Farnsworth Unit - Ochiltree Field Project

Southwest Regional Partnership on Carbon Sequestration (SWP)
DE-FC26-05NT42591

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Acknowledgements

• Many thanks to NETL and the U.S. Dept of Energy for supporting this project!
• Thank you to all the SWP partners, technical and otherwise, especially some stellar FFRDC collaborators.
• Special thanks to Schlumberger Carbon Services for their outstanding collaborative efforts.
Presentation Outline

• Introduction and Summary of Partners
• Project Overview: Goals and Objectives
• Technical Status
• Accomplishments to Date
• Summary
Introduction: Partners of the SWP

In all partner states:
• major universities
• geologic survey
• other state agencies
• National Laboratories
• over 50 partners

as well as
• Western Governors Association
• five major utilities
• seven energy companies
• three federal agencies
• the Navajo Nation
• many other critical partners
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The SWP’s Phase III will be a Large-Scale EOR-CCUS Sequestration Test

General Goals:
- One million tons CO₂ injection
- Optimization of storage engineering
- Optimization of monitoring design
- Optimization of risk assessment
- “Blueprint” for CCUS in southwestern U.S.

A key aspect of this project:
NEW FIVE SPOT PATTERNS WILL BE DRILLED EVERY SIX MONTHS. THE SWP WILL “LEARN” FROM RESULTS, RE-ADJUST AND RE-DESIGN MONITORING/ANALYSIS FOR EACH NEW SET OF INJECTION WELLS, BASED ON ANALYSIS OF RESULTS OF THE PREVIOUS SETS OF WELLS.
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Brief Summary of Accomplishments

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Major accomplishments thus far:
- site suitability evaluation completed;
- geologic characterization ongoing;
- baseline simulation models developed;
- initial history match simulation completed
- baseline monitoring completed,
- 3D surface seismic survey of full FWU completed
- 3D VSP and crosswell baselines
- 233,000 tonnes CO₂ injected
- 127,000 tonnes CO₂ stored
The SWP’s Phase III will be a Large-Scale EOR-CCUS Sequestration Test

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**Phase III Site:** Farnsworth Unit, Ochiltree, Texas
Technical Status: Project Details and Major Accomplishments to Date

- Project Location and Site Operator
- CO$_2$ Sources
- Major Accomplishments
Farnsworth Oil Field
Ochiltree County, Texas

Anthropogenic CO₂ Sources

FWU
Farnsworth Field

ANADARKO BASIN
Located in Ochiltree county in flat cultivated region
Site Operator:
Chaparral Energy, LLC
Technical Status: Project Details and Major Accomplishments to Date

- Project Location and Site Operator
- $\text{CO}_2$ Sources
- Major Accomplishments
CO₂ Sources 100% Anthropogenic

CO₂ Supply:
- Arkalon Ethanol Plant
  Liberal KS

Agrium Fertilizer Plant
Borger TX
Panhandle Area CO₂ Opportunities

- **Total OOIP**: 713 MMBO
- **Primary Production**: 74 MMBO
- **Secondary Recovery**: 116 MMBO
- **Tertiary Potential**: 74 MMBO
- **Net Tertiary Potential**: 35 MMBO

Existing CELLC CO₂ Pipelines
- 

Proposed CELLC CO₂ Pipelines
- 

CO₂ Pipelines of Others
- 

Panhandle Area: 24 Projects
Net Potential: 35 MMBoe, 18% of total
Technical Status: Project Details and Major Accomplishments to Date

• Project Location and Site Operator
• CO₂ Sources
• **Major Accomplishments:**
  – 3-D Surface, baseline VSP and crosswell surveys
  – 3 Characterization Wells drilled, logged, and cored
  – CO₂ injection and production; oil production
  – Effective Simulation Model based on Seismic and other Data
  – Initial History Match Simulation Completed
Existing and Planned Seismic Acquisitions

- 3D VSP
- Passive
- Cross-well
- Legacy 2D
- FWU Border
Seismic Acquisition

- Data gathered at a mobile site which moved as portions of the field were shot
- Coordinated vibroseis trucks
- Initial QC on data
- Stored field data for each day before overnight review and pre-processing
Comparison of the three levels of Seismic with gamma ray log

Surface Seismic Top Morrow Interpretation

Well 13-10A (GR)
Technical Status: Project Details and Major Accomplishments to Date

• Project Location and Site Operator
• CO₂ Sources

• **Major Accomplishments:**
  – 3-D Surface, baseline VSP and crosswell surveys
  – **Three Characterization Wells drilled, logged, and cored**
  – CO₂ injection and production; oil production
  – Effective Simulation Model based on Seismic and other Data
  – Initial History Match Simulation Completed
Three Characterization Well drilled

1310A: Nov ’13 – Jan ‘14
1314: Jan ‘14 – Feb ‘14
3208: Jun ‘14 – Jul ‘14
Left: GR log of well #19-5, without channel fill accumulation.

Right: GR log of well 13-10A with channel fill section.

Top Thirteen Fingers

- **Top Morrow Shale**
- **Top Morrow B**
- **Base Morrow B**
Gamma ray log, core image, facies interpretation, and ELAN mineralogy combiners from well 13-10A in the Morrow-B interval.
Technical Status: Project Details and Major Accomplishments to Date

- Project Location and Site Operator
- CO\textsubscript{2} Sources
- **Major Accomplishments:**
  - 3-D Surface, baseline VSP and crosswell surveys.
  - 3 Characterization Wells drilled, logged, and cored.
  - \textbf{CO\textsubscript{2} injection and production; oil production}
  - Effective Simulation Model based on Seismic and other Data
  - Initial History Match Simulation Completed
**FWU Production 1956 - 2012**

- **Field Discovered**: 1955
- **Unitized**: 1963
- **Water Injection Started**: 1964
- **Chaparral Purchased Field**: 2009
- **CO₂ Injection initiated**: December 2010

**Production Graph Details**

- **Y-axis**: Monthly Production
- **X-axis**: Dates from 1/1/1956 to 1/1/2012
- **Key Points**:
  - **Primary decline**
  - **Secondary Water Injection**
  - **CO₂ Injection**
CO₂ Injection (yellow) and CO₂ Production (green)
as of July 31, 2014

CO₂ 10/13 (total)

Injected: 232,912 (765,670)
Purchased: 138,730 (620,603)
Produced: 97,430 (184,321)
Flared: 11,724 (50,530)
CO₂ Injection (yellow) and Oil Production (red)
as of June 30, 2014

CO₂ Injected [tonnes]: 232,912  (765,670)
Oil Produced [barrels]: 461,345  (1,019,794)

Note: symbols all represent mass (tonnes)
Technical Status: Project Details and Major Accomplishments to Date

• Project Location and Site Operator
• CO₂ Sources

• **Major Accomplishments:**
  – 3-D Surface, baseline VSP and crosswell surveys
  – 3 Characterization Wells drilled, logged, and cored
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  – **Effective Simulation Model based on Seismic and other Data**
  – Initial History Match Simulation Completed
Well logs

- 1,009 well log curves from 181 wells
- Spontaneous potential logs
- Gamma ray
- Resistivity logs, micrologs, short normal
- Sonic logs
- Neutron porosity
- Bulk density
- Core plug porosity
- Horizontal core perm
Model Development

- 181 wells with logs within the FWU boundary

Top of Morrow B
Reservoir Model Also Calibrated to Seismic Model

Ashley Hutton, 2014
Petrophysical Modeling of Seismic and other Geological and Geophysical Data (logs)

<table>
<thead>
<tr>
<th>Deterministic Techniques</th>
<th>Stochastic Techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Kriging</td>
<td>• Sequential Gaussian Simulation</td>
</tr>
<tr>
<td>• Moving Average</td>
<td>• Gaussian Random function Simulation</td>
</tr>
</tbody>
</table>

Just Over 1000 Realizations for the Initial Analysis
Porosity Logs

- 55 Wells Included Porosity logs
- 14 wells on West Side
- 41 Wells on East Side
- based on combined core and log data used for interpretation
- extrapolation/interpolation using deterministic/stochastic techniques

Wells with Porosity data distributed throughout the field used in the initial modeling
Permeability Logs

- 48 Permeability Logs
- based on direct core measurements
- About 12 on West side
- 36 on East Side
- geometric averaging used where appropriate
- extrapolation/interpolation using deterministic/stochastic

Wells with permeability data distributed throughout the field are used in the initial modeling. Majority of the core data are concentrated on the eastern side of the field.
Interpreted Porosity Distribution

Layer 3

Layer 4
Interpreted Permeability Distribution

Layer 3

Layer 4
Some Details of the Initial Model

- Grid Cells: 381 x 233 x 8
- Grid Cell Dimensions: 100ft x 100ft
- Total # cells: 710184
Technical Status: Project Details and Major Accomplishments to Date

• Project Location and Site Operator
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• **Major Accomplishments:**
  – 3-D Surface, baseline VSP and crosswell surveys
  – 3 Characterization Wells drilled, logged, and cored
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  – Effective Simulation Model based on Seismic and other Data
  – **Initial History Match Simulation Completed**
History Match Effort: Actual Data

Farnsworth Unit

Daily Production/Injection

Legend:
- OIL
- GAS
- WTR
- INJW
- INJC
History Match Effort: Actual Data with Forecast
Primary decline

Secondary Water Injection

3-D seismic, Unocal land consolidation, infill well drilling consideration

CO₂ Injection
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Summary

Key Findings and Lessons Learned:

• Production objectives, oil prices influence CO₂ availability;
• Reservoir responding at or above expectations;
• Injectivity is excellent, but the field could accommodate much more CO₂ injection;
• Anthropogenic CO₂ sources not as stable as anticipated; source uncertainty must be factored into project economics, including carbon credits sought;
• A major key to success is cooperation of operator;
• VSP more effective than reflection; passive seismic monitoring is extremely useful for characterization;
• Fluid pressure monitoring and associated hydraulic diffusivity maps (with modeling) are very effective tools;
• Regulatory policies are still not clear.
Summary

– Future Plans

• Field:
  – Complete core analysis on three characterization wells
  – Repeat seismic (3D-VSP and crosswells)
  – Continue surface monitoring
  – Tracer tests

• Reservoir modeling:
  – Incorporate seismic, new logs, and core findings into geomodel
  – Integrate reservoir models and seismic models.

• Risk assessment: Initial quantitative risk analysis results coming online now;

• Laboratory: With initial core characterization near completion, lab testing just beginning.
Appendix

– These slides will not be discussed during the presentation, **but are mandatory**
• Describe project team, organization, and participants.
  – Link organizations, if more than one, to general project efforts (i.e. materials development, pilot unit operation, management, cost analysis, etc.).

• Please limit company specific information to that relevant to achieving project goals and objectives.
Gantt Chart

• Provide a simple Gantt chart showing project lifetime in years on the horizontal axis and major tasks along the vertical axis. Use symbols to indicate major and minor milestones. Use shaded lines or the like to indicate duration of each task and the amount of that work completed to date.
Bibliography

List peer reviewed publications generated from project per the format of the examples below

- **Journal, one author:**

- **Journal, multiple authors:**

- **Publication:**
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- Introduction and Summary of Partners
- **Benefit to the Program**
- Project Overview: Goals and Objectives
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Benefit to the Program:
Program Goals Addressed

- 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.
- Develop Best Practice Manuals for monitoring, verification, accounting, and assessment; site screening, selection and initial characterization; public outreach; well management activities; and
Benefit to the Program: Specific Benefits

- This project will demonstrate carbon storage concomitant with EOR, and elucidate aspects that maximize storage capacity without compromising EOR recovery efficacy. Although this project contributes to several program goals (previous slide), perhaps the most significant is development of technologies to improve reservoir storage efficiency while ensuring containment effectiveness.
• **Storage Capacity Verification**
  – The SWP is developing technologies that will support our industry partner's ability to predict and confirm CO2 storage capacity in geologic formations
  – The uncertainty or tolerance planned is ±30 % (target is ±10 %)
  – Injectivity determined from wellbore simulation models calibrated with CO2 injection from existing patterns, laboratory analysis of core, and well-testing of characterization wells.
  – Capacity verification via 3-D simulation models and direct data, 3D-VSP, crosswell tomography, tracers, pressure and temperature, and production data.
  – **Success Criteria:** consistency between gross totals from simulated forecasts to gross mass balance data provided by operator

• **Verification of Containment**
  – The SWP will confirm that 99 % of injected CO2 remains in the injection zones
  – **Success Criteria:** From Phase II project results, we find that the most effective criteria are results of indirect monitoring including geophysical (VSP) surveys, and results of direct monitoring including tracer measurements, pressure and geochemical monitoring
**Project Overview: Goals and Objectives**

- **Storage Permanence**
  - Storage permanence will be inferred by evaluating time-scales of CO2 migration, with results assessed by geophysical (VSP) surveys, tracer monitoring, pressure and geochemical monitoring, and detailed numerical modeling calibrated by these data.
  - **Success criteria:** for permanent storage, no criteria possible, but confirmation for the duration of the project will be continuous

- **Plume Extent and Potential Leakage Pathways**
  - The SWP will characterize and forecast potential plume extent and potential leakage pathways via geophysical surveys, tracer monitoring, pressure and geochemical monitoring, and detailed numerical modeling.
  - **Success criteria:** confirm forecasts through continuous direct monitoring (especially tracers in the production stream) during and after injection
Risk Assessment

- The SWP has developed a comprehensive risk assessment strategy which is “Adaptive”—iterative modeling-monitoring approach for assessment of uncertainty and performance assessment: healthy/safety risks, economic and programmatic risks, and otherwise

- Success criteria: review of risk assessment results by NETL and external panel of risk experts

As indicated previously: NEW FIVE SPOT PATTERNS WILL BE DRILLED EVERY SIX MONTHS. THE SWP WILL “LEARN” FROM RESULTS, RE-ADJUST AND RE-DESIGN DEPLOYMENT FOR EACH NEW SET OF INJECTION WELLS, BASED ON ANALYSIS OF RESULTS OF THE PREVIOUS SETS OF WELLS.