Optimizing and Quantifying CO_2 Storage Capacity/Resource in Saline Formations and Hydrocarbon Reservoirs

U.S. DOE NETL Carbon Storage R&D Project Review Meeting
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Senior Research Manager

Presentation Outline

- Project overview
- Saline formations
  - Base case geocellular models complete (nine)
  - Simulations on base case models complete (nine)
  - Optimization cases ongoing
- Hydrocarbon reservoirs
  - Base case geocellular models complete
  - Simulation on oil reservoir fluvial base case complete (one)
  - Simulation on other oil reservoir base cases ongoing (11)
  - Simulation of base case gas reservoirs ongoing (12)

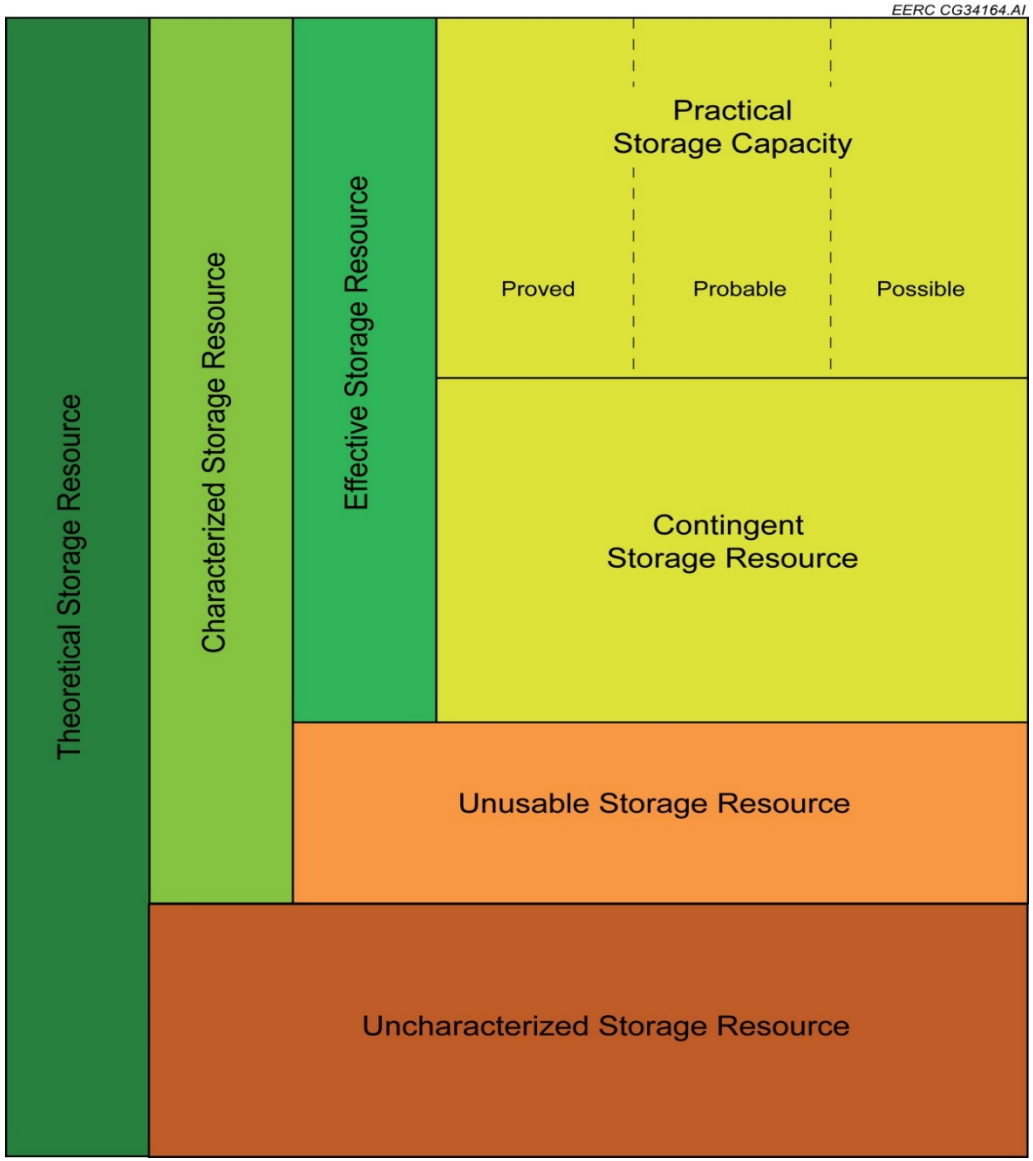
Project Overview

Goal

- To refine current methods and terms used to estimate CO_2 storage resource in saline formations and hydrocarbon reservoirs.
- Two concurrent areas of investigation will be undertaken to accomplish project goals:

Optimizing and Quantifying CO_2 Storage Resource in **Saline Formations**	Optimizing and Quantifying CO_2 Storage Resource in **Hydrocarbon Reservoirs**

CO_2 Storage Resource/Capacity

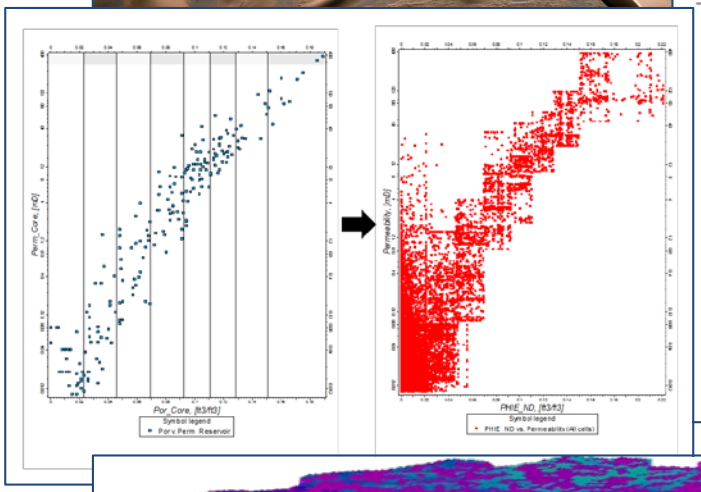


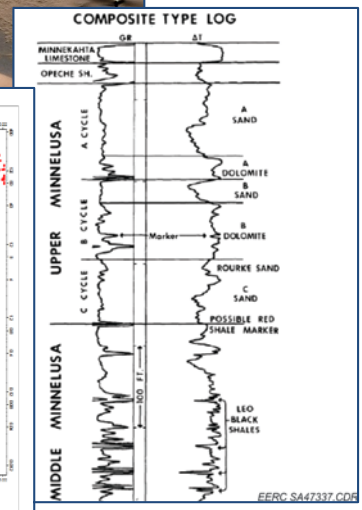
IEA Greenhouse Gas R&D Programme, 2009, Development of storage coefficients for CO_2 storage in deep saline formations: 2009/12, October 2009.

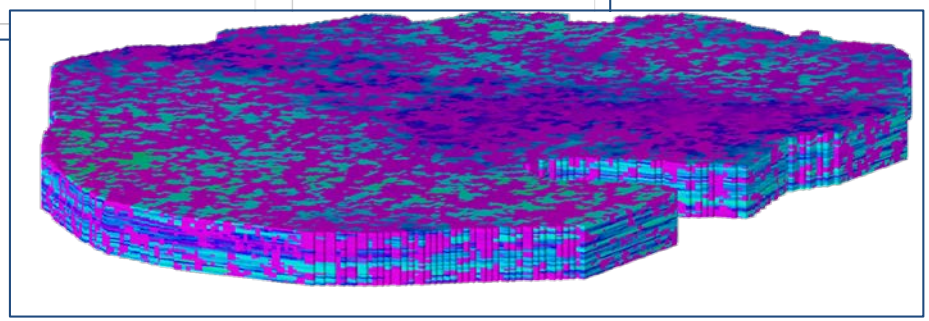
Saline Formations: Modeling

Approach

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







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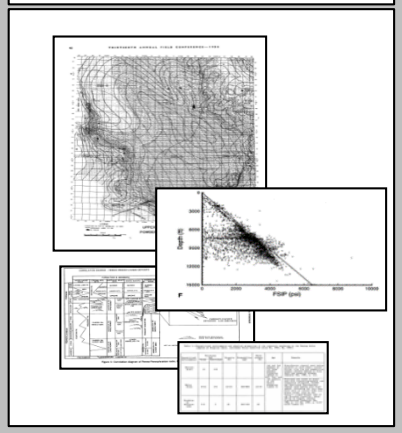
Schlumberger

Saline Formations Selected

Saline Formations and Depositional Environments Selected		
	Primary Depositional Environment	Secondary Depositional Environment
Broom Creek	Eolian	N/A
Inyan Cara	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
Winnipegosis	Reef	Carbonate Shelf

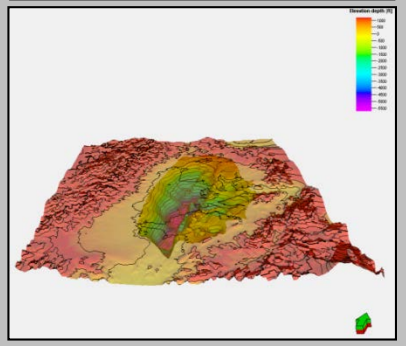
Modeling Workflow

Literature Review

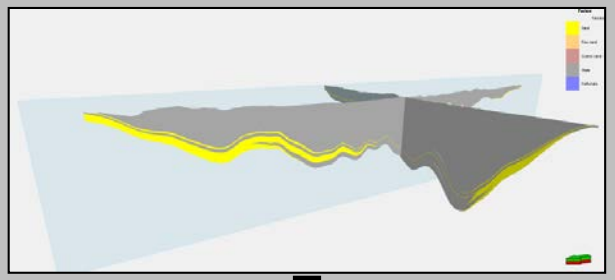


Digitize Data

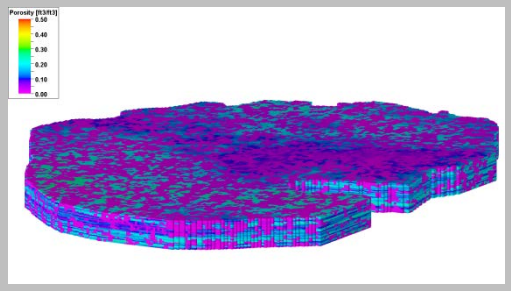
Structural Model



Facies Model

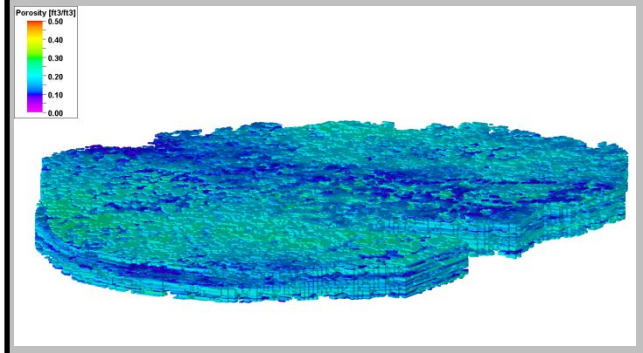


Petrophysical Modeling with AGD to Determine P10, P50, and P90 Cases

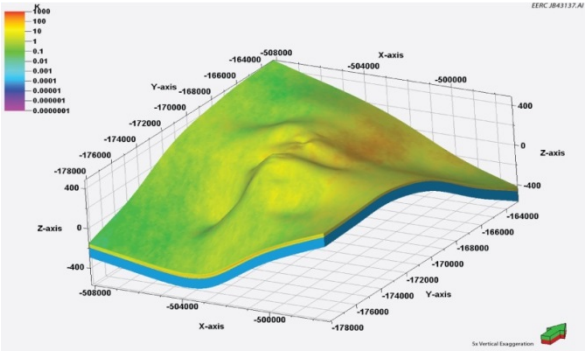


Clip Model to Effective Pore Volume, Based on Porosity and Permeability Cutoffs

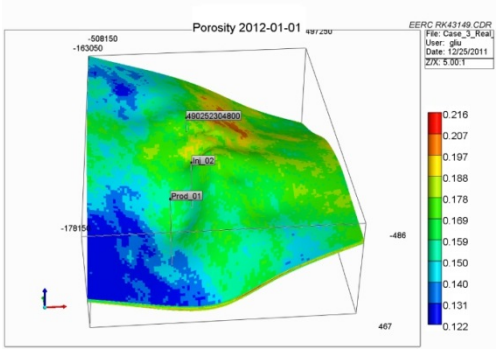
Static Geocellular Models



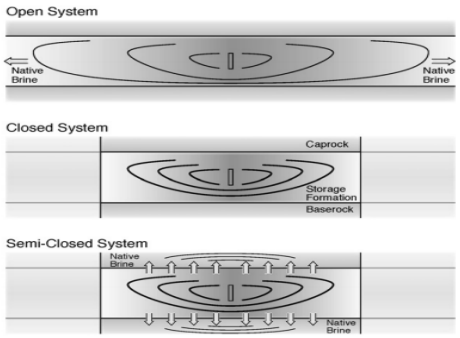
Simulation Workflow



Geocellular Models with High-, Mid-, and Low-Pore Volume

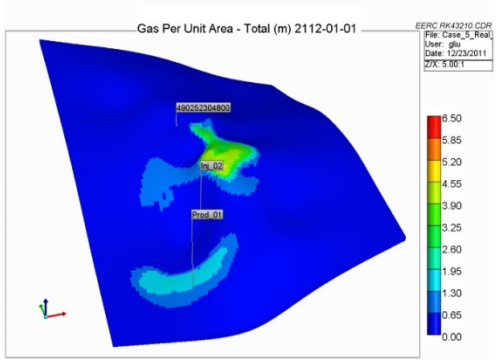


Injection Simulation Design

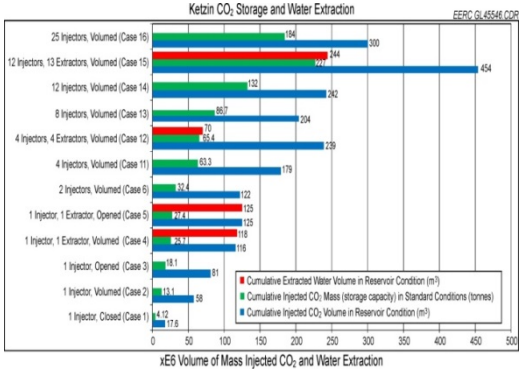


Boundary Condition Testing

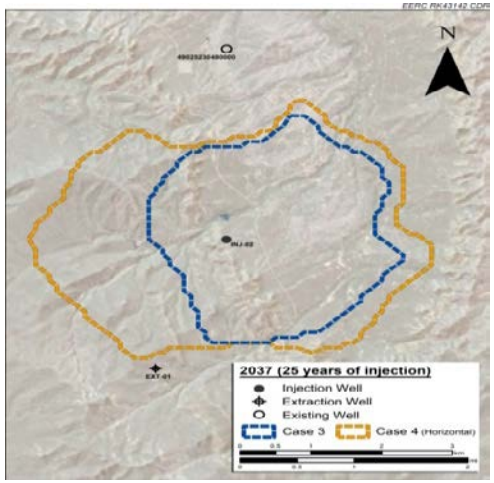
http://esd.lbl.gov/files/research/programs/gcs/projects/storage_resources/journal_3_NETL_zhou_etal_IJGGC.pdf



Operational Storage Capacity Enhancement



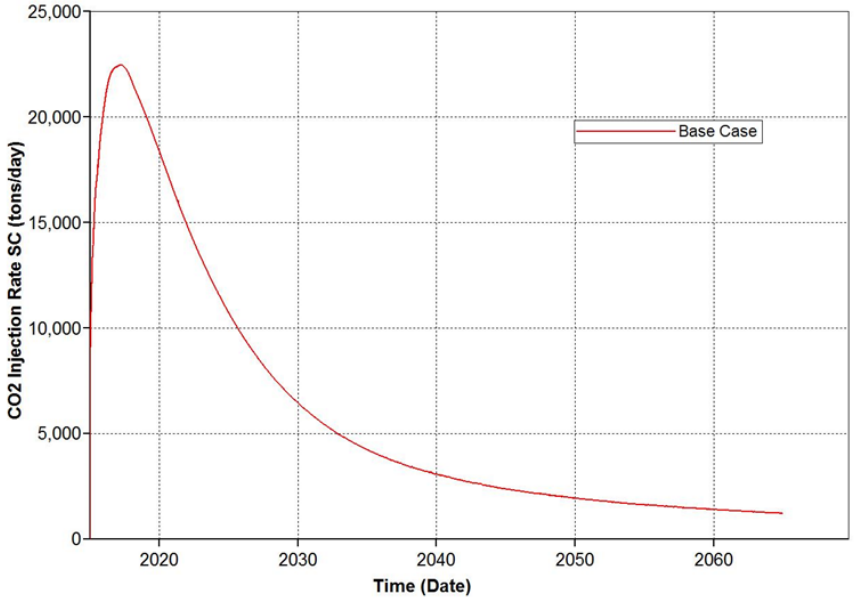
Dynamic Storage Capacity Estimates



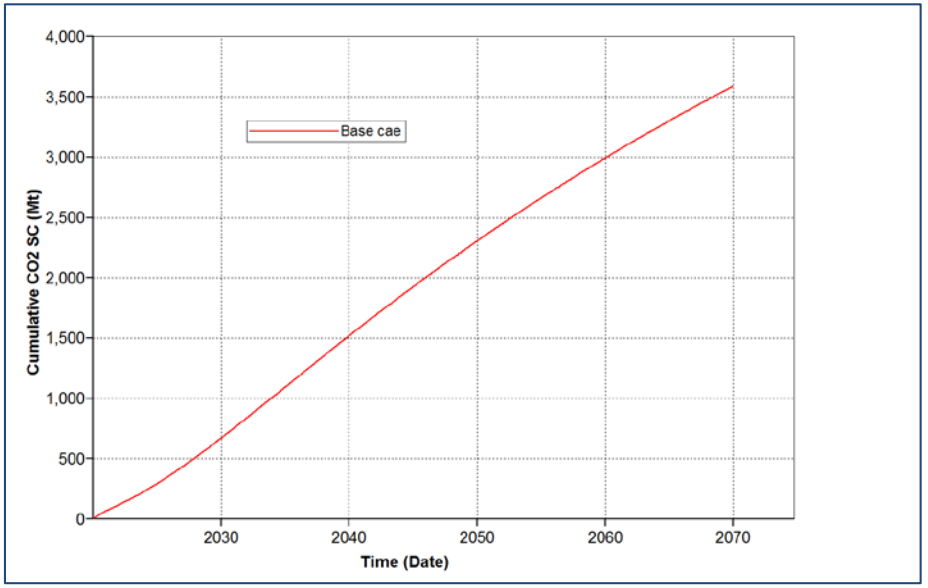
Storage Capacity Comparisons and Analysis

Saline Formation Simulation

- Base case dynamic CO_2 injection simulations were performed.



CMG COMPUTER MODELLING GROUP LTD.



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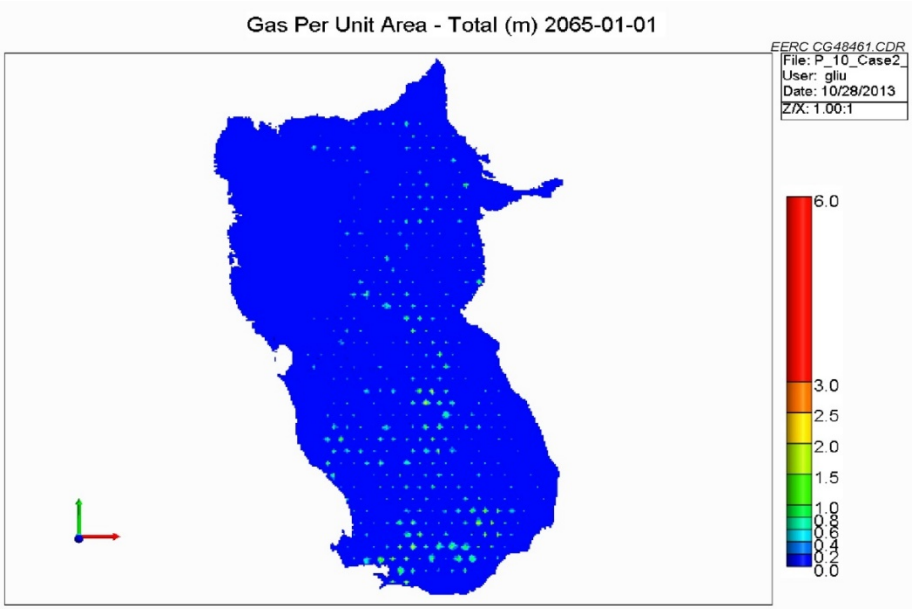
Base Case Simulation Results

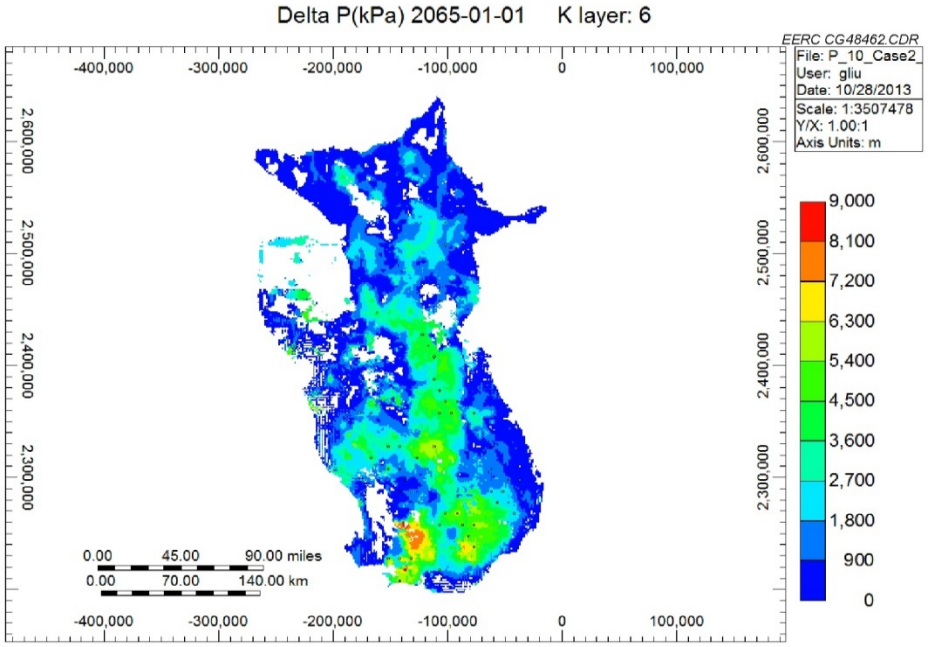
Formation	1st Depositional Environment	2st Depositional Environment	Injection Wells	Stored CO_2, Mt
Broom Creek	Eolian		138	3586
Inyan Cara	Delta	Fluvial	41	1602
Leduc	Reef	Carbonate Shelf	39	123
Minnelusa	Eolian		663	1442
Mission Canyon	Carbonate Shelf	Peritidal	139	4734
Qingshankou andYaojia	Lacustrine	Fluvial	127	3887
Stuggart	Fluvial	Delta	122	6296
Utsira	Clastic slope	Strand Plain	391	19247
Winnipegosis	Reef	Carbonate Shelf	1	0.25

- Base Case simulations and stored volume are not meant to represent actual storage in these formations, the properties that were used in each depositional model were from the P50 properties from the AGD. The goal is to look at storage efficiency in different depositional environments.

Saline Formations: Next Steps

- Simulations will be conducted for P10, P50 and P90 realizations (base case was run on the P50 models, but may not result in the P50 storage efficiency).
- Optimization simulations will be performed. Multiple scenarios (e.g., water extraction, horizontal wells) will be designed to maximize storage resource and determine impact of site-specific factors and depositional environment on CO_2 storage resource.





Hydrocarbon Reservoirs: Literature Review

- 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 enhanced oil recovery (EOR) projects.
- A statistical analysis was performed for 31 CO_2 EOR sites.

Hydrocarbon Reservoirs: Literature Review, continued

Summary

- The P10, P50, and P90 at 300% hydrocarbon pore volume injection (HCPVI) estimates for:
  - CO_2 retention = 23.1, 48.3, and 61.8% retention
  - Incremental oil recovery = 5.3, 12.1, and 21.5% original oil in place (OOIP)
  - Net CO_2 utilization = 4.5, 8.7, and 10.5 Mscf/stock tank barrel (STB)
- Additional investigation into the factors that control these parameters in the existing projects are being performed (depositional environments, operational plans, etc.). In this way, candidate oil fields not currently under CO_2 injection, can be screened and estimates of the associated CO_2 storage potential can be made.

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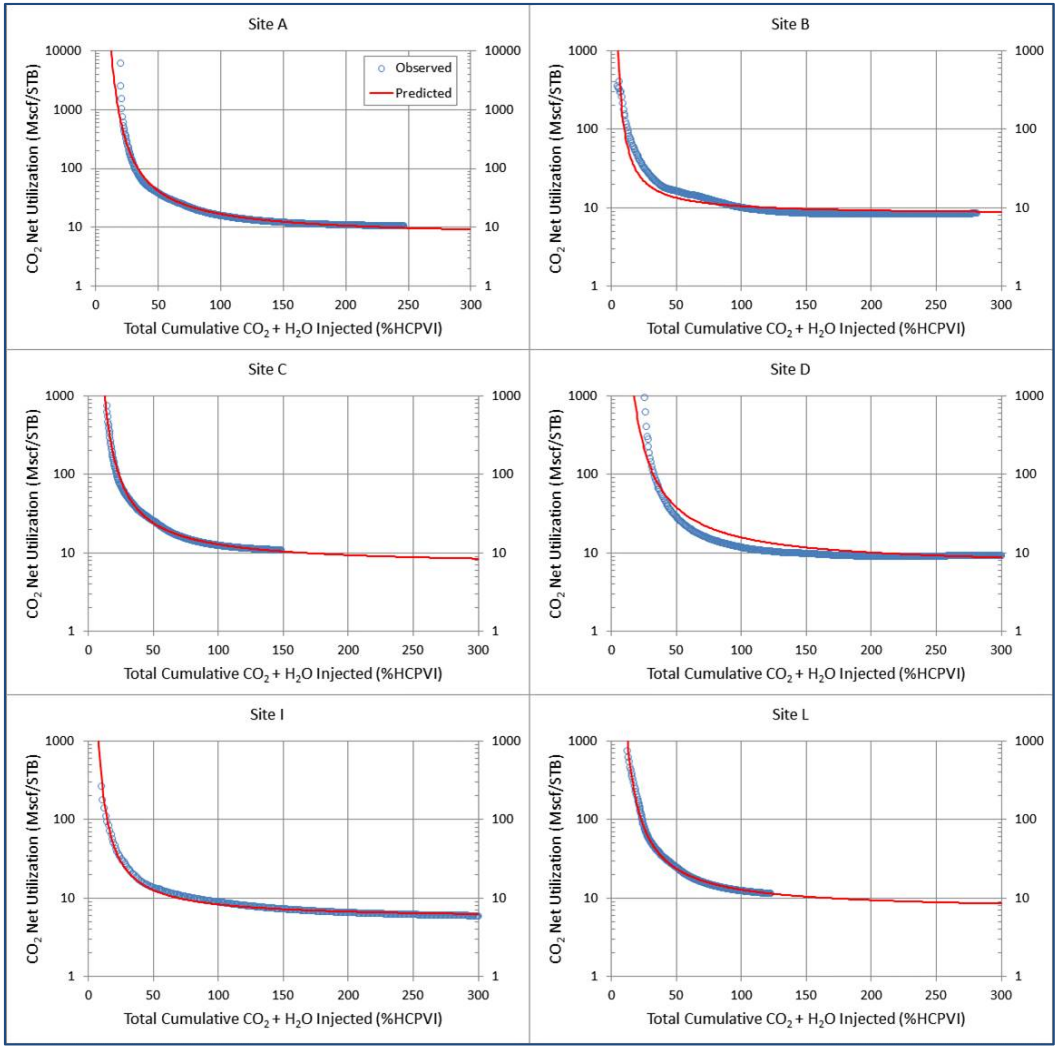
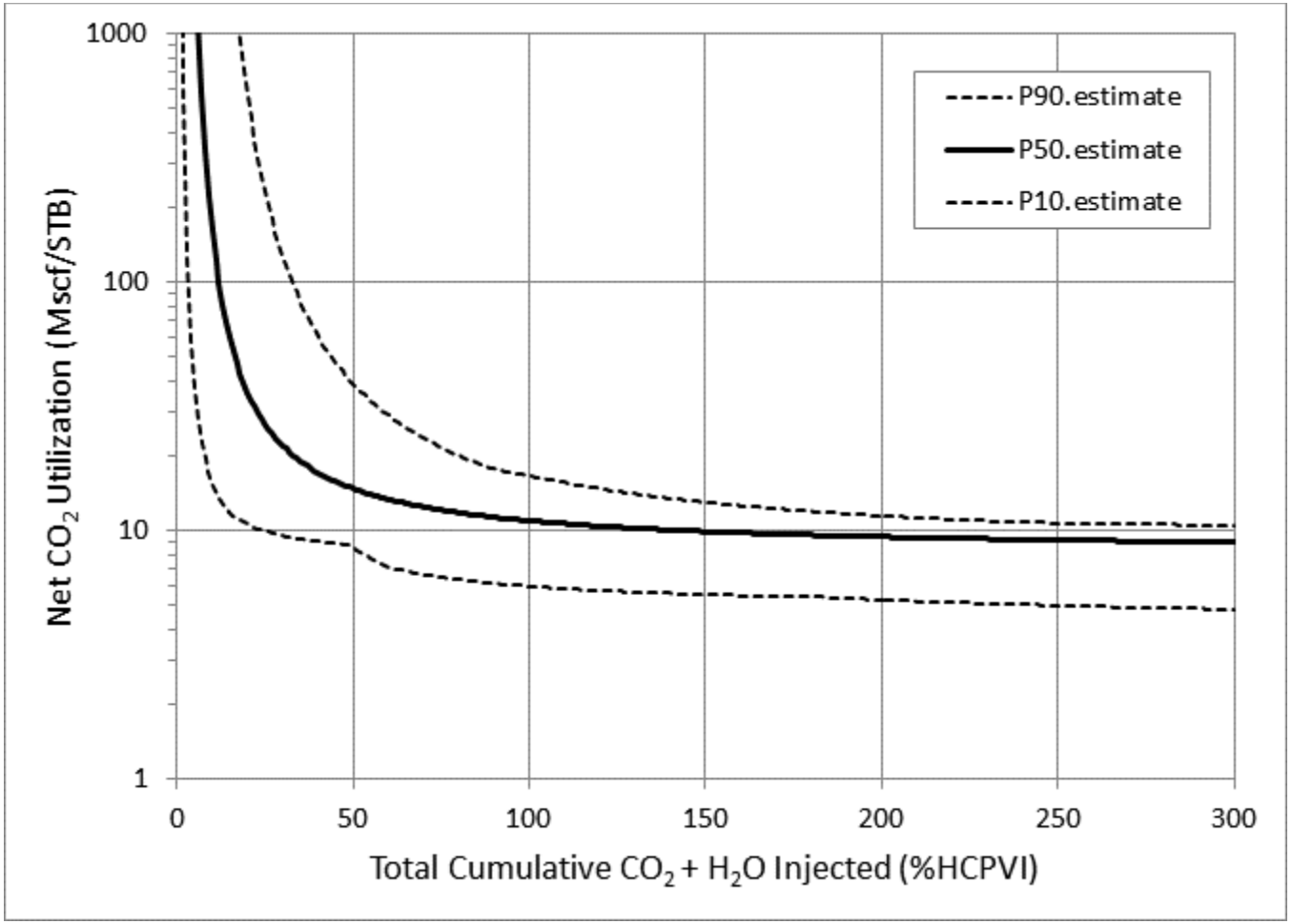
A paper with these findings is currently under review by the Society of Petroleum Engineers for publication in its journal *Reservoir Evaluation & Engineering – Reservoir Engineering.*

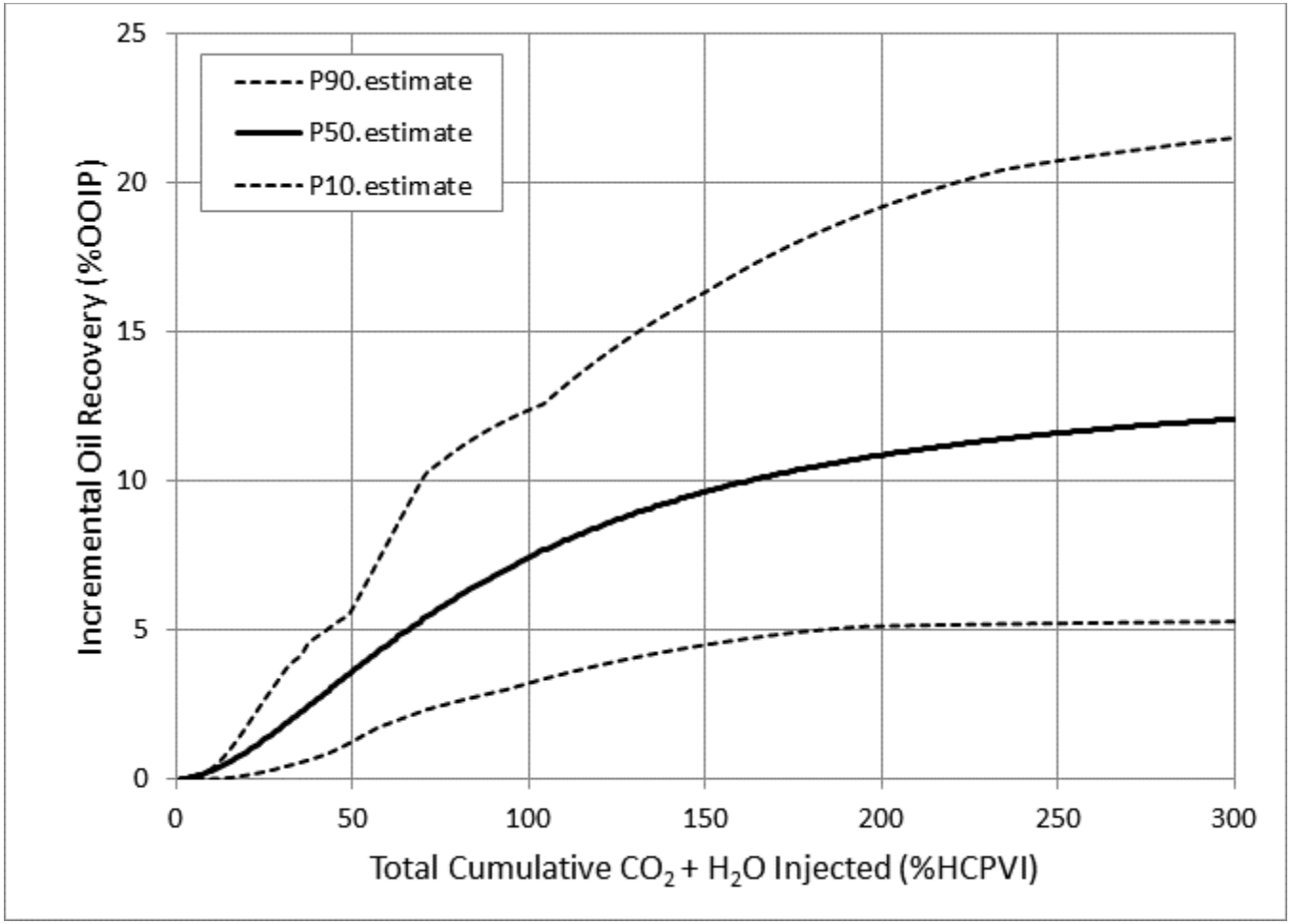
Net CO_2 Utilization Response



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



Uncertainty Quantification: Incremental Oil RF P10, P50 and P90



Hydrocarbon Reservoirs: Modeling

Approach

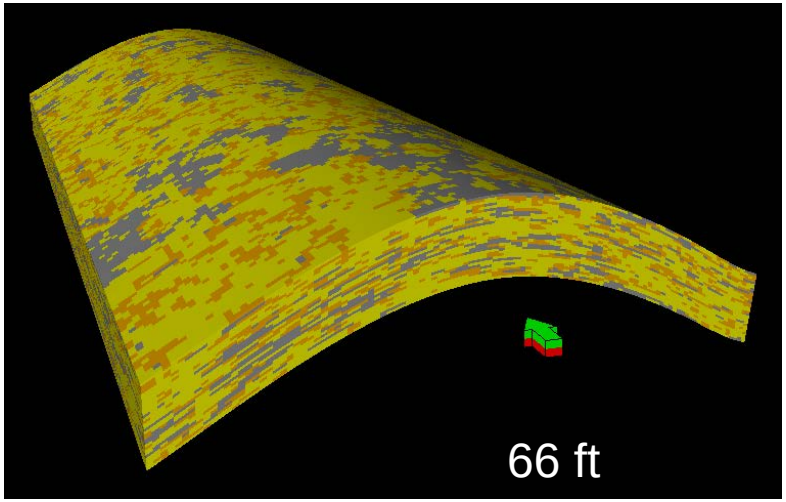
- Construct 12 field-scale models (2 miles x 4 miles) representative of existing oil fields.
- Statistics for P10, P50, and P90 values derived from actual EOR oil fields.
- Porosity and permeability properties populated into each model by the AGD.

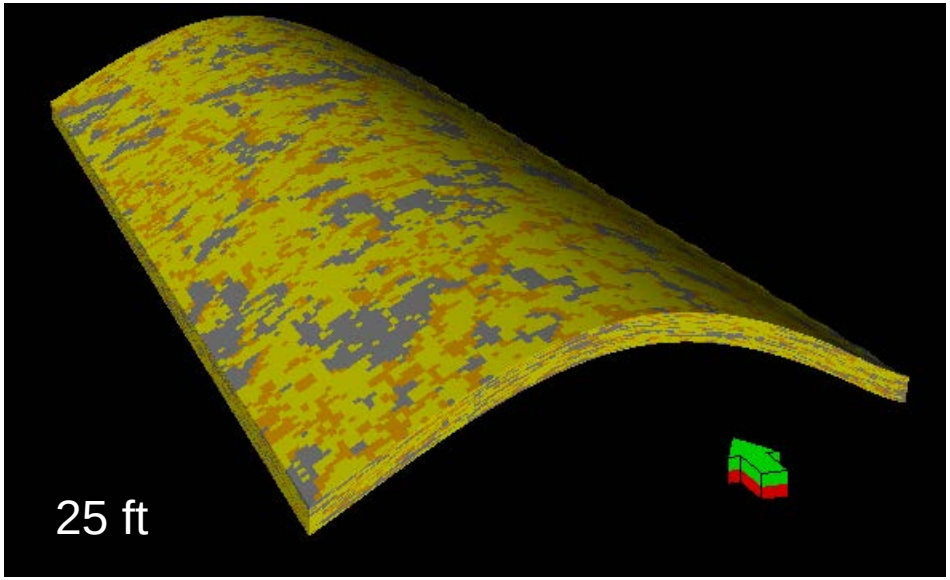
Hydrocarbon reservoir model characteristics

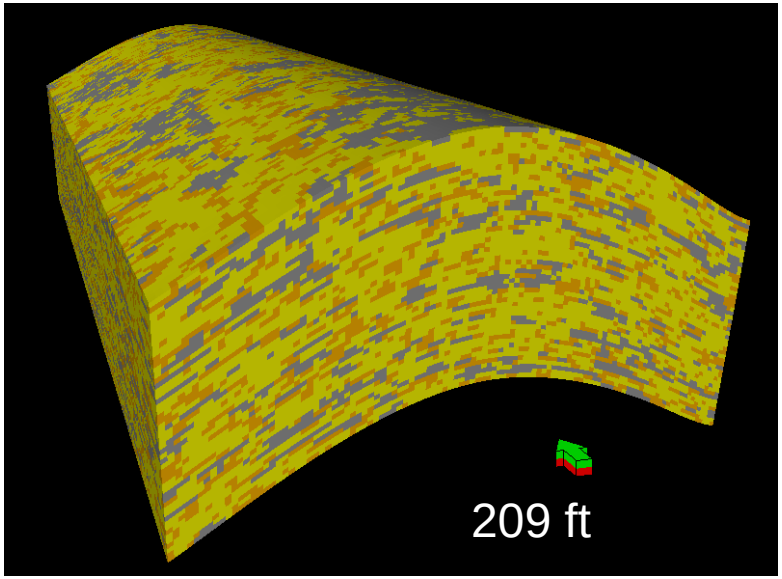
Structure	Lithology	Thickness	Depth	Ave. Reservoir Porosity
Anticline	Fluvial	25	4000	26.6
Anticline	Fluvial	25	8000	26.6
Anticline	Fluvial	66	4000	26.6
Anticline	Fluvial	66	8000	26.6
Anticline	Fluvial	209	4000	16.9
Anticline	Fluvial	209	8000	16.9
Anticline	Carbonate shallow shelf	25	4000	33.7
Anticline	Carbonate shallow shelf	25	8000	33.7
Anticline	Carbonate shallow shelf	66	4000	34.5
Anticline	Carbonate shallow shelf	66	8000	34.5
Anticline	Carbonate shallow shelf	209	4000	21.9
Anticline	Carbonate shallow shelf	209	8000	21.9

Hydrocarbon Reservoirs: Structural Modeling

- Anticline structures with 100-ft closure were used with reservoir thicknesses of 25, 66, and 209 ft thick, based on statistics of operating CO_2 EOR projects.







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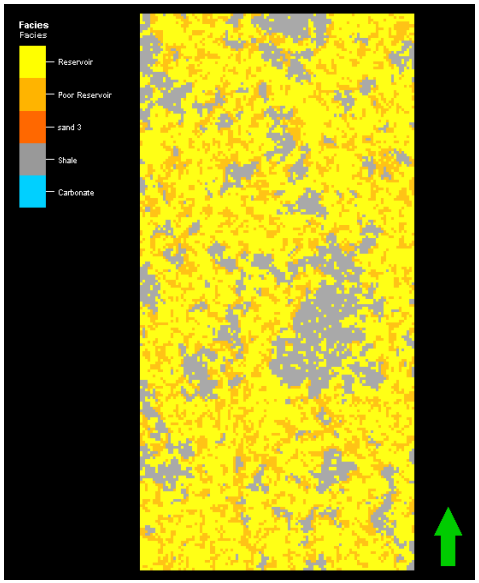
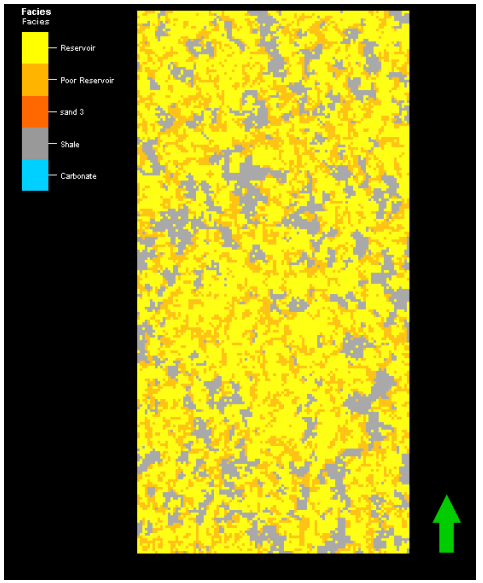
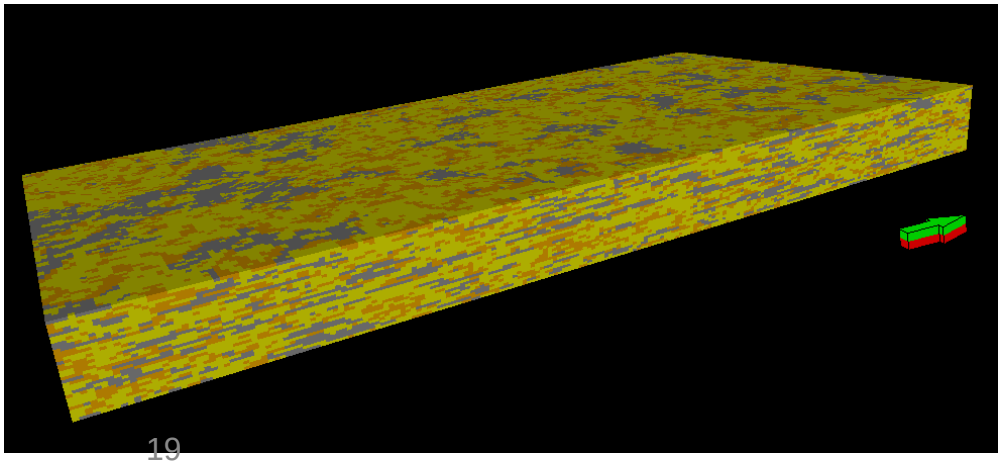
Hydrocarbon Reservoirs: Fluvial Facies

- Fluvial facies were populated using a combined object-modeling/multiple-point statistical algorithm.
- Training image was based on sections of the Platte River in Nebraska and logs from the Weber Sandstone, Rangely Field, Colorado.
- Three facies were populated: reservoir, poor reservoir, and shale.







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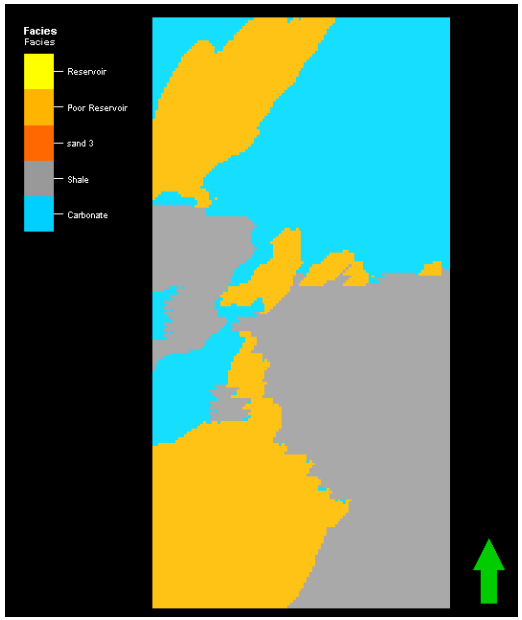
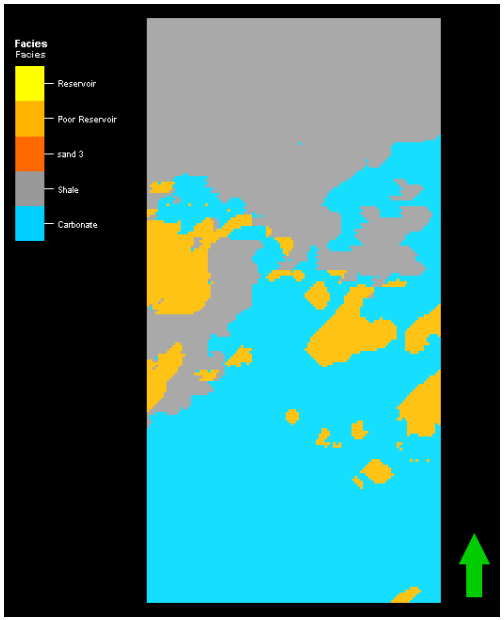
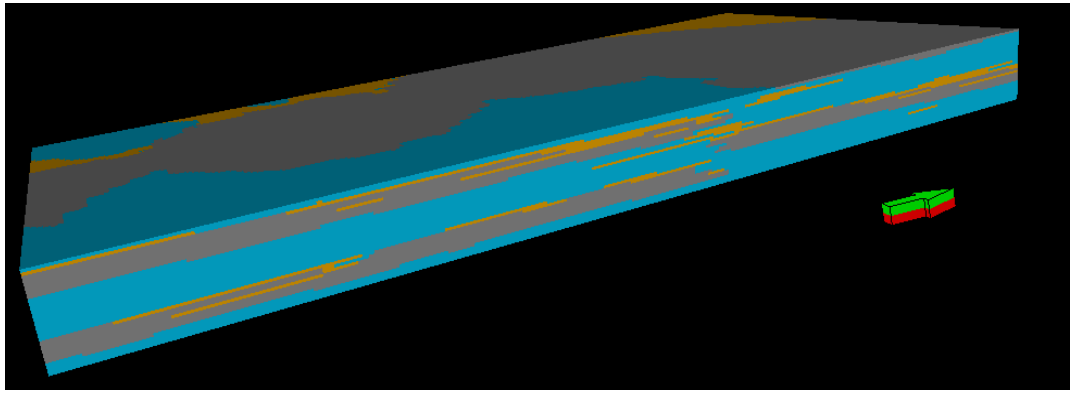
Hydrocarbon Reservoirs: Carbonate Facies

- Carbonate facies were populated using a multiple-point statistical algorithm.
- Training image based on carbonate shelf block model and log from Central Vacuum Unit, New Mexico.
- Three facies were populated: reservoir, poor reservoir, and shale.

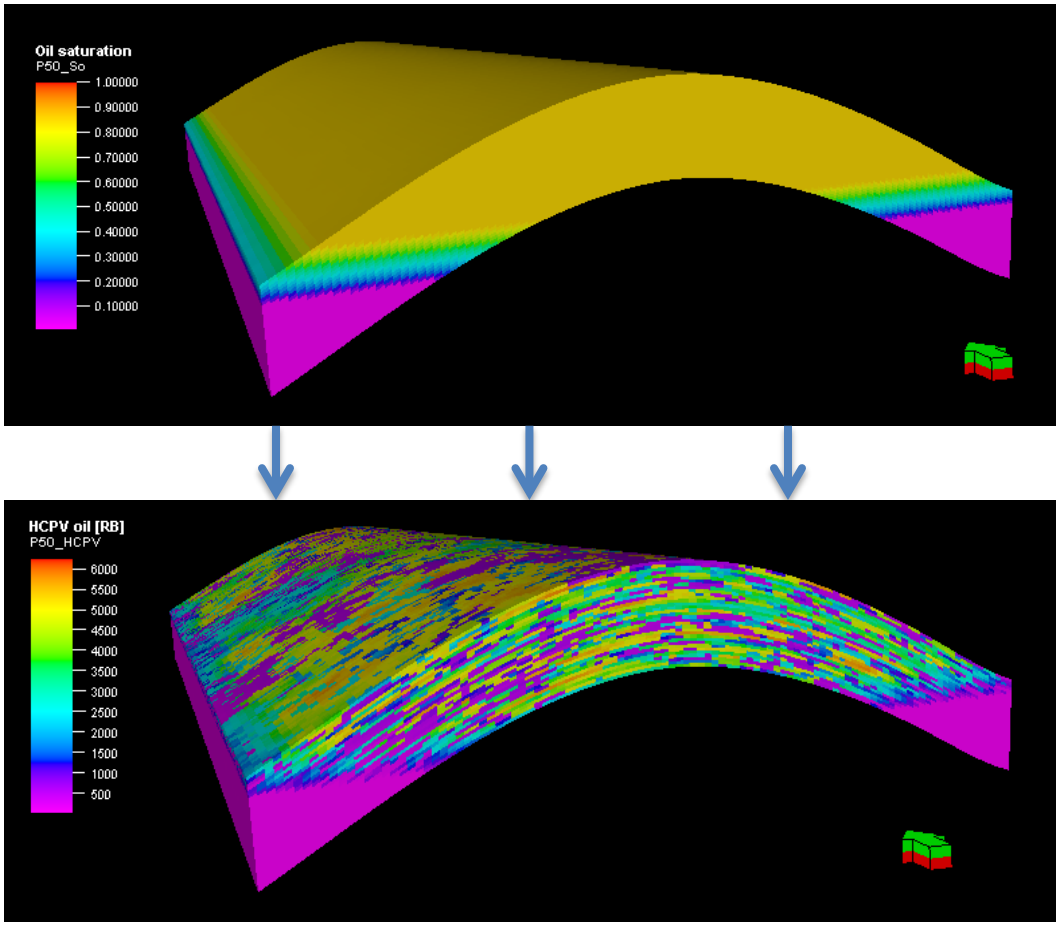


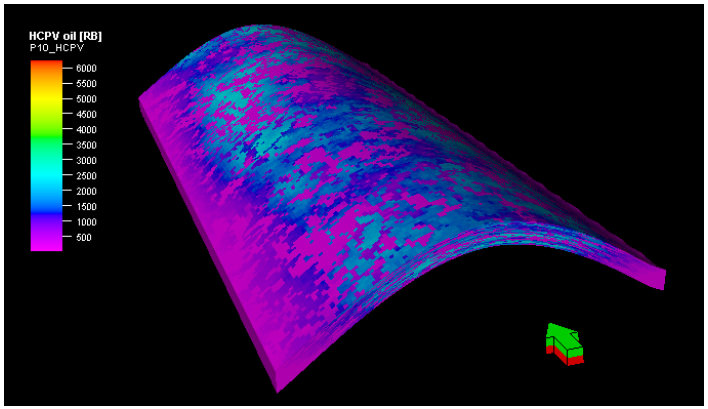




Hydrocarbon Reservoirs: Model Saturations

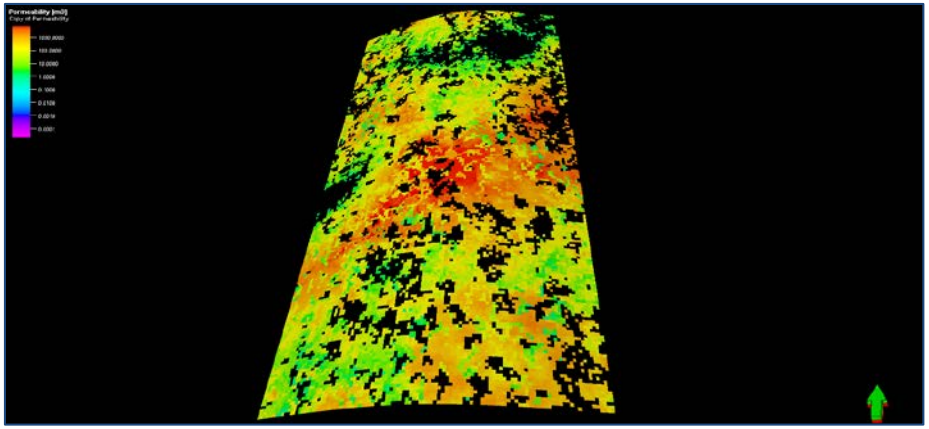
- Oil saturations were incorporated to match statistics of OOIP from the CO_2 EOR database.
- Oil–water contact, maximum saturation and residual oil zones were adjusted to fit the target value.

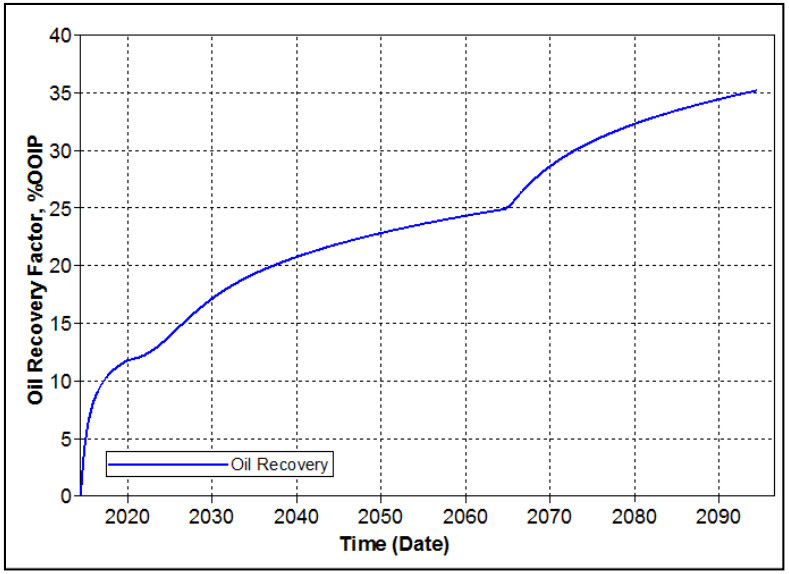




Hydrocarbon Reservoirs: Simulation

- Perform dynamic simulations, including primary, secondary, and tertiary recovery (CO_2), to evaluate the relationship between CO_2 storage and EOR.
- Utilization and recovery factors will be assessed.
- Assess the balance between associated CO_2 storage and CO_2 EOR.





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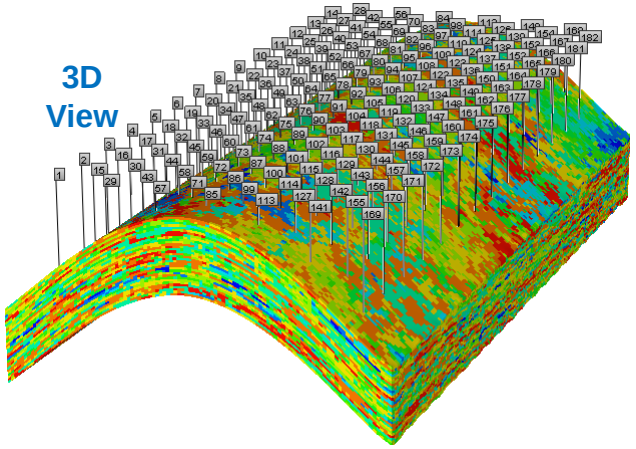
Hydrocarbon Reservoirs: CO_2 Enhanced Gas Recovery (EGR) and Storage

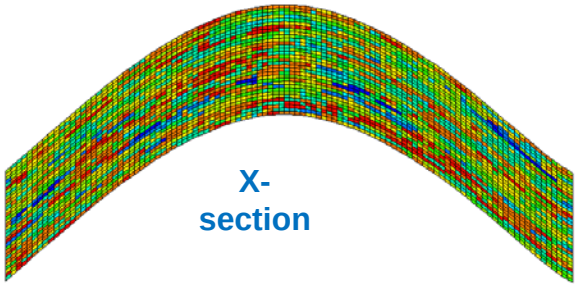
- **Why gas reservoirs?**
  - EGR potential exists in depleted conventional gas reservoirs.
  - Demonstrated ability to trap and store hydrocarbons for millions of years.
  - Typically well characterized because of historic hydrocarbon production.
  - Large storage resource potential after ultimate recovery of approximately 65%–75% of original gas in place (OGIP).
- **Objectives**
  - Evaluate reservoir response to the injection and long-term storage of CO_2 in gas reservoirs.
  - Determine CO_2 recovery efficiency.
  - Correlate gas recovery and CO_2 storage efficiency.
  - Assess engineering constraints for CO_2 injection and storage in a natural gas reservoir.

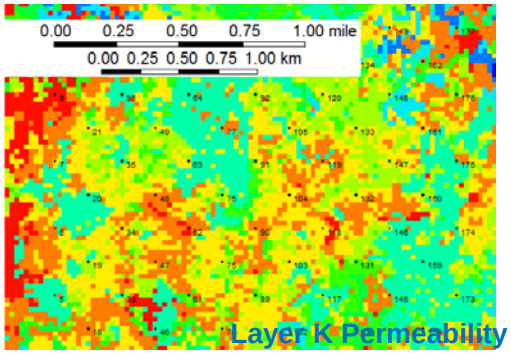
Hydrocarbon Reservoirs: CO_2 EGR and Storage, continued

Approach

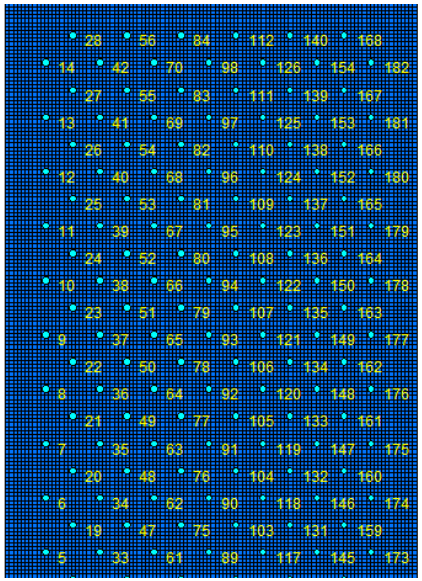
- Analysis of existing injections
- Field scale modeling and simulation
- Focus on majority (gas condensate)
- Various depositional environments
- Secondary or tertiary
- Efficiency and timing of CO_2 injection
- Potential of CO_2 storage and utilization







Well Pattern



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Summary

Task 2

- Nine base case models have been constructed.
- Base case simulations finished.
- Optimization cases started.

Task 3

- Twelve base case models have been constructed.
- One base case oil reservoir simulation finished.
- Base case gas reservoir simulation started.
- Optimization cases for both oil and gas reservoirs will be conducted.

Future goals – validate or adjust methods and storage efficiency values for saline formations and hydrocarbon reservoirs. Consider depositional environments and operational approaches.

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