Leakage through Existing Wells: Models, Data Analysis, and Lab Experiments

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<table>
<thead>
<tr>
<th>Peter Jaffe</th>
<th>Rob Bruant</th>
<th>Andre Duguid</th>
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</thead>
<tbody>
<tr>
<td>Satish Myneni</td>
<td>Andrew Altevogt</td>
<td>Sarah Gasda</td>
</tr>
<tr>
<td>Catherine Peters</td>
<td>Mileva Radonjic</td>
<td>Li Li</td>
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<td>Jean Prevost</td>
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Outline

◆ Overview of activities in 2003
  – Continue focus on leakage and wells.
  – Refocus effort toward detailed studies of well cements.

◆ Brief presentation of selected results
  – Analysis of wells and tools for leakage estimation.
  – Unsaturated zone and responses to elevated CO$_2$.

◆ Cement studies (presented by G. Scherer)
  – New laboratory for cement experiments.
  – Design of experiments and preliminary results.
  – Focused activities for CY 2004 including local-scale modeling.
## Mature Sedimentary Basins: Analysis of Wells

### Viking Formation: 195,000 Wells

### Alberta Basin: 350,000 Wells

<table>
<thead>
<tr>
<th></th>
<th>Very High-Density (Heavy-oil)</th>
<th>High-Density</th>
<th>Medium-Density</th>
<th>Low-Density (Background)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of clusters</td>
<td>32</td>
<td>268</td>
<td>963</td>
<td>--</td>
</tr>
<tr>
<td>Number of wells [% total]</td>
<td>5.2</td>
<td>28.0</td>
<td>28.6</td>
<td>38.2</td>
</tr>
<tr>
<td>Area [% total]</td>
<td>0.1</td>
<td>2.7</td>
<td>10</td>
<td>87.2</td>
</tr>
<tr>
<td>Mean intrinsic density [wells/km²]</td>
<td>17.1</td>
<td>3.75</td>
<td>1.13</td>
<td>0.15</td>
</tr>
</tbody>
</table>

Note: The table shows the distribution of wells across different density categories in two major sedimentary basins. The Viking Formation has 195,000 wells, while the Alberta Basin has 350,000 wells. The densities are categorized into Very High-Density (Heavy-oil), High-Density, Medium-Density, and Low-Density (Background). The table includes the number of clusters, the percentage of wells, the area, and the mean intrinsic density for each category.
### Number of Wells Impacted by ‘typical’ Injection

<table>
<thead>
<tr>
<th>Density Type</th>
<th>Mean</th>
<th>Median</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-density clusters</td>
<td>241.5</td>
<td>216</td>
<td>45-721</td>
</tr>
<tr>
<td>Medium-density clusters</td>
<td>62.6</td>
<td>61</td>
<td>8-144</td>
</tr>
<tr>
<td>Low-density Background</td>
<td>17.8</td>
<td>11</td>
<td>0-130</td>
</tr>
</tbody>
</table>

*(Numbers from Gasda et al., 2003)*
CO$_2$ Injection and Leakage Pathways

- Numerical Simulations
- Analytical Solutions

Flow Dynamics

- Spatial Locations
- Well Properties
- Cement Degradation

Shallow-zone Effects
- Unsaturated Soils
- Groundwater Resources
Overview of Selected Results from 2003

- Simplified Solutions for CO₂ Transport and Leakage Estimation (3 Papers):
  - Analytical solutions to accommodate many potentially leaky wells and multiple geological layers.
  - Framework for linear equations (e.g., hazardous waste injection), showing importance of caprock thickness and storage in layers above injection.
  - Energy minimization arguments yield simple equations for evolution of CO₂ plume and pressure field; solution applies to all practical ranges of densities and viscosities (P,T,S) for CO₂ injection in aquifers.
  - Bounding calculations for leakage of brine and CO₂ through leaky well.
  - Comparisons to Eclipse show excellent match of results.
  - Ongoing extensions: Intersecting CO₂ plumes, variable density along the well, redistribution of CO₂ after cessation of injection.

- Unsaturated Zone Studies (2 Papers)
  - Modeling studies for CO₂ transport: dominant transport mechanisms.
  - Modeling studies of geochemical response to elevated CO₂ concentrations: evolving redox profiles.
  - Laboratory column study for geochemical tests.
New Analytical Solutions
New Analytical Solution: Two-Phase Flow

Analytical solution (sharp interface) versus Effective Saturation from Eclipse

Analytical solution:

\[
b(r,t) = \frac{1}{\lambda_c - \lambda_w} \left[ \sqrt{\frac{\lambda_c \lambda_w V}{\pi Br^2}} - \lambda_w \right]
\]

Solution includes unfavorable mobility ratio and gravity override.

Full Numerical Solution (from Eclipse)
Effect of CO₂ Leakage on the Redox Profile in the Vadose Zone

- **O₂ (mole/L)**
- **NO₃ (mole/L) x10⁻²**
- **Mn(IV) (mole/L) x10⁻⁴**
- **Fe(III) (mole/L) x10⁻⁴**
Ongoing Efforts for 2004

- Leakage Modeling for specific field site:
  - Apply numerical and analytical models to estimate leakage, coupled with well statistics for spatial locations.
  - Determine threshold statistics for well parameters associated with target leakage amounts.
  - Incorporate transient well parameters based on cement degradation estimates.

- Unsaturated Zone Studies:
  - Continue with laboratory column study.
  - Test models against laboratory data.

- Well-cement experiments and analysis will be the major effort for 2004.
General Overview of 2003 – Topics Covered

**Analysis of Well Statistics in Viking Formation, Alberta Basin:**


**Simplified Solutions for CO₂ Transport and Leakage Estimates:**


**Large-scale Compositional Simulations:**

General Overview of 2003 – Topics Covered

Shallow-zone Transport and Geochemistry:


Upscaling Studies: