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
Pittsburgh, Pennsylvania
August 12–14, 2014

Charles D. Gorecki
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 CO₂ storage resource in saline formations and hydrocarbon reservoirs.
- Two concurrent areas of investigation will be undertaken to accomplish project goals:

  - Optimizing and Quantifying CO₂ Storage Resource in **Saline Formations**
  - Optimizing and Quantifying CO₂ Storage Resource in **Hydrocarbon Reservoirs**
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).
## Saline Formations Selected

<table>
<thead>
<tr>
<th>Saline Formations and Depositional Environments Selected</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary Depositional Environment</strong></td>
</tr>
<tr>
<td><strong>Secondary Depositional Environment</strong></td>
</tr>
<tr>
<td>Broom Creek</td>
</tr>
<tr>
<td>Inyan Cara</td>
</tr>
<tr>
<td>Leduc</td>
</tr>
<tr>
<td>Minnelusa</td>
</tr>
<tr>
<td>Mission Canyon</td>
</tr>
<tr>
<td>Qingshankou and Yaojia</td>
</tr>
<tr>
<td>Stuttgart</td>
</tr>
<tr>
<td>Utsira</td>
</tr>
<tr>
<td>Winnipegosis</td>
</tr>
</tbody>
</table>
Modeling Workflow

- Literature Review
- Structural Model
- Facies Model

Static Geocellular Models

Digitize Data

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

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

- Modeling Workflow
Simulation Workflow

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

Injection Simulation Design

Boundary Condition Testing

Storage Capacity Comparisons and Analysis

Dynamic Storage Capacity Estimates

Operational Storage Capacity Enhancement

Saline Formation Simulation

- Base case dynamic CO\textsubscript{2} injection simulations were performed.
Base Case Simulation Results

Depositional Models Based on These Formations

- Winnipegosis: 0.25 Mt
- Utsira: 19,247 Mt
- Stuggart: 6,296 Mt
- Qingshankou and Yaojia: 3,887 Mt
- Mission Canyon: 4,734 Mt
- Minnelusa: 1,442 Mt
- Leduc: 123 Mt
- Inyan Cara: 1,602 Mt
- Broom Creek: 3,586 Mt

Total CO₂ Stored, Mt
### Base Case Simulation Results

<table>
<thead>
<tr>
<th>Formation</th>
<th>1&lt;sup&gt;st&lt;/sup&gt; Depositional Environment</th>
<th>2&lt;sup&gt;nd&lt;/sup&gt; Depositional Environment</th>
<th>Injection Wells</th>
<th>Stored CO&lt;sub&gt;2&lt;/sub&gt;, Mt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broom Creek</td>
<td>Eolian</td>
<td>Fluvial</td>
<td>138</td>
<td>3586</td>
</tr>
<tr>
<td>Inyan Cara</td>
<td>Delta</td>
<td>Carbonate Shelf</td>
<td>41</td>
<td>1602</td>
</tr>
<tr>
<td>Leduc</td>
<td>Reef</td>
<td>Carbonate Shelf</td>
<td>39</td>
<td>123</td>
</tr>
<tr>
<td>Minnelusa</td>
<td>Eolian</td>
<td></td>
<td>663</td>
<td>1442</td>
</tr>
<tr>
<td>Mission Canyon</td>
<td>Carbonate Shelf</td>
<td>Peritidal</td>
<td>139</td>
<td>4734</td>
</tr>
<tr>
<td>Qingshankou and Yaojia</td>
<td>Lacustrine</td>
<td>Fluvial</td>
<td>127</td>
<td>3887</td>
</tr>
<tr>
<td>Stuggart</td>
<td>Fluvial</td>
<td>Delta</td>
<td>122</td>
<td>6296</td>
</tr>
<tr>
<td>Utsira</td>
<td>Clastic slope</td>
<td>Strand Plain</td>
<td>391</td>
<td>19247</td>
</tr>
<tr>
<td>Winnipegosis</td>
<td>Reef</td>
<td>Carbonate Shelf</td>
<td>1</td>
<td>0.25</td>
</tr>
</tbody>
</table>

- 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.
• A literature review of current storage estimation methodologies in oil and gas reservoirs was performed.
• Data were collected from existing oil fields and ongoing CO₂ enhanced oil recovery (EOR) projects.
• A statistical analysis was performed for 31 CO₂ EOR sites.
Summary

- The P10, P50, and P90 at 300% hydrocarbon pore volume injection (HCPVI) estimates for:
  - CO₂ 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 CO₂ 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 CO₂ injection, can be screened and estimates of the associated CO₂ storage potential can be made.

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.

<table>
<thead>
<tr>
<th>Structure</th>
<th>Lithology</th>
<th>Thickness</th>
<th>Depth</th>
<th>Ave. Reservoir Porosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anticline</td>
<td>Fluvial</td>
<td>25</td>
<td>4000</td>
<td>26.6</td>
</tr>
<tr>
<td>Anticline</td>
<td>Fluvial</td>
<td>25</td>
<td>8000</td>
<td>26.6</td>
</tr>
<tr>
<td>Anticline</td>
<td>Fluvial</td>
<td>66</td>
<td>4000</td>
<td>26.6</td>
</tr>
<tr>
<td>Anticline</td>
<td>Fluvial</td>
<td>66</td>
<td>8000</td>
<td>26.6</td>
</tr>
<tr>
<td>Anticline</td>
<td>Fluvial</td>
<td>209</td>
<td>4000</td>
<td>16.9</td>
</tr>
<tr>
<td>Anticline</td>
<td>Fluvial</td>
<td>209</td>
<td>8000</td>
<td>16.9</td>
</tr>
<tr>
<td>Anticline</td>
<td>Carbonate shallow shelf</td>
<td>25</td>
<td>4000</td>
<td>33.7</td>
</tr>
<tr>
<td>Anticline</td>
<td>Carbonate shallow shelf</td>
<td>25</td>
<td>8000</td>
<td>33.7</td>
</tr>
<tr>
<td>Anticline</td>
<td>Carbonate shallow shelf</td>
<td>66</td>
<td>4000</td>
<td>34.5</td>
</tr>
<tr>
<td>Anticline</td>
<td>Carbonate shallow shelf</td>
<td>66</td>
<td>8000</td>
<td>34.5</td>
</tr>
<tr>
<td>Anticline</td>
<td>Carbonate shallow shelf</td>
<td>209</td>
<td>4000</td>
<td>21.9</td>
</tr>
<tr>
<td>Anticline</td>
<td>Carbonate shallow shelf</td>
<td>209</td>
<td>8000</td>
<td>21.9</td>
</tr>
</tbody>
</table>
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 CO₂ EOR projects.
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.
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 CO₂ 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 (CO₂), to evaluate the relationship between CO₂ storage and EOR.
- Utilization and recovery factors will be assessed.
- Assess the balance between associated CO₂ storage and CO₂ EOR.
Hydrocarbon Reservoirs: $\text{CO}_2$ 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 $\text{CO}_2$ in gas reservoirs.
  – Determine $\text{CO}_2$ recovery efficiency.
  – Correlate gas recovery and $\text{CO}_2$ storage efficiency.
  – Assess engineering constraints for $\text{CO}_2$ 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
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.
Energy & Environmental Research Center
University of North Dakota
15 North 23rd Street, Stop 9018
Grand Forks, ND 58202-9018

World Wide Web: www.undeerc.org
Telephone No. (701) 777-5355
Fax No. (701) 777-5181

Charles Gorecki, Senior Research Manager
cgorecki@undeerc.org
Acknowledgment

This material is based upon work supported by the U.S. Department of Energy National Energy Technology Laboratory under Award No. DE-FE0009114.

Disclaimer

This presentation was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government, nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.