Experience and Challenges in Canadian Gas Storage Projects

Malcolm Wilson

Energy INet and University of Regina

Presented to Stanford University GCEP

June 13, 2005
A collaborative innovation network that promotes an integrated energy strategy

Serves as a catalyst to bring groups together to:
- Link and leverage existing research and innovation efforts
- Unlock the next generation of ideas and technology
- Provide a long-term, abundant supply of environmentally responsible energy
- Create lasting economic prosperity and social well-being
EnergyINet Innovation Programs

- Alternative & Renewable Energy
- Clean Carbon & Clean Coal
- CO₂ Management
- Water Management
- Recovery
- Upgrading
CO$_2$ Supply

- Regina
- Weyburn
- Saskatchewan
- Canada
- USA
- North Dakota
- Bismarck

www.energyinet.com
Production Forecast with CO$_2$ EOR
CO₂ injection into Phase 1A started September 15, 2000

108 BCF CO₂ (approx. 5.7 million tonnes) from DGC injected as of Feb 14th, 2005 (currently 5000+ tons per day & the projected total is 20 million tons).

Current daily CO₂ purchase is 105MMscfd (approx. 5,500 tonnes)

19 mmscfd of associated gas and CO₂ being recycled

EOR Operations include Phase 1a (start Sept 2000), Phase 1b (start Oct 2002) and Phase 1c (start June 2003)

Incremental Production Phase 1A exceeds 9000 bbl/day

Current Unit production 22,400 bbl/day

130 million barrels are expected to be produced by CO₂ flooding.
Weyburn Field: Phase 1A EOR Area

Producing Fm.

Mississippian,

Midale

Discovered: 1954

Area: 70 sq. miles

Current oil rate: 22,000 BOPD

Number of wells: 1072 total

660 vert. oil

200 hz. oil

197 vert. inj.

15hz. inj.

Sour crude: 25-34 API

Depth: 1450m (4760 ft)

OOIP: 1,400 MMbbls

Cum. Prod. (02/01): 360 MMbbls

Total recovery to date: 26%

18km

R13

R14

R12

T 7

T 6

T 5

W2M

22km

Hz Producer

Hz Injector
SSWG Operating Strategy

Simultaneous but Separate Water and CO₂ Injection
Areal extent 10 km beyond CO₂ flood limits

Geological architecture of system

Properties of system
- lithology
- hydrogeological characteristics
- faults

Can be tailored for different RA methods and scenario analyses
## BIOSPHERE CHARACTERISTICS

<table>
<thead>
<tr>
<th>PERIOD</th>
<th>STRATIGRAPHY</th>
<th>LITHOLOGY</th>
<th>HYDROGEOLOGY</th>
<th>THIS STUDY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Surficial stratified deposits</td>
<td>Gravel, sand, silt, clay</td>
<td>Aquifer</td>
<td>Surfacal aquifers</td>
</tr>
<tr>
<td>Quaternary</td>
<td>Battleford Fm</td>
<td>Till</td>
<td>Aquitard</td>
<td>Undifferentiated Quaternary Aquifers and Aquitards</td>
</tr>
<tr>
<td></td>
<td>Saskatchewan Group</td>
<td>Upper Till</td>
<td>Aquitard</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Riddell Mb</td>
<td>Stratified deposits</td>
<td>Aquifer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lower Till</td>
<td>Till</td>
<td>Aquitard</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mennon Fm</td>
<td>Stratified deposits</td>
<td>Aquifer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sutherland Group</td>
<td>Stratified deposits</td>
<td>Aquifer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dundurn Fm</td>
<td>Stratified deposits</td>
<td>Aquifer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Warman Fm</td>
<td>Stratified deposits</td>
<td>Aquifer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Empress Gr</td>
<td>Upper Unit</td>
<td>Aquifer</td>
<td>Empress Group Aquifers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower Unit</td>
<td>Aquitard</td>
<td></td>
</tr>
<tr>
<td>Tertiary</td>
<td>Saskatchewan</td>
<td>ND</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ravenscrag Fm</td>
<td>Ludlow, Golden Valley, Fort Union</td>
<td></td>
<td>Undifferentiated Tertiary/Cretaceous Aquifer</td>
</tr>
<tr>
<td></td>
<td>Frenchman Fm</td>
<td>Hell Creek</td>
<td>Sand, silt, clay</td>
<td>Aquifer</td>
</tr>
<tr>
<td></td>
<td>Battle Fm</td>
<td>Fox Hills</td>
<td>Sand, silt, clay</td>
<td>Aquitard</td>
</tr>
<tr>
<td></td>
<td>Whitewood Fm</td>
<td>Pierre Shale</td>
<td>Silt, clay</td>
<td>Aquafer</td>
</tr>
<tr>
<td></td>
<td>Eastend Fm</td>
<td></td>
<td></td>
<td>Aquitard</td>
</tr>
<tr>
<td></td>
<td>Bearpaw Fm</td>
<td></td>
<td></td>
<td>Aquitard</td>
</tr>
<tr>
<td></td>
<td>Judith River Fm</td>
<td></td>
<td></td>
<td>Aquitard</td>
</tr>
<tr>
<td></td>
<td>Lea Park Fm</td>
<td>Upper Colorado</td>
<td></td>
<td>Aquitard</td>
</tr>
<tr>
<td>Cretaceous</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Seismic and HRAM Correlation
75-Pattern Simulation Model and Results

CO₂ Global Mol. Fr.

End of EOR

Vertical/Horizontal Scale = 30/1

01/01/2034
CO₂ Distribution at end of EOR

@ 01 / 01 / 2034 (End of EOR)
Gas Saturation with Time

At the end of EOR

100 yrs after

2000 yrs after

5000 yrs after

Marly

Vuggy

Gas Saturation

0.0  0.16  0.32  0.48  0.64

www.energyinet.com
No gas and oil phases migrate into the Midale Evaporite over 5000 yrs.
4D-3C Time-Lapse Seismic Surveys
vs. Baseline survey (Sept. 2000)

Marly Zone

2001-2000

2002-2000
Amplitude anomalies at the Reservoir

2000-2001

0613
1613
0618
1612

1.3
0.4
1.6
1.3

2000-2002

3.2
0.4
3.0
2.4

Area proportional to net volume of CO₂ injected at time of monitor survey
Location of horizontal crosswell survey shown in Fig. 5.2.3.3
Dual-leg horizontal production well
Dual-leg horizontal injection well
Vertical well

1 km
Injected CO$_2$ Dissolution

$\delta^{13}$C$_{HCO_3}$ in produced fluids

Pre-injection

12 months

31 months

Injected CO$_2$ dissolution (decreasing $\delta^{13}$C in produced fluid)

Injected CO$_2$: $\delta^{13}$C = -34‰

$$\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}^+ + \text{HCO}_3^-$$
Beyond EOR

Total CO₂ Stored = 23.21 MT

- In Gas: 25.3%
- In Oil: 44.2%
- In Water: 30.5%

www.energynet.com
Dissolution in Oil: 28.0%
Solubility Trapping in Water: 0.3%
Ionic Trapping in Water: 27.5%
Mineral Trapping: 44.2%

Trapping Mechanisms
Bounding Seal Performance
Integrity Methodology

(loads)
PRESSURE
TEMPERATURE

CASING
ANNULUS
CEMENT
ANNULUS
ROCK

ADVECTION
DIFFUSION
AGING PROCESSES
HYDRATED CEMENT PARTICLE
AGED HYDRATED CEMENT PARTICLE

Dissolved CO2
P = Kh X (HENRY'S LAW)
(dissolution)

Gaseous CO2

Internal Filter Cake

www.energyinet.com
**RA Approaches**

- **Deterministic Risk Assessment (RA)** provides an estimate of risk associated with a specific set of parameter values.
- **Probabilistic Risk Assessment (PRA)** provides risk distribution attributed to the uncertainty in all parameter values.
Risk Assessment Methodology

- FEP’s (Features, Events and Processes)
- Systems Analysis
- Scenario Development
  - Base Scenario
  - Alternative Scenario’s
- Deterministic Risk Assessment
- Probabilistic Risk Assessment
Integration of Assessment Components

Transient Stage of Reservoir Pressure After EOR

\[ P_{\text{inj}} \approx 25 \text{ MPa} \]
\[ P_0 \approx 15 \text{ MPa} \]

ECLIPSE Simulation for 5000 yr period

CQUESTRA Simulation for 5000 yr period

Time period = ?
(determined from ECLIPSE simulation not from GEM simulation)

Wellbore Studies

Pinj \approx 25 \text{ MPa}
Po \approx 15 \text{ MPa}

GEM Simulation to end of EOR
GEM Simulation to pressure equilibration
GEM to ECLIPSE data transfer

ECLIPSE Simulation to pressure equilibration
ECLIPSE to CQUESTRA data transfer (AT PRESSURE EQUILIBRIUM)
Base Scenario

Spatial and temporal domain
- The main reservoir area is that part of the reservoir which will undergo EOR using injected CO2. The surrounding buffer zone is the area within 10 km of the main reservoir area.
- The time frame of concern starts from the inception of EOR using injected CO2 and extends out to 5,000 years.

Geologic formations
- The complete stratigraphic column.
- The caprock (the Midale Evaporite) may have natural fractures or discontinuities but all are isolated or sealed such that caprock integrity is not impaired.
- The base scenario will consider physical trapping features, which have naturally contained the oil/gas within the reservoir.
Base Scenario ...

Biosphere
- Extends to a depth of about 300 m below ground surface).
- The biosphere also includes soil, surface water and the atmosphere, and flora and fauna found within these areas.

Wells
- The base scenario includes the presence of all wells found within the scenario area.
- All wells have been deactivated following current standard field abandonment procedures applicable at the time of abandonment.

Other Features, Processes and Events
- The base scenario includes consideration of but are not limited to, processes such as hydrodynamics, geochemistry, buoyancy and density driven flow, dissolution of CO2 in water and residual oil, and pressure-temperature changes occurring within formations.
Alternative Scenarios

- Engineering options for EOR
- Reservoir operation options
- Well abandonment options
- Impact of salt dissolution
- Fault activation/re-activation
- Tectonic activity
- Human intrusion
CO₂ Movement in the Reservoir Plane

Reservoir boundary

- Initial
- 30 yrs
- 200 yrs
- 1800 yrs
- 3400 yrs
- 5000 yrs
CO₂ Migration Rate

- Migration within Midale Layers
- Migration into Geosphere above Midale
- Migration into Geosphere below Midale
- Average Pressure in the 75-Pattern Area

Time since end of EOR (yrs)

CO₂ Migration Rate (kg/yr)

Pressure (bar)
Conformance Control

Impact of conformance control treatment on two nearby producers

(a) 91/01-13-006-14W2

(b) 92/09-12-006-14W2

www.energyinet.com
Limitations and Barriers

- All activities must fit into oilfield operations and timing
- Sampling generally at surface not at reservoir pressures and temperatures
- Nature of the surface – climatic conditions
- Differences of opinion on value of research
- Research integration
- Four years of monitoring, how long is enough for some techniques?
- Public and regulator understanding limited.
Technically what stands out?

The value of the baseline survey to all subsequent work.
The value of existing information, core samples etc.
Understanding the long term storage capability of the caprock
The level of detail from the time-lapse seismic surveys.
Partial discrimination of the Marly from the Vuggy.
Seismic expression of CO₂ channels suggested.
The geological interpretation, particularly the upper geosphere and reservoir work. This includes understanding the aquifer-aquitard packages, fluid flows etc.
Geochemical interpretation, including the use of carbon as a tracer.
Technically where can we improve?

- There is much room to improve simulation.
- There is room to improve in the area of risk assessment.
- Improved understanding of fracture systems.
- Improved understanding of cement and wellbore integrity over time.
- Improved understanding of the biosphere and longer term issues with lower geosphere.
- Increased quantification of seismic results.
- Undertake risk assessment as a parallel not sequential activity.
- Improved integration of geological interpretation and monitoring.
Coal-Bearing Strata in the Alberta Basin

- Paskapoo Fm.
- Scollard Fm.
- Horseshoe Canyon Fm.
- Belly River Fm.
- Mannville Group

Coal-Bearing Strata
## Characteristics of Coal Bed Methane Plays in the Alberta Basin

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Shallow Basin</th>
<th>Deep Basin</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Depth</strong></td>
<td>300-1200 m</td>
<td>1200-3000 m</td>
</tr>
<tr>
<td><strong>Coal Thickness</strong></td>
<td>5-15 m</td>
<td>2-11 m</td>
</tr>
<tr>
<td><strong>Gas Content</strong></td>
<td>2-4 cm³/g</td>
<td>8-15 cm³/g</td>
</tr>
<tr>
<td><strong>Permeability</strong></td>
<td>1-10 md</td>
<td>&lt;0.1-2 md</td>
</tr>
<tr>
<td><strong>Water Flow</strong></td>
<td>Topography driven</td>
<td>Erosional rebound</td>
</tr>
<tr>
<td><strong>Water Salinity</strong></td>
<td>Fresh</td>
<td>Saline to brine</td>
</tr>
<tr>
<td><strong>Infrastructure</strong></td>
<td>Good</td>
<td>Good</td>
</tr>
</tbody>
</table>
Figure 4. Typical production curves for a coalbed methane well showing relative volumes of methane and water produced through time. Modified from Kuuskraa and Brandenburg (1989).
Canada ECBM Project in Alberta

ARC led Phases II & IIIA Pilot Site: Fenn Big Valley (Upper Mannville Coal)

Suncor led Phase IIIB Pilot Site: Red Deer Area (Ardley Coal)
Forecast Full-Field Development Production Numerical Modelling - 5-Spot Pattern

Nitrogen Injection
Excessive N₂ Production Terminate Injection
CO₂ Injection
CO₂ Breakthrough Terminate Project

Methane Production Rate

Time
Forecast Full-Field Development Production
Numerical Modelling - 5-Spot Pattern

**CO₂ Injection**

N₂ Injection

1/4 of 5-Spot Pattern

Constant Injection Rate
Location and Status of the Acid-Gas Injection Operations in the Alberta Basin, Canada
Acid Gas Disposal Targets

Acid Gas

mixing

Waste Water

$H_2S/CO_2$

$H_2O$

Aquifers

Enhanced Oil (EOR), Coalbed Methane (ECBM)

Depleted Oil & Gas

Gas (EGR), and Recovery

Reservoirs
In-Situ Gas Pressure and Temperature at Acid-Gas Injection Sites in Western Canada
Acid Gas Injection Projects

Depth vs. Wellhead Pressure for Western Canada

Depth m

0 1000 2000 3000 4000

Wellhead Pressure kPa

0 5000 10000 15000

Sleipner (Norway)
Cumulative Injection Rates for CO₂ and H₂S Actually Injected at Acid-Gas Disposal Operations in Western Canada
Cumulative Amount of CO₂ and H₂S Actually Injected at Acid Gas Disposal Operations in Western Canada
## Results

### Aquifer and Reservoir Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td>705 to 3475 m</td>
</tr>
<tr>
<td>Lithology</td>
<td>25 Carbonate 17 Sandstone</td>
</tr>
<tr>
<td>Net pay</td>
<td>3 to 100 m</td>
</tr>
<tr>
<td>Porosity</td>
<td>4 to 30 %</td>
</tr>
<tr>
<td>Permeability</td>
<td>1 mD to 10 D</td>
</tr>
<tr>
<td>Original pressure</td>
<td>5.9 to 36 MPa</td>
</tr>
<tr>
<td>Temperature</td>
<td>35 to 110 °C</td>
</tr>
</tbody>
</table>
### Results

**Licensed Operations**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{CO}_2$ fraction</td>
<td>15 to 98 %</td>
</tr>
<tr>
<td>$\text{H}_2\text{S}$ fraction</td>
<td>1 to 85 %</td>
</tr>
<tr>
<td>Maximum WHIP</td>
<td>3.75 to 21 MPa</td>
</tr>
<tr>
<td>Maximum BHIP</td>
<td>6.7 to 39 MPa</td>
</tr>
<tr>
<td>Maximum injection rate</td>
<td>2 to 391 ($10^3$ m$^3$/d)</td>
</tr>
<tr>
<td>Total injection volume</td>
<td>6 to 1,876 ($10^6$ m$^3$)</td>
</tr>
</tbody>
</table>
Conclusions

- 1.5 Mt CO₂ and 1 Mt H₂S have been successfully injected to date in the Alberta basin.
- Depth, pressure, temperature, porosity and permeability are characteristic of on-shore sedimentary basins in North America in areas with high CO₂ emissions.
- Confirmation of long-term storage predictions through monitoring is not currently in place.
Capacity

- EOR 638 megatonnes
- Depleted oil and gas pools 9,500 megatonnes in 35,000 pools
- ECBM 10,000 – 100,000 megatonnes
- Saline aquifers 100,000 – 1,000,000 megatonnes

After Shaw and Bachu, GHGT 7 paper, 2004
Experience

- EOR effective – but this is the “best” reservoir
- Monitoring appears effective
- Creation of good database for further work
- Acid gas injection effective way to remove $\text{H}_2\text{S}$
- No leaks apparent from current operations
- Preliminary tests on enhanced coal-bed methane suggest some prospects
Challenges

- Still much to do on data interpretation
- Risk assessment requires more effort – particularly in well-bore response
- Limited monitoring in acid gas injection situation
- Storage in coal – understanding in its infancy
- Regulation requires considerably more effort
- Communication of scale and opportunity needs to be clearly defined
QUESTIONS?