the ENERGY lab

PROJECT FACTS

Carbon Storage – Fit for Purpose

# IEA-GHG Weyburn-Midale $CO_2$ Monitoring and Storage Project

## Background

The goal of the Department of Energy's (DOE) Carbon Storage Program is to develop and advance technologies to significantly improve the effectiveness of geologic carbon storage, reduce implementation costs, and prepare for widespread commercial deployment between 2025 and 2035. Research to develop these technologies will ensure safe and permanent storage of carbon dioxide ($CO_2$) to reduce greenhouse gas (GHG) emissions without adversely affecting energy use or hindering economic growth.

Geologic carbon storage involves securely and permanently injecting $CO_2$ into onshore and offshore underground formations. Current research and field studies are focused on developing a better understanding of the science and technologies needed for safe and permanent $CO_2$ storage in onshore and offshore storage reservoirs, which include: clastic formations, carbonate formations, unmineable coal seams, organic-rich shales, and basalt interflow zones. DOE's Storage Program is accomplishing this through: (1) developing technologies that address technical challenges and ensure the cost effectiveness of carbon storage, (2) validating technologies that ensure safe and permanent carbon storage, and (3) facilitating public, industry, and international community awareness of research and development (R&D) efforts underway related to carbon storage. These technologies will facilitate future $CO_2$ management for coal-based electric power generating facilities and other industrial $CO_2$ emitters by enabling the safe, cost-effective, permanent geologic storage and utilization of $CO_2$ in all storage types.

The Storage Infrastructure portion of the Carbon Storage Division research portfolio (Regional Carbon Sequestration Partnerships) focuses on conducting research in the field, including carrying out regional characterization and field validation testing to demonstrate that different storage types in various formation classes, distributed over different geographic regions, and both onshore and offshore, have the capability to safely and permanently store $CO_2$. This research will provide a sound basis for commercial-scale $CO_2$ projects. The Storage Infrastructure Technology Area works to validate new technologies and benefits from specific solutions developed in the Core Storage R&D component. In turn, data gaps and lessons learned from small- and large-scale field projects are fed back to the Core Storage R&D component to guide future R&D.

Experience and knowledge gained through the Regional Carbon Sequestration Partnerships (RCSP) Initiative large-scale field projects is providing a firm foundation for future large-volume field projects, both onshore and offshore. The RCSP Initiative has been instrumental in developing processes and procedures for site characterization applicable for future commercial-scale projects. In addition to work conducted through

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## PARTNERS

**None**

## PROJECT DURATION

| Start Date | End Date |
|---|---|
| 10/01/2010 | 09/30/2015 |

## COST

**Total Project Value**
$5,698,756

**DOE/Non-DOE Share**
$4,500,000 / $1,198,756

## AWARD NUMBER

DE-FE0002697

the RCSPs, research within the Storage Infrastructure Technology Area is focused on next-generation onshore characterization projects, offshore prospective storage resource assessment, and "fit-for-purpose" projects. "Fit-for-purpose" projects are designed to address different types of research needs necessary to advance CCS. These research needs include subsurface engineering, utilizing brine extraction for pressure management, and efforts to characterize and understand residual oil zones as a possibility for "net carbon negative oil." The Weyburn-Midale $CO_2$ Monitoring and Storage Project is an international collaboration which brings together Canada, the U.S., the European Community, and Japan, as well as numerous other industrial and government sponsors. The research initiative integrates studies with the large-scale $2 billion commercial enhanced oil recovery (EOR) and carbon storage operations at the Weyburn and Midale oil fields in the Williston Basin, Saskatchewan, Canada.

## Project Description

The IEA GHG Weyburn-Midale $CO_2$ Monitoring and Storage Project in Saskatchewan, Canada is a research project associated with the ongoing commercial $CO_2$-EOR operations in the Weyburn and Midale oil fields (Figure 1a). The commercial operations are now the world's largest geologic storage site of $CO_2$ with about 2.8 million metric tons of $CO_2$ being stored annually. Both fields combined have stored more than 25 million metric tons of anthropogenic $CO_2$. The $CO_2$ in these operations is captured from the Great Plains Synfuel plant in Beulah, North Dakota and transported via pipeline 180 miles north to the Weyburn and Midale fields (Figures 1b and 2).

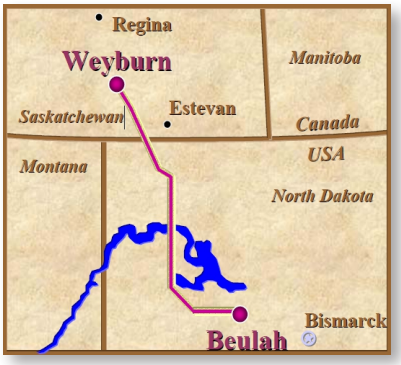

*Figure 1a and b. The Great Plains Synfuel plant in Beulah, North Dakota is the $CO_2$ source for the project. Carbon dioxide is transported via pipeline 180 miles north to the Weyburn and Midale fields.Figure 1a. Location map. Figure 1b. A $CO_2$ injection well rests near an oil production well in a field near Weyburn, Saskatchewan. (Photo courtesy of the Petroleum Technology Research Centre.)*

The first phase of the research project was conducted from 2000 through 2004 and completed research in four areas: Geologic Characterization; Prediction, Monitoring, and Verification of $CO_2$ Movement; $CO_2$ Storage Capacity and Distribution Predictions and the Application of Economic Limits; and Long-term Risk Assessment of the Storage Site. Accomplishments included development of a robust model of the geosphere and the biosphere that served as a platform for long-term risk assessment, seismic monitoring clearly demonstrated the ability to detect anomalies resulting from injected $CO_2$, and monitoring with geochemical fluid sampling gave good insight into the movement of $CO_2$ within the reservoir. The final phase of the project (initiated in 2005) involves research addressing high priority research needs of the operators and is organized into research themes described in the following. This research also supports efforts to integrate results and data into comprehensive, scientific documents available to the public.

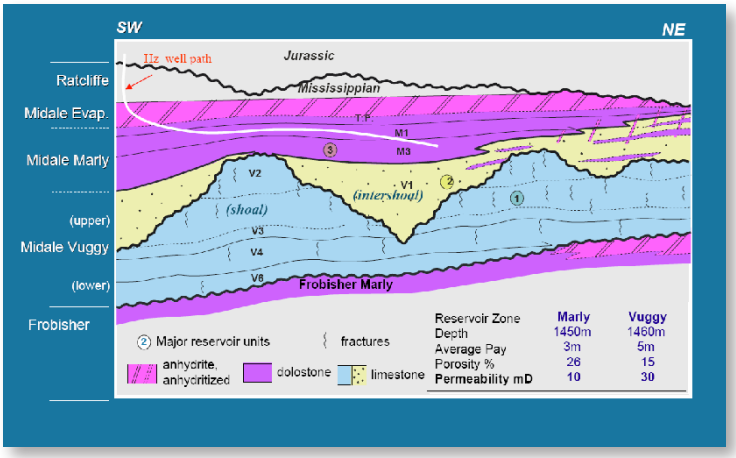


*Figure 2. Cross-section of the Midale carbonate reservoir*

A primary focus of the initial stage of the final phase project was to produce a Best Practice Manual to summarize lessons learned from monitoring a $CO_2$-EOR and storage project. Technical reports were generated from more than thirty tasks, including extensive reservoir fluid monitoring; seismic monitoring and analyses; reactive transport modeling and experimental $CO_2$-brine-rock investigations; large-scale percolation modeling of the fate of injected $CO_2$; and shallow groundwater monitoring surveys conducted from pre-injection to the present. The results assure the safety and permanence of long-term storage of $CO_2$ in the subsurface.

## Objectives

Research conducted in the IEA GHG Weyburn-Midale $CO_2$ monitoring and storage final phase initial stage supported four main technical research objectives critical for understanding geologic storage of $CO_2$ in conjunction with EOR operations. These objectives included:

- **Site Characterization and Geologic Integrity:** Conducted studies of the geological integrity of the Weyburn and Midale fields and associated seals as a $CO_2$ storage container. This included identifying criteria for selection of suitable sites for $CO_2$ geologic storage; integrating hydrogeological, geophysical, and geological data sets to create a robust model of the geologic reservoir and seals; and describing conditions that would lead to high and low risk environments. The results of this work support site selection of other $CO_2$ EOR storage sites.

- **Wellbore Integrity:** Conducted research investigating wellbore integrity for the Weyburn and Midale EOR fields. This work included identifying wellbore integrity parameters such as permeability and flow within cement sheaths, probabilities for failure, and effectiveness of past well abandonment techniques. Developed a database of wells and their current integrity condition within the Weyburn field. Conducted testing (e.g., logging, acquired sidewall cores, and conducted nondestructive testing of borehole exposed to $CO_2$ conditions) of wellbore exposed to $CO_2$ conditions. Compiled a list of remediation activities for wellbores that could be applied if required for remediation.

- **Storage Monitoring (geophysical and geochemical):** Studies for geophysical and geochemical monitoring and verification of $CO_2$ storage (Figure 3). This work included (1) assessing the accuracy of monitoring technologies for quantitatively determining the location of $CO_2$ in the reservoir; (2) conducted geochemical and selective seismic monitoring and modeling; and (3) predicted the impact of $CO_2$ and $CO_2$-rich fluids on the geochemical and geomechanical processes affecting regional reservoirs and seals.

- **Performance/Risk Assessment:** Studied risk assessment methods and risk mitigation measures to confirm the safety and reliability of geologic storage of $CO_2$. This included conducting full field risk assessments

The results of these research initiatives were integrated into a Best Practice Manual for $CO_2$ EOR and storage.

The final phase project was recently extended to build upon successes, accomplishments, and lessons learned of the project, including the Best Practice Manual. This stage of research is focused on high priority research needs identified for the $CO_2$ EOR and storage operator; applied research products and processes developed by numerous research projects that are sponsored can be used by an operator to: ensure permanent storage by monitoring; improve efficiency of floods and storage in the reservoir; reduce risks of wellbore integrity; and transition $CO_2$ EOR-storage fields to solely storage. The scope of this ongoing research effort includes the following technical themes as applied to the Weyburn and Midale $CO_2$ EOR and storage operations: $CO_2$ EOR Design for Storage Performance; Monitoring; and Wellbore Integrity. Results and research products developed will also be applicable to $CO_2$ storage operations worldwide. Continued collaboration with international researchers and partners will aid in technology transfer of project results worldwide.

## Accomplishments

- Project personnel published the Best Practice Manual "Best Practices for Validating $CO_2$ Geological Storage, Observations and Guidance from the IEAGHG Weyburn-Midale $CO_2$ Monitoring and Storage Project." The document aims to provide technical guidance to future project operators, regulators, and other stakeholders with an interest in the validation of safe and permanent geologic storage of $CO_2$.

- A supplementary edition of the International Journal of Greenhouse Gas Control, dedicated to the project, was recently published with 24 peer-reviewed scientific papers.

- The wellbore integrity testing program was conducted in a well planned for abandonment. Testing included cased-hole logging, pressure transient tests, cement sampling, and mini-frac tests. A pressure-transient testing tool was used as part of the testing program to quantify the hydraulic conductivity of the cemented annulus over three predetermined intervals in the Watrous Formation (regional seal). Cement cores were retrieved from the Watrous Formation and the interface between the Ratcliffe and the Midale Anhydrite. Results have demonstrated the long term integrity of the well cement.

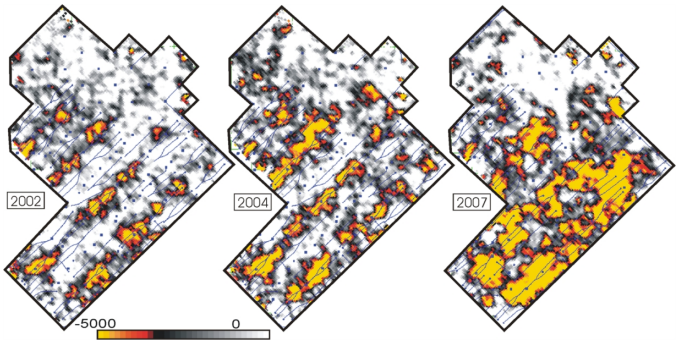


*Figure 3. Seismic reflection amplitude difference maps (monitor survey minus baseline survey) at the reservoir level detecting the presence of $CO_2$.*

- 4D surface seismic monitoring has been proven as a powerful tool for monitoring the distribution of $CO_2$ within the storage reservoir (Figure 3), and has yielded additional information. For example, an amplitude variation with offset and azimuth inversion was applied to 3D seismic data from the Weyburn field to assess the integrity of two sealing units of interest: the Watrous Formation (regional cap) and a composite caprock layer comprising the Midale Evaporite and Ratcliffe Beds (directly overlying the Midale reservoir). The research team concluded that the regional seal (Watrous Formation) has relatively few inferred fracture zones.

## Benefits

The Weyburn and Midale oil fields now contain well in excess of 25 million metric tons of injected, monitored and geologically stored anthropogenic $CO_2$ from the Great Plains Synfuels plant in Beulah, North Dakota, making it the world's largest existing CCS project. By the completion of the project, the Weyburn and Midale oil fields will have produced an expected 220 million barrels of incremental oil. Research efforts have included extensive geologic and geochemical characterization of the storage environment to allow comprehensive risk assessments; successful application of seismic surveys to map the distribution of injected $CO_2$ within the storage reservoir; geochemical monitoring of $CO_2$ behavior and micro-seismic monitoring of reservoir response to $CO_2$ injection; and development of new tools to aid in the assessment of wellbore integrity. In summary, the $CO_2$-EOR operations at the Weyburn and Midale oil fields and associated research have successfully demonstrated the safe operation and integrity of CCS at industrial scale.