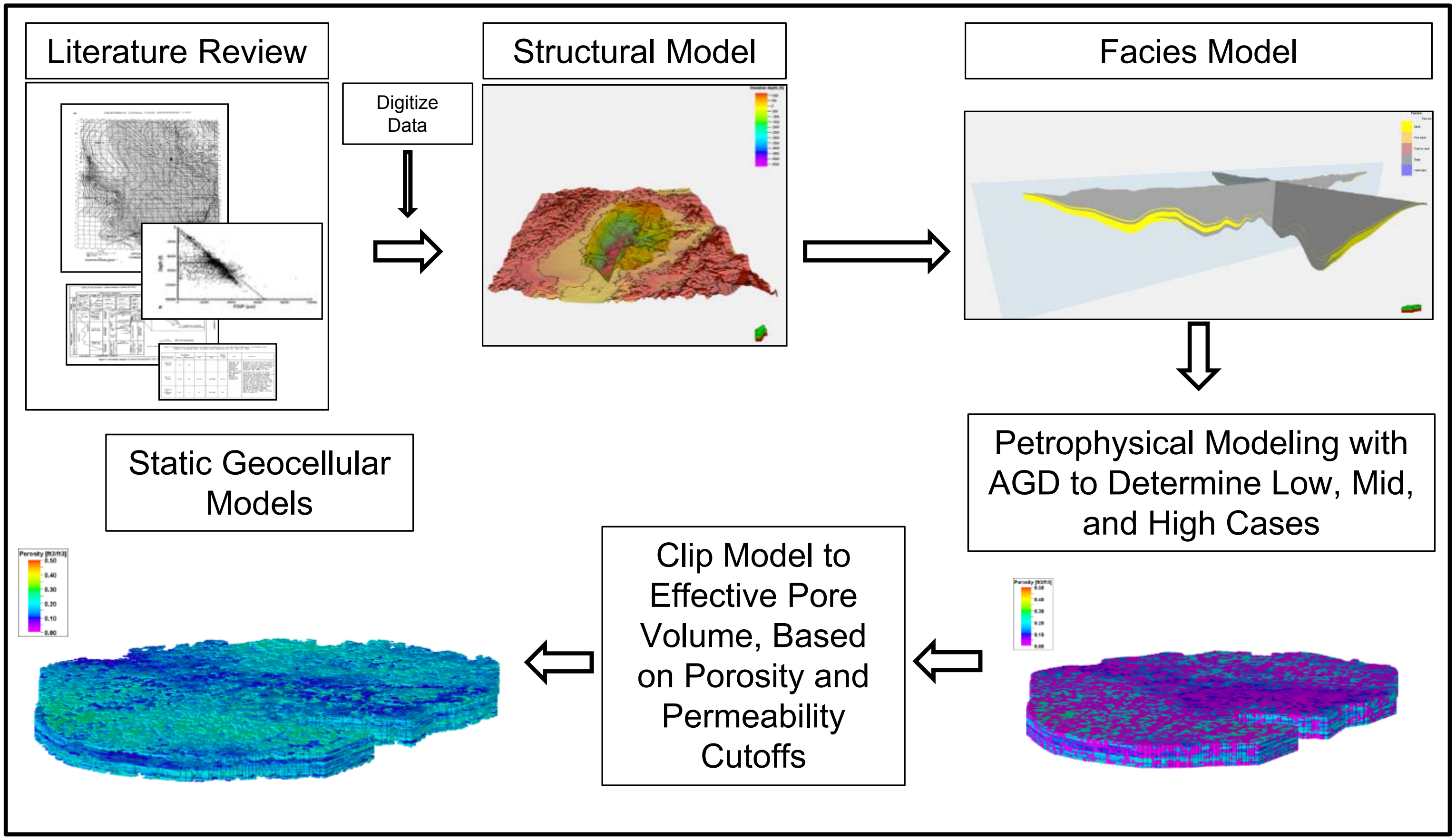
SALINE FORMATIONS SELECTED

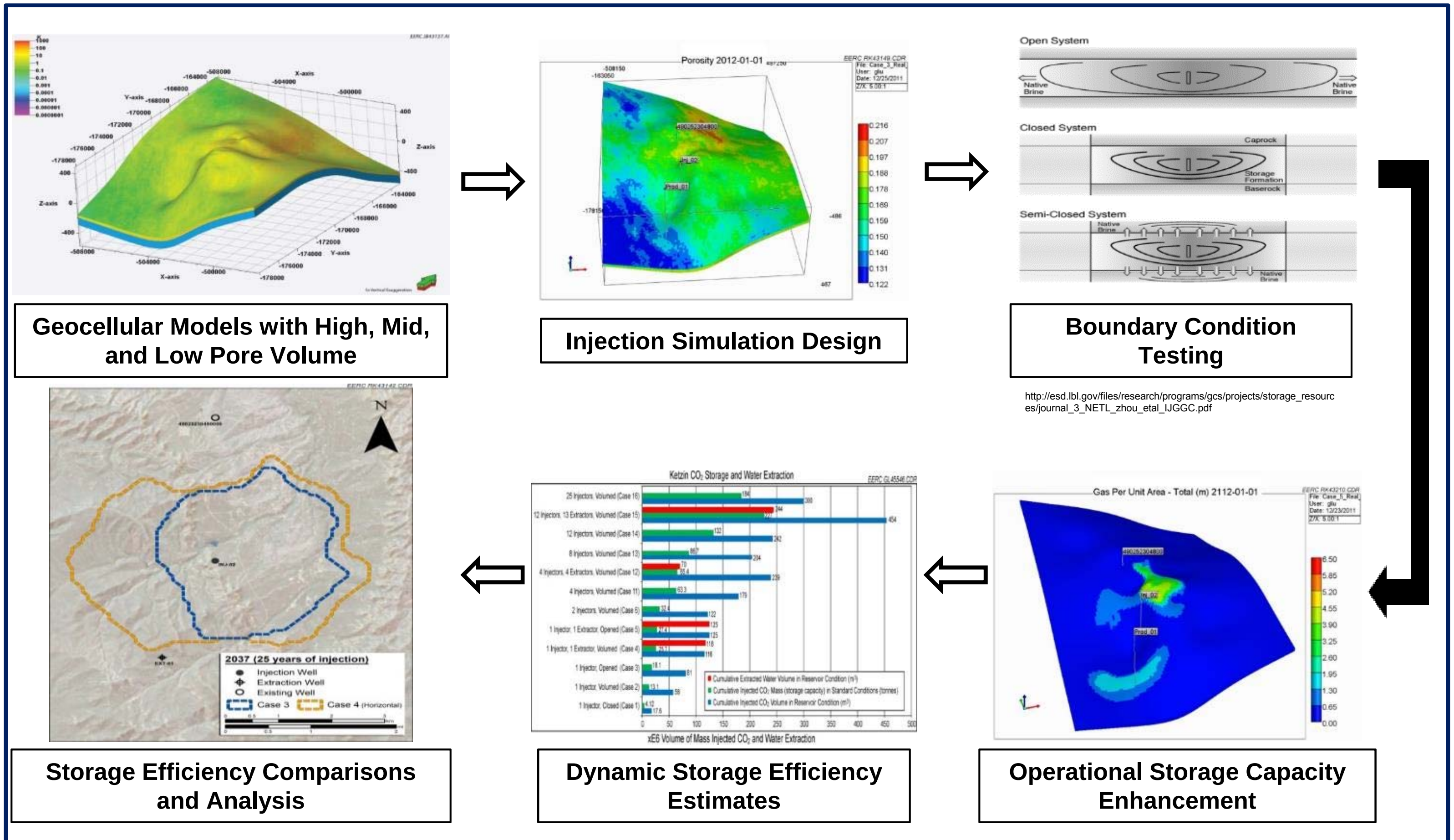
Saline Formations and Depositional Environments Selected		
Model Structural Basis	Primary Depositional Environment	Secondary Depositional Environment
Broom Creek	Eolian	N/A
Inyan Kara	Delta	Fluvial
Leduc	Reef	Carbonate Shelf
Minnelusa	Eolian	N/A
Mission Canyon	Carbonate Shelf	Peritidal
Qingshankou and Yaojia	Lacustrine	Fluvial
Stuttgart	Fluvial	Delta
Utsira	Clastic Slope	Strand Plain
Utsira	Clastic Shelf	Strand Plain
Winnipegosis	Reef	Carbonate Shelf

- Note: Models are not meant to represent the actual formation. The properties that were used in each depositional model were from the AGD.
- **The goal is to look at the effect of depositional environment on storage efficiency.**

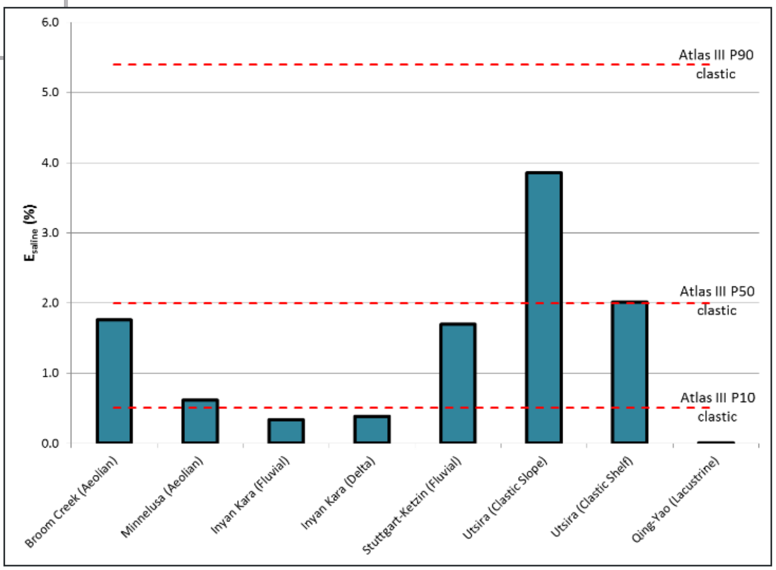
STATIC MODELING WORKFLOW



SIMULATION WORKFLOW



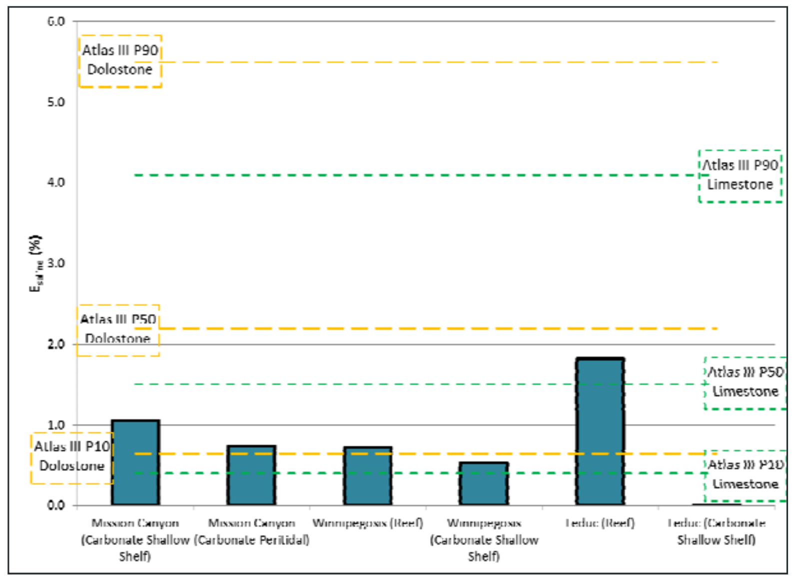
OPTIMIZATION CASES AND RESULTS



- Optimization cases investigating various parameters (i.e., boundary conditions, water extraction, and horizontal wells) were conducted.
- Dashed lines show efficiency values from the U.S. Department of Energy (DOE) Atlas III.

Saline Formation Efficiency Factors for Geologic and Displacement Terms $E_{saline} = E_{An/At} E_{hn/hg} E_{\phi e/\phi tot} E_v E_d$			
Lithology	P_{10}	P_{50}	P_{90}
Clastics	0.51%	2.0%	5.4%
Dolomite	0.64%	2.2%	5.5%
Limestone	0.40%	1.5%	4.1%

Table from DOE National Energy Technology Laboratory, 2010. Carbon sequestration atlas of the United States and Canada (3rd ed.).

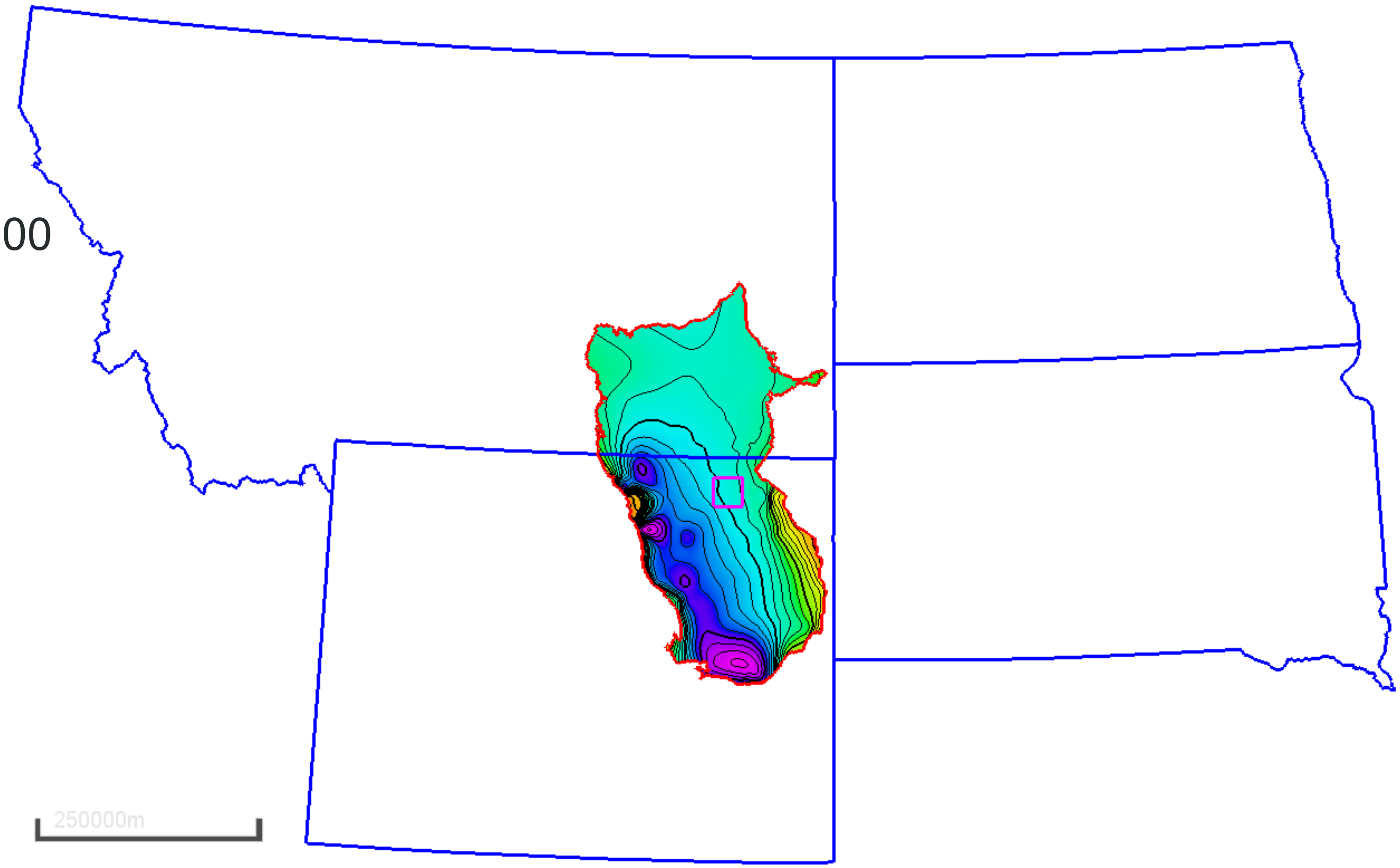


TASK 2 CHALLENGES

- Analysis of results led to discovery of a shortcoming with the approach:
  - Upscaling core-sized data points to basin-scale models created unrealistic property distribution.
  - Regional- to basin-scale models were no longer representative of depositional environment (e.g., Mission Canyon cells: 13,000’ x 13,000’ x 10’).
- Need to balance three factors:
  - Large-scale static model.
  - Geologic property distribution, which realistically captures depositional environment and facies.
  - Simulation software and computing power limitations (i.e., models with high cell count cannot be simulated easily or in a reasonable time frame).

ADDRESSING THE CHALLENGE: BASIN-SCALE MODELS

- Previous "Minnelusa" model extent (red)
  - ~250 mi N–S and ~100 miles W–E
- Revised model size (purple)
  - 20 mi × 20 mi
- New model represents "unit block" that can be extrapolated to basin scale.



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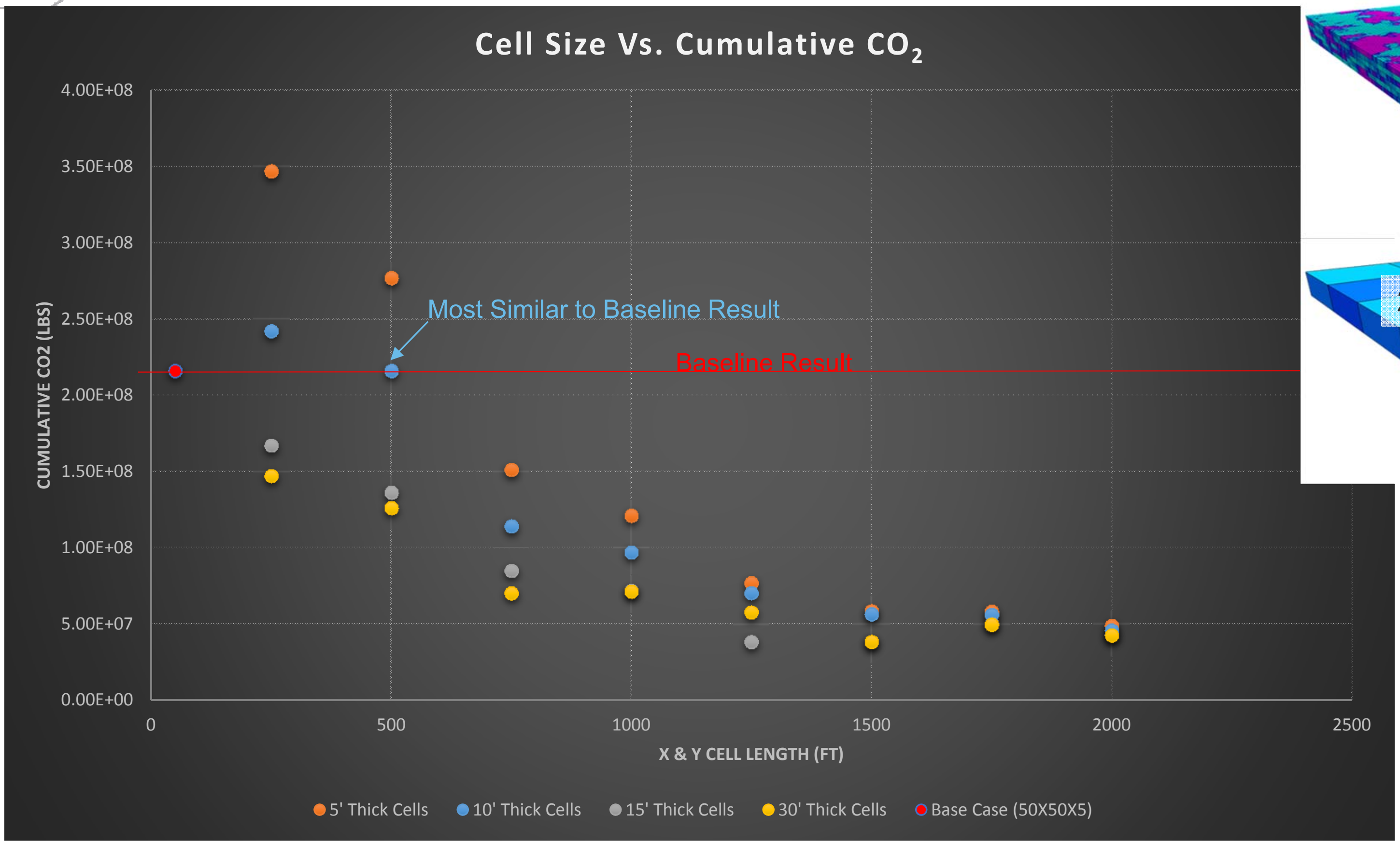
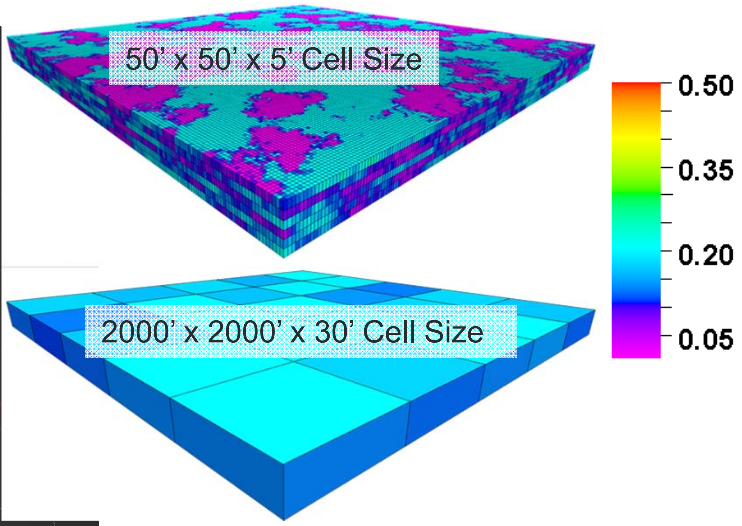
ADDRESSING THE CHALLENGE: GRID AND CELL SIZE



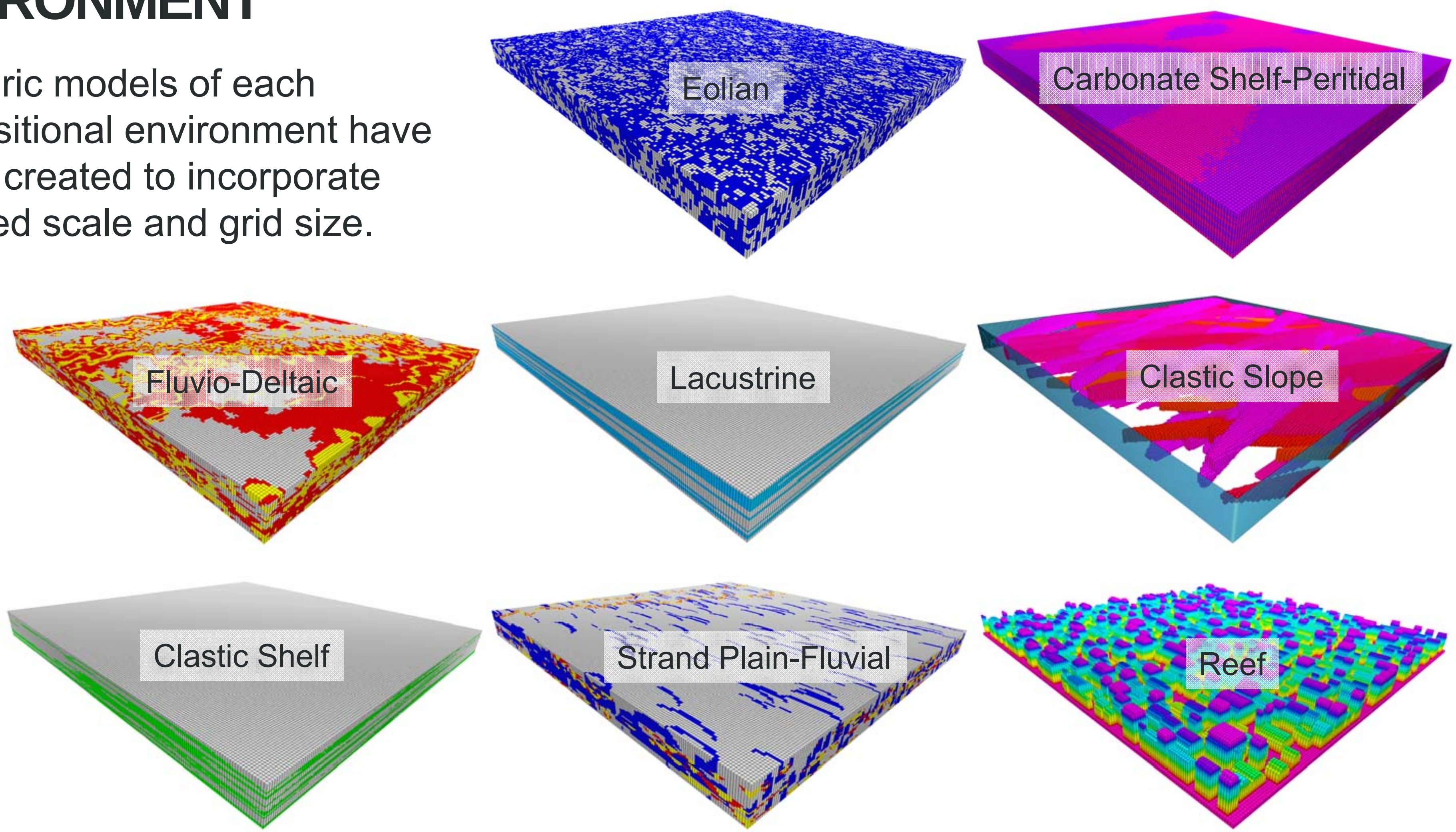
Porosity Distribution



- Optimum grid size determined.

ADDRESSING THE CHALLENGE: DEPOSITIONAL ENVIRONMENT

- Generic models of each depositional environment have been created to incorporate revised scale and grid size.



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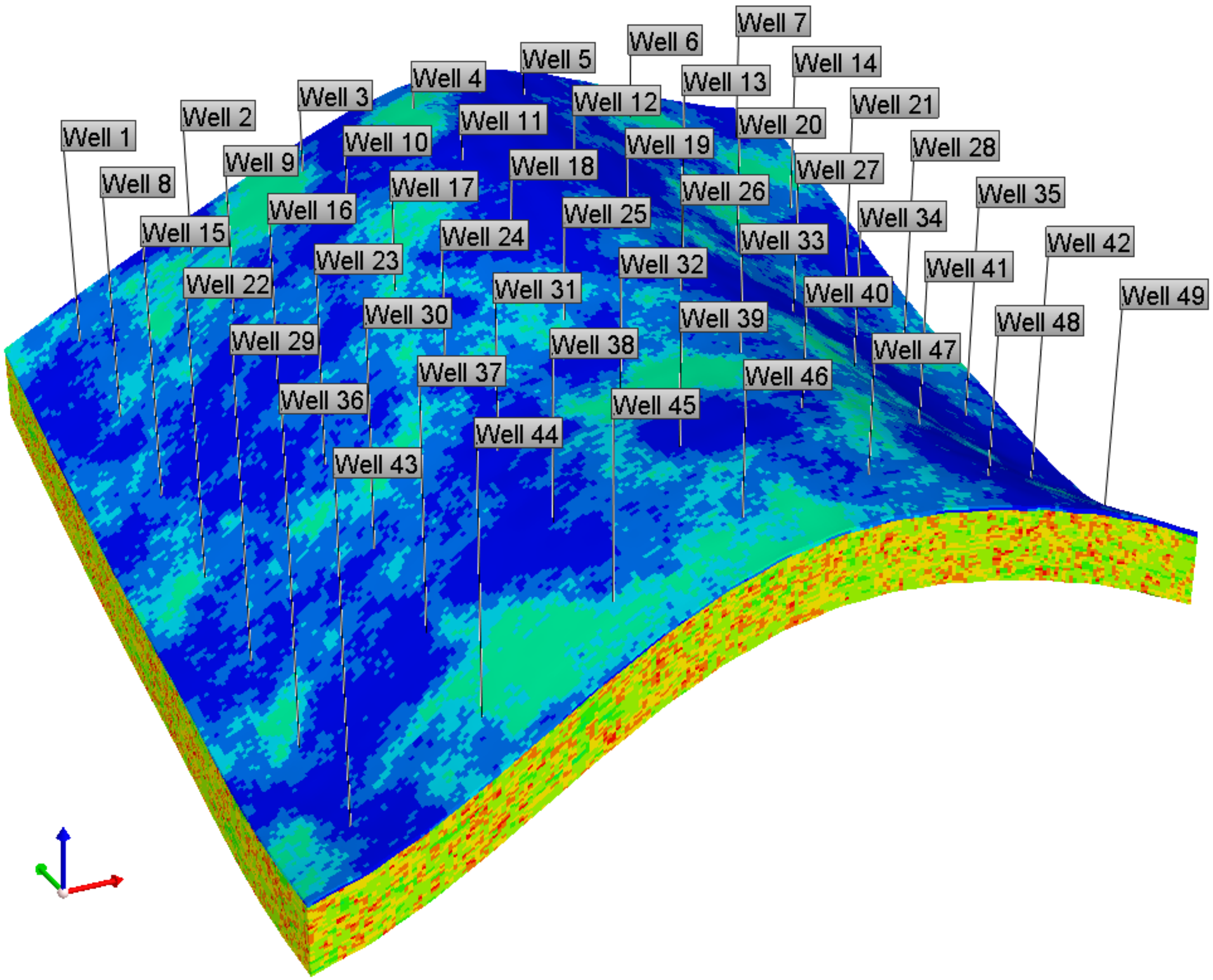
TASK 2: PATH FORWARD

- Closed-boundary lateral boundary simulations are being rerun using the revised models.
- Representative caprock properties are used to mimic pressure movement through the caprock.



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TASK 3: HYDROCARBON RESERVOIRS

- A literature review of current storage estimation methodologies in oil and gas reservoirs was performed.
- Data were collected from existing oil fields and ongoing CO_2 EOR projects.
- A statistical analysis was performed for 31 CO_2 EOR sites.

A paper with these findings was published in the *International Journal of Greenhouse Gas Control*.

International Journal of Greenhouse Gas Control 37 (2015) 384–397

Contents lists available at ScienceDirect

International Journal of Greenhouse Gas Control

journal homepage: www.elsevier.com/locate/ijggc

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CO_2 storage associated with CO_2 enhanced oil recovery: A statistical analysis of historical operations

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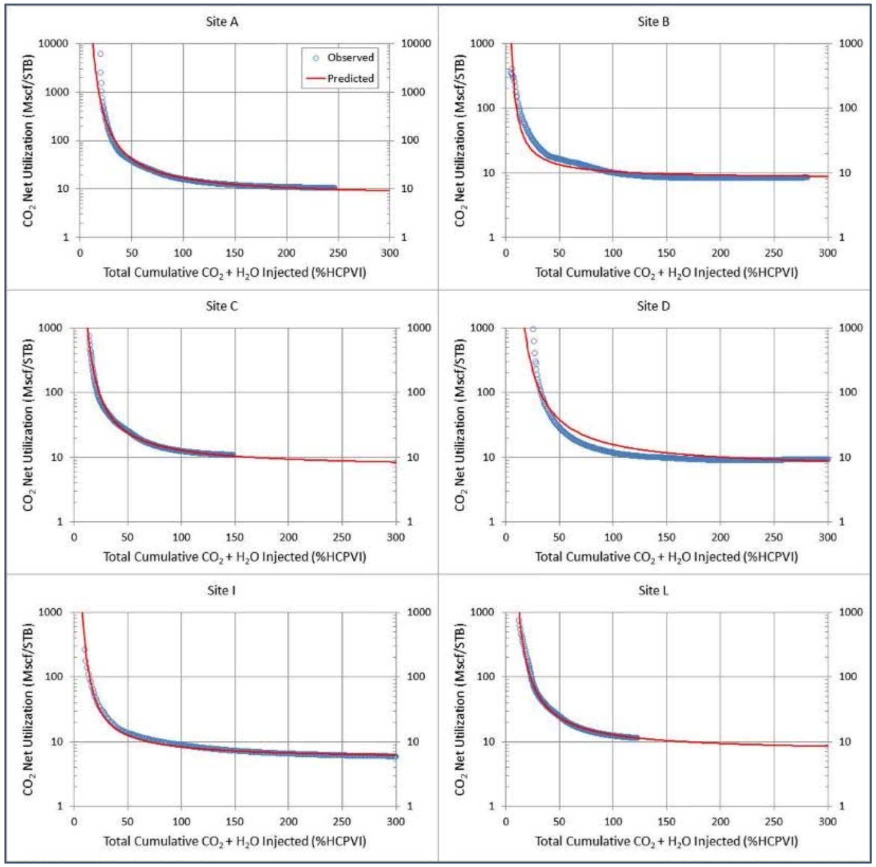
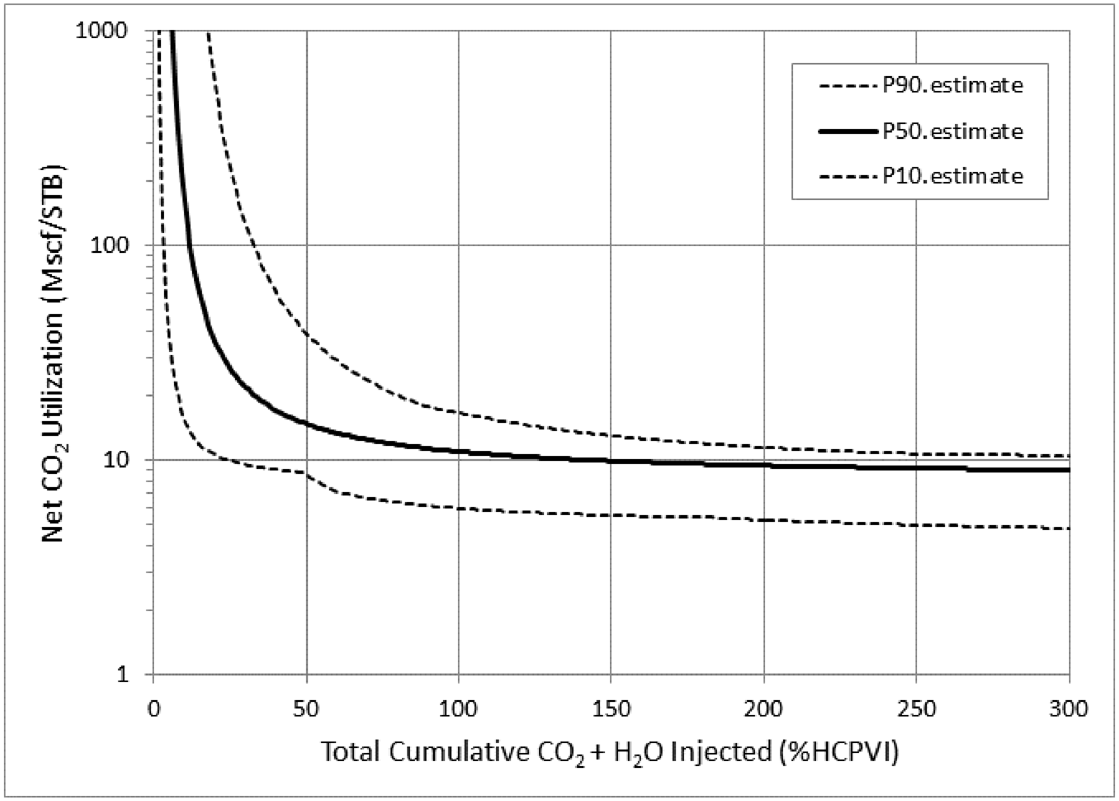
NET CO_2 UTILIZATION RESPONSE

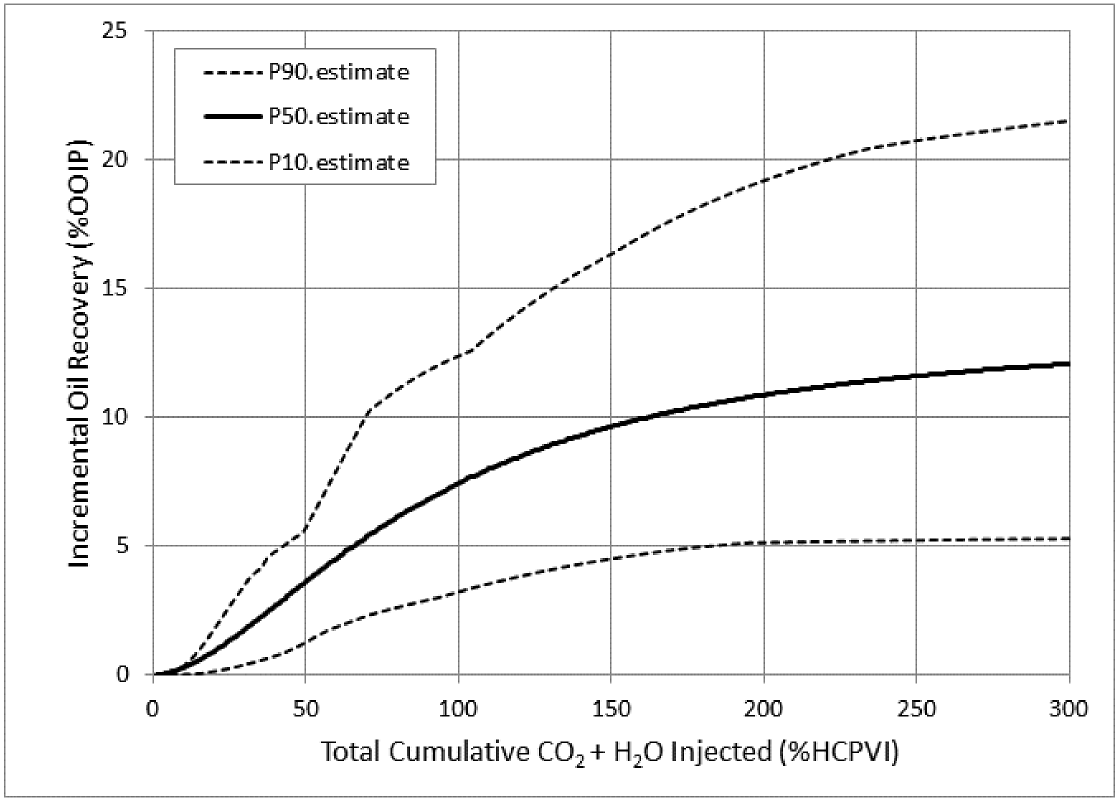
Fits of net CO_2 utilization to six representative sites from industry data. The blue line represents observed data; the red line represents the fitted response from a two-parameter asymptotic model.



Uncertainty Quantification: Net CO_2 Utilization P10, P50, and P90



Uncertainty Quantification: Incremental Oil RF P10, P50 and P90



HYDROCARBON RESERVOIRS: MODELING

Approach

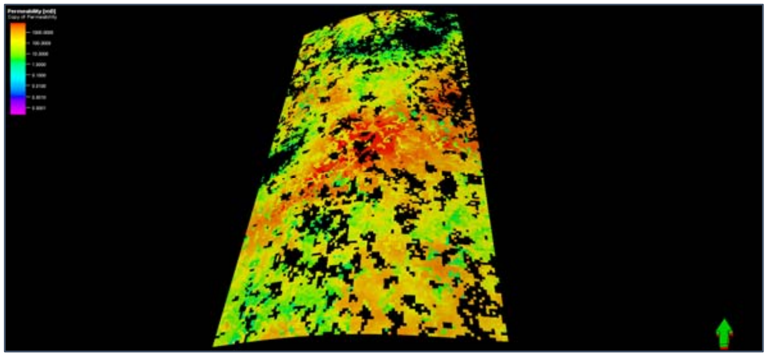
- Construct 12 field-scale models (2 miles × 4 miles) representative of existing oil fields.
- Structure (anticline), thickness, and oil saturations for P10, P50, and P90 models derived from actual EOR oilfield data.
- Geologic properties populated into each model from the AGD.

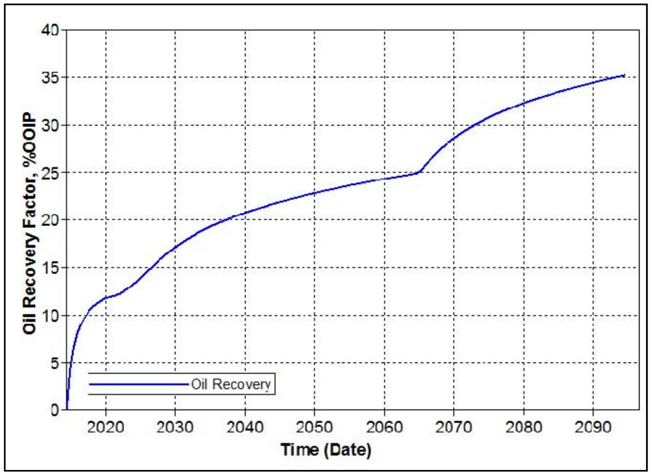
Case No.	Lithology/Environment	Depth, ft	Thickness, ft	P10	P50	P90	P50_WAG
1	Fluvial – Clastic	4000	25		Complete		Complete
2	Fluvial – Clastic	4000	66	Complete	Complete	Complete	Complete
3	Fluvial – Clastic	4000	209		Complete		
4	Fluvial – Clastic	8000	25		Complete		
5	Fluvial – Clastic	8000	66	Complete	Complete	Complete	
6	Fluvial – Clastic	8000	209		Complete		Complete
7	Shallow Shelf Carbonate	4000	25		Complete		Complete
8	Shallow Shelf Carbonate	4000	66	Complete	Complete	Complete	Complete
9	Shallow Shelf Carbonate	4000	209		Complete		
10	Shallow Shelf Carbonate	8000	25		Complete		
11	Shallow Shelf Carbonate	8000	66	Complete	Complete	Complete	
12	Shallow Shelf Carbonate	8000	209		Complete		Complete

Hydrocarbon Reservoir Model Characteristics

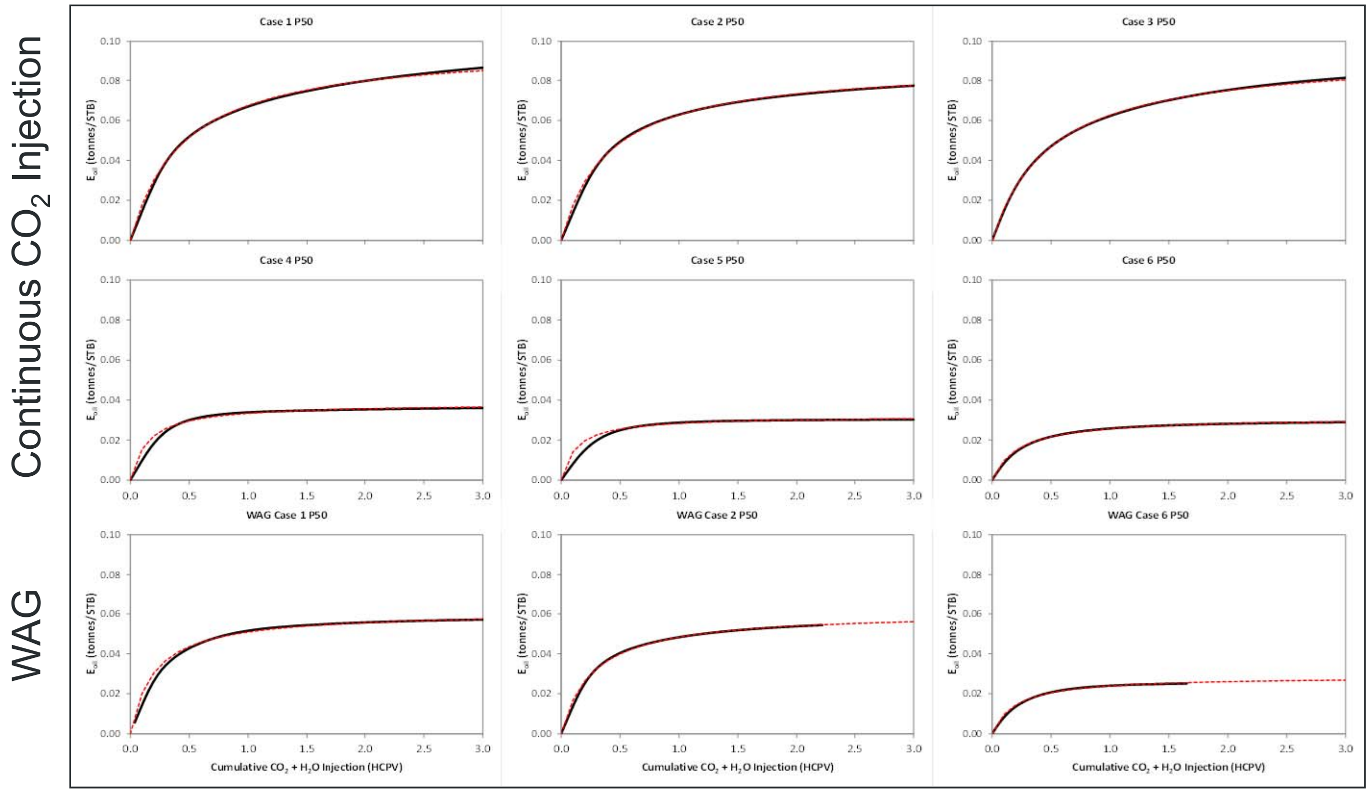
HYDROCARBON RESERVOIRS: SIMULATION

- Performed dynamic simulations, including primary, secondary, and tertiary recovery (CO_2), to evaluate the relationship between CO_2 storage and EOR.
- Utilization and recovery factors were assessed.
- Investigated the balance between associated CO_2 storage and CO_2 EOR.





SIMULATION RESULTS



Cumulative CO_2 or CO_2 + H_2O injection (HCPV) versus CO_2 storage efficiency (tonnes/STB) for the fluvial clastic simulation models. The red dashed line represents the fitted Michaelis–Menten model.

TASK 3 CHALLENGES

- Discovered that hydrocarbon pore volume (HCPV) calculation resulted in varying injection totals across all the models.
  - Results cannot confidently be compared to each other or the industry data set.

Path Forward

- Simulations have been rerun using new 3 HCPV trigger.
- Results are being compared to earlier statistical analysis of industry data set.

ACCOMPLISHMENTS TO DATE

- **Saline formations**
  - Optimum grid size determined.
  - Revised geocellular models completed.
  - Updated simulations ongoing.
  - Storage efficiency calculation by depositional environment for a 100-year time frame forthcoming.
- **Hydrocarbon reservoirs**
  - Base case geocellular models completed.
  - Updated simulations completed.
  - Analysis of results under way.
  - Journal article published.

SYNERGY OPPORTUNITIES

CO_2 Storage Capacity/Efficiency

- Combining an analytical tool with numerical simulations to quantify uncertainty.
- Sharing actual field data across projects would help constrain model properties and simulation results.
- Project learnings can be adopted by others estimating CO_2 storage resource.

SUMMARY

Task 2

- Models presented challenges when balancing three factors:
  - Basin-scale static model.
  - Geologic property distribution, which realistically captures depositional environment and facies.
  - Simulation software and computing power limitations (i.e., models with high cell count cannot be simulated easily or in a reasonable time frame).
- Storage efficiency values are being developed at the effective storage resource level, for a 100 year duration and by depositional environment.

Task 3

- Storage efficiency values for CO_2 storage associated with EOR have been developed both by analyzing industry data and through numerical simulation.
- Post EOR storage is also being evaluated through this effort.

ACKNOWLEDGMENT

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DISCLAIMER

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THANK YOU!

Critical Challenges. **Practical Solutions.**


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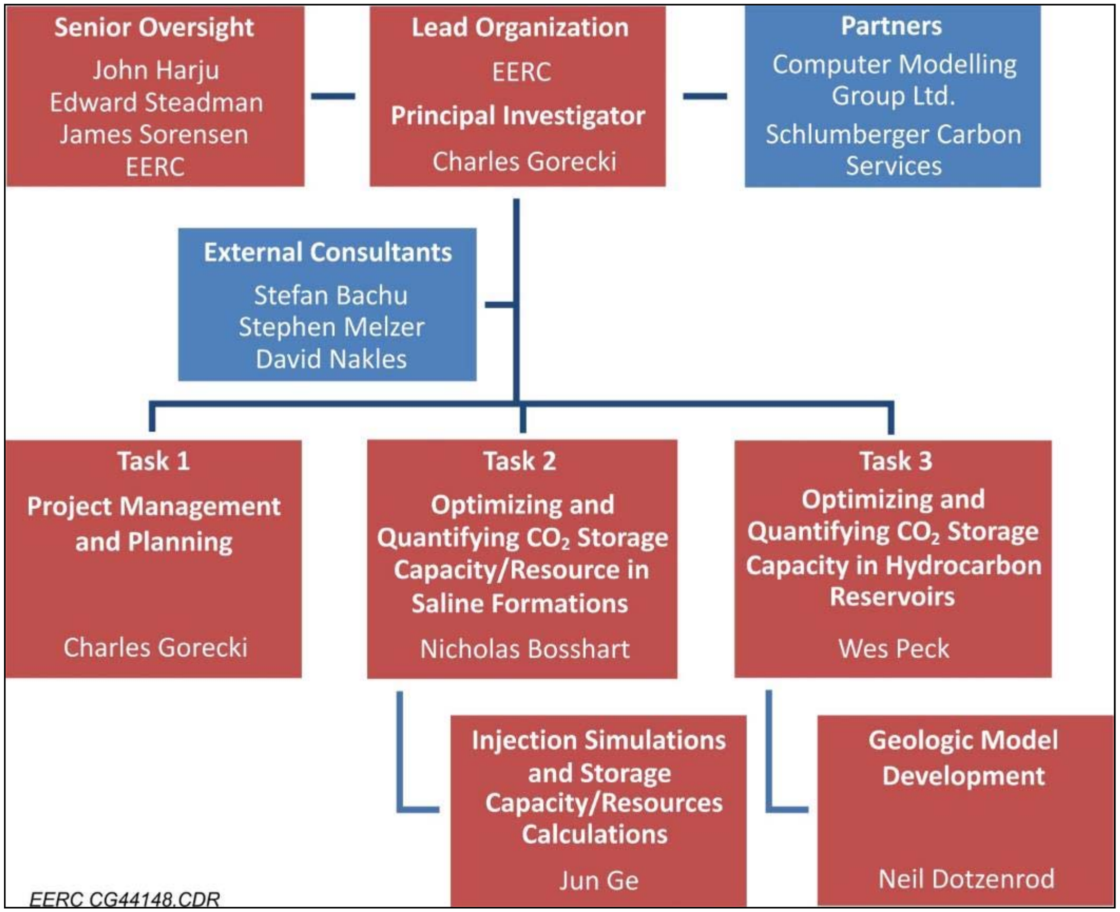
ORGANIZATION CHART



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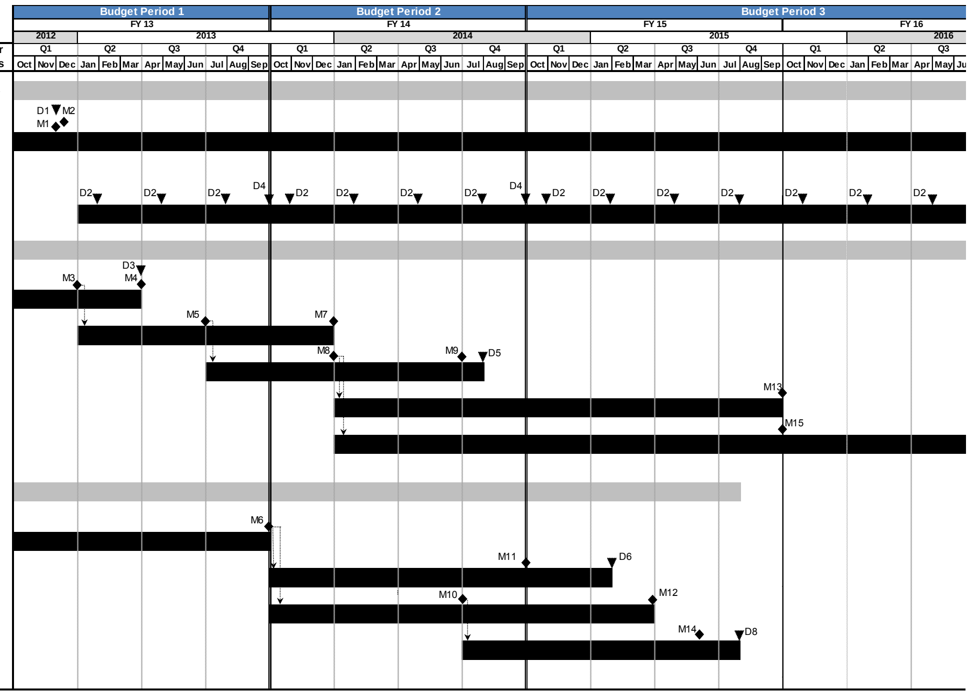
GANTT Chart

Task	Duration (months)	Start Date	End Date	$ Cost	Labor Hours
Task 1 – Project Management, Planning, and Reporting	**48**	**10/1/2012**	**9/30/2016**	**$ 288,978**	**1384**
1.1 – Perform Project Management	48	10/1/2012	9/30/2016		
1.2 – Project Reporting	45	1/1/2013	9/30/2016		
Task 2 – Optimizing and Quantifying CO_2 Storage Capacity/Resource in Saline Formations	**48**	**10/1/2012**	**9/30/2016**	**$ 701,771**	**1890**
2.1 – Literature Review	6	10/1/2012	3/31/2013		
2.2 – Geologic Model Development	12	1/1/2013	12/31/2013		
2.3 – Simulations to Predict CO_2 Storage Performance	13	7/1/2013	7/31/2014		
2.4 – Optimize CO_2 Storage Efficiency and Resource	21	1/1/2014	9/30/2015		
2.5 – Refine Storage Resource Estimation Methodologies and Storage Coefficients	33	1/1/2014	9/30/2016		
Task 3 – Optimizing and Quantifying CO_2 Storage Resource in Hydrocarbon Reservoirs	**34**	**10/1/2012**	**7/31/2015**	**$ 609,251**	**1460**
3.1 – Literature Review	12	10/1/2012	9/30/2013		
3.2 – Evaluation of CO_2 EOR and CO_2 Storage	16	10/1/2013	1/31/2015		
3.3 – Hydrocarbon Reservoir Modeling and Simulation	18	10/1/2013	3/31/2015		
3.4 – CO_2 Storage Resource Methodologies in Hydrocarbon Reservoirs	13	7/1/2014	7/31/2015		



Summary Task
Activity Bar
Milestone (M)◆
Deliverable (D)▼
Critical Path

Key for Deliverables (D) ▼
D1 – Updated Project Management Plan
D2 – Quarterly Progress/Milestone Report
D3 – Identification of Geologic Formations Selected for Evaluation
D4 – Data Submission to EDX
D5 – Interim Report: Simulation Results for CO_2 Storage Performance
D6 – Interim Report: Balance Between CO_2 EOR and CO_2 Storage
D7 – Manuscript on CO_2 Storage Performance for Submission to Peer-Reviewed Journal
D8 – Manuscript on the Balance Between CO_2 EOR and CO_2 Storage for Submission to Peer-Reviewed Journal
D9 – Best Practices Manual on Optimizing and Quantifying CO_2 Storage Resource in Saline Formations and Hydrocarbon Reservoirs
D10 – Final Report

Key for Milestones (M) ◆
M1 – Updated Project Management Plan Submitted to DOE
M2 – Project Kickoff Meeting Held
M3 – First Saline Formation Selected
M4 – Saline Formations Literature Review Completed
M5 – First Geologic Model Completed
M6 – CO_2 EOR and Associated Storage Literature Review Completed
M7 – All Geologic Models Completed
M8 – First Injection Simulation Completed
M9 – Simulations to Predict CO_2 Storage Performance Completed
M10 – First CO_2 EOR and Storage Simulation Completed
M11 – Reservoir Evaluations Completed
M12 – Field- to Pattern-Sized Geologic Models Completed
M13 – Simulations to Optimize CO_2 Storage Efficiency Completed
M14 – Examination and Refinement of Storage Capacity and Incremental Hydrocarbon Production Completed
M15 – Evaluation and Validation of Estimation Methodologies Completed

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BIBLIOGRAPHY

- Azzolina, N.A., Nakles, D.V., Gorecki, C.D., Peck, W.D., Ayash, S.C., Melzer, L.S., and Chatterjee, S., 2015, CO_2 storage associated with CO_2 enhanced oil recovery—a statistical analysis of historical operations: International Journal of Greenhouse Gas Control, v. 37, p. 384–397.