Framework for Storage Risks and Risk Assessment in Geological Storage

Bill Senior
Senior CCS Solutions Ltd.
bill@senior-ccs.co.uk
Outline

1. Storage Risk Management Framework
2. Storage Risks
3. Injection Well Risks
Widespread acceptance that geological storage will be safe and effective is an essential goal

By all stakeholders:
- Public /Communities
- NGOs
- Industry
- Government/Regulators
EU CCS Directive (2009) is the framework for Regulatory Requirements in European countries

- **Article 1**
  
  The purpose of environmentally safe geological storage of CO₂ is permanent containment of CO₂ in such a way as to prevent and, where this is not possible, eliminate as far as possible negative effects and any risk to the environment and human health.

- A geological formation shall only be selected as a storage site, if under the proposed conditions of use there is no significant risk of leakage, and if no significant environmental or health risks exist.

- Annex I details Site Characterisation & Risk Assessment requirements
CO₂ Storage Life Cycle Risk Management Framework

- Focused on storage security/integrity and risks related to leakage
  - distinct from but overlapping Project Risk Management, Safety processes or Environmental Impact Assessment

- 3 Step Approach:
  1. Risk identification and assessment
  2. Risk ranking
  3. Risk management measures

- Iterative approach throughout lifecycle
How Long?

Pre-injection
3-15 Years

Injection
5-50 Years

P-C./Pre-T
~20 Years

?100’s
Years

Based on EC Guidance Document 1 (2010)
Risk identification and assessment:

- Risk = Probability x Consequence or Impact

1. Risk identification
   - Hazard identification
     - Leakage Pathways
     - Likelihood of Leak
     - Amount, Flux, Duration
     - Critical parameters
     - Secondary effects
   - Exposure assessment
   - Effects Assessment

2. Risk Ranking, e.g Matrix

3. Risk Management Measures
   - Impact on Risk

Originally from CO2QUALSTORE Report, DNV, 2009
Storage Risk Management is Ongoing, iterative and site specific

## Storage Risks

### Local Risks
- Public/Workforce Safety
- Environmental impacts
- Impacts to water, oil, gas or other resources, Assets
- Ground displacement/induced seismicity

### Global Risks
- Release of CO₂ from Storage to Atmosphere
- Storage may not be effective CO₂ mitigation

### Controls
- Movement, trapping and behaviour of CO₂ in the storage complex
- Leakage of CO₂ to shallow formations/biosphere
- Leakage pathways & mechanisms at the site
- Site characteristics (location, population density, etc)
- Exposure/Effects of CO₂ (toxicity, concentration, duration)
Main Leakage Pathways and Leakage mechanisms well understood

- **Geological**
  - Faults and Fractures
  - Seal or Caprock
  - Spill from Trap

- **Wells**
  - Abandoned wells
  - Injection operations

- **Other Manmade**
  - Mines, caverns
Trapping mechanisms lead to immobilisation of injected CO$_2$ on different timescales

Ref: IPCC Special Report on CCS, 2005

Ref: NETL, 2010-from US West Coast Regional Partnership
Well Leakage Risk Scenarios

Abandoned Wells

• Operations, Post Closure and Post-Transfer Phases
• Pre-existing wells (all types)
• Injection wells - once abandoned
• Leakage due to degradation of cement and well materials
• Pathways between/through cements, casings, well materials and formation

Injection Wells (Operational)

• Operations Phase only - not Post-closure
• Pathway through injection well tubing and/or behind production casing – potentially open
• Potential for uncontrolled release to surface or well blow out of CO₂ in worse case scenario

Potential leakage pathways along an existing abandoned well: between cement and casing (Paths a and b), through the cement (c), through the casing (d), through fractures (e), and between cement and formation (f) (Celia et al., 2004).
Analogue Data for Injection Well Leakage: Oil & Gas Release/Blowout Datasets

- **Oil & Gas Industry Dataset (OGP 2010)**
  - >36,000 wells
  - 50+Years
  - North Sea Standard (including Gulf of Mexico)

- **3 Categories of Release/Flow from Well (or between formations)**
  - **Blowouts**: after all the pre-defined technical barriers have failed
  - **Well release**: flow was stopped by use of the barrier system that was available on the well at the time of the incident
  - **Shallow gas releases**: where shallow gas zone has been penetrated before the Blowout Preventer (BOP) has been installed
### Analogue Data for Injection Well Leakage: Oil & Gas Blowout Frequencies

<table>
<thead>
<tr>
<th>Oil and Gas Blowout Frequency</th>
<th>Average Frequency</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development Drilling</td>
<td>6.0 x10^{-5}</td>
<td>4.9 x10^{-4}</td>
</tr>
<tr>
<td>Deep Normal wells</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Completions</td>
<td>9.7 x10^{-5}</td>
<td>3.9 x10^{-4}</td>
</tr>
<tr>
<td>Wirelining</td>
<td>6.5 x10^{-6}</td>
<td>1.1 x10^{-5}</td>
</tr>
<tr>
<td>Workovers</td>
<td>1.8 x10^{-4}</td>
<td>5.8 x10^{-4}</td>
</tr>
<tr>
<td>Gas Injection Wells</td>
<td>1.8 x10^{-5}</td>
<td>2.0 x10^{-5}</td>
</tr>
</tbody>
</table>

*Ref OGP 2010*

Excludes: Exploration Drilling, High Pressure, High Temperature, Production and Water Injection well categories
### Oil and Gas Blowout Duration

Calculation of expected blowout duration for a hypothetical conventional oil/gas well drilled in 337 metres of water in the Norwegian Sea using state-of-the-art technology and modern procedures.

<table>
<thead>
<tr>
<th>Duration (Days)</th>
<th>&lt;0.5</th>
<th>0.5-2</th>
<th>2-5</th>
<th>5-14</th>
<th>&gt;14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Topside (20%)</td>
<td>0.49</td>
<td>0.19</td>
<td>0.12</td>
<td>0.13</td>
<td>0.07</td>
</tr>
<tr>
<td>Subsea (80%)</td>
<td>0.33</td>
<td>0.2</td>
<td>0.14</td>
<td>0.16</td>
<td>0.17</td>
</tr>
</tbody>
</table>

- 56% Chance 2 Days or Less
- 15% Chance >14 Days

Ref EC 2011; Originally from Det Norske Veritas, Environmental Risk Assessment of Exploration Drilling in Nordland VI, Report No. 20/04/2010
Sheep Mountain CO2 Field
Colorado, USA

1982: Blow out of Development Well 4-15-H

- Loss of control while circulating with drill string in hole
- Flow of CO2 and solid dry ice
- Flowing at surface through fissures away from wellsite and offset well
- Underground blowout
- Initial well control methods unsuccessful
- Flowed for 17 days before well controlled and flow stopped
- Estimated flow rate of $90-200 \times 10^6$ scf/day
- $4,700-10,500$ Tonnes/day
- $\Rightarrow$ CO2 released $80-179,000$ Tonnes

Ref: Lynch et al, SPE 1983

- Natural CO2 Field
- Cretaceous Dakota Fm
- 2.5 Tcf Reserves
- Gas phase - 97% CO2
- Shallow reservoir (TVD 875m)
- CO2 produced for EOR in Permian Basin (West Texas)

Ref: Allis et al, 2001
Analogue Implications for CO₂ Injection Well Leakage

- CO₂ Leakage/blow out risk differs from Oil and Gas:
  - No CO₂ in reservoir at outset prior to start of injection and storage
  - Risk confined to areas where wells penetrate CO₂ plume
  - Normally dense phase CO₂ in reservoir during storage
  - Phase behaviour during release will be different
- CO₂ release/blow outs are a potential source of CO₂ leakage during injection (ie. Lifecycle Operations Phase)
  - Mainly related to Injection, Wirelining, Workover activities
  - May be high flux
  - Usually short duration
  - in worse case this may take 2-3 months where relief well required
- Risk depends on specific conditions (e.g. reservoir, well)
  - Plume, P/T, productivity, well design
- Risk management by drilling practises, standards & blow out controls
  - Leakage can be stopped and well remediated
Storage Risk - issues

- Need better quantification and prediction of:
  - probability of leakage,
  - potential flux rates, duration & amount
- Improve understanding:
  - dynamic controls
  - variation of risks with time
  - dispersion models
  - marine impacts
- Integration between technical assessments and commercial and regulatory aspects, for example relating to transfer of liability and financial security.

Risk Profile through CCS Lifecycle

Figure 1: Full quantitative risk profile through time for the In Salah CO₂ Storage Project. Risk Exposure and Time axes are in logarithmic scale. Vertical lines represent temporal end of lateral migration paths and end of injection. The red line is the cumulative risk profile for the project. All risks associated with well leakage (orange) and migration direction & exceeding spill point risks (blue) are grouped.

Ref Dodds et al, 2010
Summary

- Ongoing Risk Management an essential activity to ensure storage will be safe
- Storage risks well understood in general terms
- Generally dealing with very low probability hazards for well characterised sites
- Further work to develop capability and case studies, particularly to improve quantification and assessment of risks through time and for wells during operational phase
Contact Details

- Bill Senior
- Senior CCS Solutions Ltd
- bill@senior-ccs.co.uk
Disclaimer

While Senior CCS Solutions Ltd consider that the data and opinions contained in this presentation are sound, all parties must rely upon their own skill and judgement when using it. The author does not make any representation or warranty, expressed or implied, as to the accuracy or completeness of the presentation. Senior CCS Solutions Ltd assume no liability for any loss or damage arising from decisions made on the basis of this presentation.