Optimizing and Quantifying CO$_2$ Storage Capacity/Resource in Saline Formations and Hydrocarbon Reservoirs

DE-FE0009114

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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
Presentation Outline

• Benefit to the Program
• Project Overview
• Technical Status
• Accomplishments to Date
• Summary
Benefit to the Program

- Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness.
- Develop best practice manuals (BPMs) for monitoring, verification, and assessment; site screening, selection, and initial characterization; public outreach; well management activities; and risk analysis and simulation.
- The research project is seeking to optimize carbon dioxide (CO$_2$) storage resource and containment in geologic formations by establishing field methodologies focused on quantifying and enhancing storage resource in saline formations and hydrocarbon reservoirs associated with enhanced oil recovery (EOR). These methodologies will better enable stakeholders to estimate, predict, and optimize storage resource and demonstrate long-term CO$_2$ storage in these formations. This project addresses the goals listed above.
Project Overview: Goals and Objectives

- To refine current methods and terms used to estimate CO$_2$ storage resource in saline formations and hydrocarbon reservoirs.

- Two concurrent areas of investigation (Tasks 2 and 3) will be undertaken to accomplish project goals:

  - Task 1: Project Management
  - Task 2: Optimizing and Quantifying CO$_2$ Storage Resource in Saline Formations
  - Task 3: Optimizing and Quantifying CO$_2$ Storage Resource in Hydrocarbon Reservoirs
Task 2 Objectives

- Perform a literature review and update and expand the Average Global Database (AGD) with saline formation reservoir properties.
- Develop regional- and formation-scale geologic models using Schlumberger Carbon Services (Schlumberger) Petrel geologic modeling software package for several clastic and carbonate depositional environments (i.e., reservoir classes) and up to seven defined structural frameworks based on available real-world data.
- Perform CO₂ storage injection simulations on the models, using Computer Modelling Group Ltd. (CMG) GEM and CMOST software packages, to identify local and regional pressure buildup effects on reservoir storage resource, injectivity, storage efficiency, and plume footprint for the different reservoir classes.
- Perform simulations on the different regional models to determine ways to enhance storage resource and storage efficiency by using different well configurations, horizontal wells, and water extraction wells.
- Refine current methodologies and coefficients used to optimized CO₂ storage resource.
Project Overview:
Goals and Objectives (continued)

Task 3 Objectives

- Perform a literature review on current CO₂ EOR projects to develop a database with reservoir and CO₂ flooding properties for the different cases and reservoir types.
- Conduct reservoir evaluations on current and hypothetical CO₂ EOR projects to better define when an EOR project with incidental CO₂ storage changes to a) an EOR and CO₂ storage project and b) a CO₂ storage project with incidental hydrocarbon recovery.
- Develop pattern-sized geologic models and perform simulations to determine the effects that different reservoir/depositional types have on sweep efficiency, utilization factor, and CO₂ retention.
- Evaluate different types of injection strategies with respect to their ability to optimize utilization factor, storage permanence, and hydrocarbon recovery in different reservoir classes.
- Develop more refined methods for estimating CO₂ storage resource in hydrocarbon reservoirs and the terms used to estimate storage resource for different reservoir classes.
Project Overview: Goals and Objectives (continued)

- Accomplishment of goals will provide insight into the optimization of CO\textsubscript{2} efficiency, important factors for site selection, the impact of field activities on storage resource, and site-specific effects such as pressure, sweep efficiency, etc.

- **Success criteria**
  - Completion of literature review of current methodologies
  - Collection of publicly available data for real-world reservoirs
  - Creation of geocellular models for both saline formations and hydrocarbon reservoirs
  - Accomplishment of dynamic CO\textsubscript{2} injection simulations investigating field- and regional-based effects (e.g., pressure)
  - Development of a BPM
Approach

- Literature review
- Build static geologic 3-D models using Petrel
  - Base case properties from publicly available data
  - P10, P50, P90 properties from expanded AGD
  - Ten selected formations covering seven major depositional environments
  - Nine base case models, both regional and formation scale, to capture effects of various depositional environments and heterogeneities
  - Both intracratonic and intermountainous basin deposition systems
Technical Status – Task 2 (continued)

Approach (continued)

- Perform dynamic simulations using CMG software
  - Validate and optimize geologic models
    - Upscale base, high, mid, and low cases
    - Sensitivity analysis and numerical tuning
  - Perform predictive simulations
    - Pressure buildup
    - Sweep efficiency
    - Plume footprint
Literature Review

Structural Model

Facies Model

Static Geocellular Models

Digitize Data

Uncertainty and Optimization

Application of the AGD to determine a P10, P50 & P90

Is Facies Data Available?

Yes

No

Petrophysical Model

Technical Status – Task 2 (continued)
Technical Status – Task 2 (continued)

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

Injection Simulation Design

Boundary Condition Explorations

Storage Capacity Comparisons and Analysis

Dynamic Storage Capacity estimates

Operational Storage Capacity Enhancement

Transitional Marine Formations (Fms)

• Broom Creek Fm
  – Eolian, marginal marine and marine sediments
  – Intracratonic Williston Basin, North Dakota

• Minnelusa Fm
  – Eolian and marine sediments
  – Intermountain Powder River Basin, Wyoming
Nonmarine Formations

- **Inyan Kara Fm**
  - Predominantly fluvial transitioning to marginal marine sediments
  - Intracratonic Williston Basin, North Dakota

- **Stuttgart Fm**
  - Predominantly fluvial sediments
  - Intracratonic Northeast German Basin, Ketzin, Germany
Technical Status – Task 2 (continued)

Nonmarine Formations

- Qingshankou–Yaojia Fms
  - Lacustrine with interbedded deltaic sediments
  - Intermountain Songliao Basin, Heilongjiang Province, Northeast China

Marine Formations

- Mission Canyon Fm
  - Carbonate shelf sediments
  - Intracratonic Williston Basin, North Dakota

- Utsira Fm
  - Deltaic sediments
  - Intracratonic Norwegian Danish Basin

http://climatex.org/articles/climate-change-info/geosequestration-burying-problem/
Marine Formations

- **Leduc Fm**
  - Reef and shallow water carbonate sediments
  - Intracratonic regional Western Canada Sedimentary Basin, west-central Alberta, Canada

- **Winnipegosis Fm**
  - Reef structures in marine sediments
  - Intracratonic Williston Basin, North Dakota
Technical Status – Task 3

Approach

• Literature review
  – Review of existing CO2 storage resource methodologies for hydrocarbon reservoirs
  – Collection of publicly available data: Oil and Gas Journal EOR survey, technical papers, etc.
  – Initial screening based on specific criteria (e.g., enhanced recovery)
  – Detailed analysis of selected reservoirs

• Evaluation of factors involved in the CO2 EOR and CO2 storage relationship

• Hydrocarbon reservoir modeling and simulation

• Evaluation of methodology
Technical Status – Task 3
(continued)

• Develop equation for CO₂ storage resource estimation.
• Perform basic 2-D spreadsheet-based evaluations.
• Compile geologic and reservoir inputs and noted inflection points to study relationship between utilization factor and project stage (CO₂ EOR and CO₂ storage).

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Dykstra Parsons vs. Lorenz Coefficient Plot

Evaluating Relationships Between CO₂ Retention and Reservoir Production

**Type 1:**
“Mirror”
CO₂ retention and oil production track closely over time.

**Type 2:**
“Lag”
Time lag between oil production and CO₂ retention.

**Type 3:**
“Crossover”
Greater oil production prior to decline in CO₂ retention.
Technical Status – Task 3 (continued)

• Develop 2-D conceptual geologic models
• Perform intermediate-level reservoir simulation using COZView/COZSim or CO₂ Prophet software

The **AREA** entered as input to the model should correspond to the hatched area.

The partial area (crosshatched) is actually simulated in the model.
• Develop field- to pattern-sized geologic models. (Schlumberger’s Petrel™)

• Perform dynamic simulations (using CMG’s GEM™) to understand and optimize:
  – Utilization factor, sweep efficiency, storage permanence, and retention
Technical Status – Task 3 (continued)

- Simulation-based estimates of expected CO₂ EOR efficiency and CO₂ storage capacity for refined storage resource estimations/storage coefficients for EOR/storage projects.

- Simulation-based analysis of potential transition of an EOR project to a CO₂ storage project and CO₂ storage resource.
Accomplishments to Date

Task 2

- Literature review complete.
- Publicly available data have been collected, catalogued, and analyzed.
- Ten saline formations selected for evaluation, nine geocellular models under development.
- Dynamic simulation reservoir properties gathered.

<table>
<thead>
<tr>
<th>Reservoir Formation</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minnelusa</td>
<td>Base case complete</td>
</tr>
<tr>
<td>Broom Creek</td>
<td>Base case complete</td>
</tr>
<tr>
<td>Inyan Cara</td>
<td>Structure model built</td>
</tr>
<tr>
<td>Mission Canyon</td>
<td>Structure model started</td>
</tr>
<tr>
<td>Leduc</td>
<td>Structure model built; properties compiled for object modeling</td>
</tr>
<tr>
<td>Winnipegosis</td>
<td>Structure model built</td>
</tr>
<tr>
<td>Stuttgart</td>
<td>Structure model built; property modeling begun</td>
</tr>
<tr>
<td>Qingshankou–Yaojia</td>
<td>Base case complete</td>
</tr>
<tr>
<td>Utsira</td>
<td>Structure model started</td>
</tr>
</tbody>
</table>
Accomplishments to Date (continued)

Task 3

- Literature review nearly complete.
- Current oilfield CO$_2$ storage resource methodologies identified and under review.
- Existing EOR projects and reservoirs identified for detailed investigation.
- Potential equations for hydrocarbon reservoirs developed.
Summary

- Site- and reservoir-specific effects (e.g., pressure response) can have a significant impact on the optimization and estimation of storage resource—current methodologies typically ignore these effects.

- Dynamic CO₂ injection simulation is expected to provide insight into:
  1. Validity of coefficients at the formational level for different reservoir classes and basin types, thus reducing extrapolation for large-scale assessments.
  2. Property distributions for each lithology and depositional environment.
  3. Well optimization techniques for CO₂ storage (configurations, horizontal wells, etc.).
  4. Factors affecting CO₂ retention during EOR.
  5. CO₂ storage efficiency in both saline formations and hydrocarbon reservoirs.
The AGD was updated with several goals:

- Better represent global data
- Increase database organization
- Incorporate porosity-permeability crossplot data
- Be distributable
- Rely less on American Databases
- Lacustrine and Carbonate Slope environments were added.
AGD: Porosity-Permeability Relationships

- Nearly 26,000 points were added to the database recording referenced porosity-permeability.
- Data is sorted by depositional environment and sub-facies.
AGD: Findings

- Environments with tighter energy controls provide more consistent (predictable) porosity-permeability relationships.

- Crossplot data appears to produce a more representative dataset with better controls on very low and very high data (Reported histograms oversample mean data).

\[ y = 0.0358e^{0.3872x} \]
\[ R^2 = 0.6342 \]

**Clastic Aeolian Crossplot**

<table>
<thead>
<tr>
<th>Aeolian Permeability</th>
<th>Crossplot K</th>
<th>Histogram Breakdown K</th>
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</thead>
<tbody>
<tr>
<td>N=</td>
<td>1503</td>
<td>51</td>
</tr>
<tr>
<td>Min.</td>
<td>0.009251</td>
<td>0.01</td>
</tr>
<tr>
<td>0.1</td>
<td>0.11964</td>
<td>0.1</td>
</tr>
<tr>
<td>0.25</td>
<td>0.639542</td>
<td>10</td>
</tr>
<tr>
<td>0.5</td>
<td>5.14</td>
<td>63</td>
</tr>
<tr>
<td>0.75</td>
<td>38.82977</td>
<td>320</td>
</tr>
<tr>
<td>0.9</td>
<td>135.672</td>
<td>1200</td>
</tr>
<tr>
<td>Max.</td>
<td>2735.775</td>
<td>4700</td>
</tr>
<tr>
<td>Mean</td>
<td>53.66795</td>
<td>436.398</td>
</tr>
<tr>
<td>Stdev</td>
<td>169.1931</td>
<td>977.8442</td>
</tr>
</tbody>
</table>
Depo-environment based quartile statistics for porosity and permeability were developed using two methods:

- Using the raw porosity-permeability cross plot data
- Using recombined histogram breakdowns
Organizational Chart

Partners
- Schlumberger and CMG provide software use and technical support.

Consultants assisting with the following:
- Task 2
  Stefan Bachu
  David Nakles
- Task 3
  David Nakles
  Stephen Melzer
### Summary of Task 1 - Project Management, Planning, and Reporting

**1.1 Perform Project Management**

**1.2 Project Reporting**

### Summary of Task 2 - Optimizing and Quantifying CO₂ Storage Capacity/Resource in Saline Formations

**2.1 Literature Review**

**2.2 Geologic Model Development**

**2.3 Simulations to Predict CO₂ Storage Performance**

**2.4 Optimize CO₂ Storage Efficiency and Resource**

**2.5 Refine Storage Resource Estimation Methodologies and Storage Coefficients**

### Summary of Task 3 - Optimizing and Quantifying CO₂ Storage Resource in Hydrocarbon Reservoirs

**3.1 Literature Review**

**3.2 Evaluation of CO₂ EOR and CO₂ Storage**

**3.3 Hydrocarbon Reservoir Modeling and Simulation**

**3.4 CO₂ Storage Resource Methodologies**

### Key for Deliverables (D)

- D1 - Updated PMP
- D2 - Quarterly Progress/Milestone Report
- D3 - Identification of Geologic Formations Selected for Evaluation
- D4 - Data Submission to EDX
- D5 - Interim Report: Simulation Results for CO₂ Storage Performance
- D6 - Interim Report: Balancing between CO₂ EOR and CO₂ Storage
- D7 - Manuscript on CO₂ Storage Performance for Submission to Peer-Reviewed Journal
- D8 - Manuscript on the Balance between CO₂ EOR and CO₂ Storage for Submission to Peer-Reviewed Journal
- D9 - Best Practices Manual on Optimizing and Quantifying CO₂ 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 - CO₂ EOR and Associated Storage Literature Review Completed
- M7 - All Geologic Models Completed
- M8 - First Injection Simulation Completed
- M9 - Simulations to Predict CO₂ Storage Performance Completed
- M10 - First CO₂ EOR and Storage Simulation Completed
- M11 - Reservoir Evaluations Completed
- M12 - Field to Plateau Geologic Models Completed
- M13 - Simulations to Optimize CO₂ Storage Efficiency Completed
- M14 - Examination and Refinement of Storage Capacity and Incremental Hydrocarbon Production Completed
- M15 - Evaluation and Validation of Estimation Methodologies Completed
No publications to date.