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The Quest project

- CO2 capture from 3 hydrogen manufacturing units at the Scotford Upgrader, with an average expected rate of 3000 tonnes/day.
- CO2 compressed to about 10 MPa so that it is in dense phase throughout the system.
- Compressor includes dehydration to minimize the amount of water in the system.
- 65 km pipeline with 6 block valves (every 4-15 km).
- Currently injecting into two wells at less than 1 MPa above background reservoir pressure (third well provides contingency).
- Total injected volume through to today is more than 1,000,000 tonnes.
An Opening Thought

“Probability is not really about numbers; it is about the structure of reasoning”

Pearl, Shafer; 1983

“Perhaps the most important aspect is not the probability number, but the evidence and reasoning it summarizes”

North; 1995
## Site Selection: Risk Elimination

### Selection criteria, scores and rational -> targets risk reduction

- Eliminate or Isolation from key risks
- Favourable ranking of site “A” (lowering risk) choice over “B” or “C”, even at higher cost
- Better ability to engineer and control safeguards (MMV and site operations)

### Selection Criteria

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Selection Rationale</th>
<th>Option</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Containment</strong></td>
<td>Thickening seals updip</td>
<td>++</td>
</tr>
<tr>
<td></td>
<td>Legacy wells</td>
<td>++</td>
</tr>
<tr>
<td><strong>Capacity</strong></td>
<td>BCS thickening E-NE</td>
<td>+</td>
</tr>
<tr>
<td><strong>Injectivity</strong></td>
<td>BCS reservoir quality</td>
<td>++</td>
</tr>
<tr>
<td><strong>MMV</strong></td>
<td>Better access and less interference</td>
<td>++</td>
</tr>
<tr>
<td><strong>Pore Space Access</strong></td>
<td>Freehold –vs-crown</td>
<td>++</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>Most proximal site</td>
<td>+</td>
</tr>
<tr>
<td><strong>Growth</strong></td>
<td></td>
<td>++</td>
</tr>
</tbody>
</table>

### Action Measures

#### Eliminate
- Eliminate – Eliminate the hazard

#### Substitute
- Substitute - Use processes or methods with lower risk impact

#### Isolate/Separate
- Isolation / Separation – Segregate hazards and/or targets

#### Engineered Safeguards
- Engineered Safeguards –
  - **PREVENTION**
    - Design to prevent an unwanted event
  - **RECOVERY**
    - Design to mitigate harmful consequences

#### Organisational Controls
- Training, Competency, Communication

#### Procedural Controls
- Operating procedures, Work instructions, Permits
- Maintenance regimes
- Emergency Response procedures

#### Personal Protective Equipment
- Protect the person

---

**Most Effective**

**Least Effective**
Screening Stage

Define screening basis

Pre-feasibility

Develop screening plan

Review available data and identify potential sites

Feasibility

Estimate capacity and level of uncertainty

Identification and assessment of uncertainty and risks

Select site(s) for assessment. Produce Screening Report

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QUEST Site Selection

Selection based on many factors:

Reservoir quality, seal placement, fractures/ faults, predicted pressure response, stakeholder concerns, legacy wells, ability to conduct MMV…

September 2016
## Subsurface Risks And Uncertainties

<table>
<thead>
<tr>
<th>Risk Group</th>
<th>Risk Description</th>
<th>Key Uncertainty</th>
<th>Addressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wells</td>
<td>Loss of Containment Through Wells</td>
<td>Ability to drill &amp; cement gauge hole DTS (for leak detection) Integrity of Legacy Wells</td>
<td>3rd Well 3rd Well Study in Progress</td>
</tr>
<tr>
<td>Containment</td>
<td>LoC through the Subsurface</td>
<td>Structural interpretation Regional correlation of seals Geomechanics</td>
<td>HRAM, 2D,3D, VSP 2D, logs Core, logs</td>
</tr>
<tr>
<td>Injectivity</td>
<td>Non-commercial rates of injection</td>
<td>Permeability height (Kh) Skin Non-Darcy skin, relative permeability Connected volume CO₂ injectivity</td>
<td>H₂O inj. test H₂O inj. test No, SCAL (core) HRAM, 2D, 3D CO₂ inj. test</td>
</tr>
<tr>
<td>Capacity</td>
<td>Low connected pore volume</td>
<td>Compartmentalisation Reservoir properties (h, N/G, phi &amp; cr)</td>
<td>HRAM, 3D, ext.H₂O inj. test 3rd well, core</td>
</tr>
<tr>
<td>MMV</td>
<td>Conformance risk</td>
<td>Unexpected plume migration Differentiation CO₂ contamination Detectability</td>
<td>HRAM, 2D, 3D, 3rd well Water sampling ....... MDT, sampling, INSAR</td>
</tr>
</tbody>
</table>
Managing Risk – The Bowtie Concept

What barriers and controls are there to prevent the event happening, or escalating?

UNWANTED EVENT

Prevention (proactive)
reduce likelihood of harmful event

Control and Recovery (reactive)
limit and mitigate consequence, re-instate

Likelihood

Consequence

No escalation giving least potential impact

Full escalation giving largest potential impact

September 2016
Bow-tie: CCS Storage Containment Risk Example

Legend

- **Passive** safeguards; these are always present
- **Active** safeguards; these are only present when a decision to intervene is made triggered by monitoring information
Systematic Evaluation of Passive Safeguards

- Evidence based using collective expert judgement (internal and external)
- Informed by appraisal data and site characterization studies
- Subject to independent expert review
- May steer further studies/ data gathering to reduce white space

<table>
<thead>
<tr>
<th>Threats</th>
<th>Safeguard</th>
<th>Evidence For</th>
<th>Evidence Against</th>
<th>EF</th>
<th>EA</th>
</tr>
</thead>
</table>
| Migration along a legacy well  | Injectors located away from legacy | 1. IHS database identifies legacy wells  
2. Shortest offset distance is 21km | 1. IHS database may not be complete  
2. IHS database may be inaccurate | 0.8 | 0.1 |
| Drilling mud forms impermeable plug | 1. Weighted drilling fluid used  
2. Settlement creates low K filtrate plug  
3. Plug forms at bottom hole over several | 1. Plug may not cover first seal | 0.4 | 0.2 |
| Lotsberg salt creep seals borehole | 1. Open-hole over Lotsberg salts  
2. Documented shrinkage in LPG caverns  
3. Small hole (<10 in) - long time (50 yr)  
4. Thick salt layers (55-127 m)  
5. Greater than 90% halite | 1. None | 0.7 | 0.0 |
| Cement plugs                   | 1. Well abandonment and drilling reports  
2. Four wells with plugs inside BCS complex | 1. No positive pressure test results reported  
2. Cement may degrade over c. 50 years  
3. Darling lacks plugs in storage complex | 0.3 | 0.4 |
MMV – Risk Analysis & Mitigation

Establish Monitoring Requirements → MMV Design → Identify Risks → Implement Safeguards → MMV Plan

Select Monitoring Plans

Establish Performance Targets

Identify Contingency Monitoring

Identify Control Measures

Evaluate these Additional Safeguards

Storage Risks Acceptable?

Risk-Based
- Verify geological & engineered safeguards
- Reduce containment risk to ALARP

Site-Specific
- Tailor-made monitoring
- Informed by appraisal data

Adaptive
- Respond to observed performance
- Contingency plans in place

Risk Evaluation

Risks reduced to ALARP

DOMAINS

Atmosphere

Hydrosphere (film)

Geosphere (brine)

Risk-Basesd

Site-Specific

Adaptive
Active Safeguards: Risk Profile

- Informed by appraisal data and feasibility studies
- Based on collective expert judgement
Performance & Closure

The Government or Regulators View Of Remaining Risk

Closure Plan Outline

- Intro
- Project Overview
- Storage Performance Tasks for Site Closure
  - CCS Targets from the Regulator
- Storage Performance Data
  - Well inventory
  - CO2 inventory
  - Containment Performance
  - Conformance Performance
- Operating Plan Updates
  - SDP changes
  - MMV changes
- Proposed Closure Activities
  - Storage site reclamations
  - Well decommissioning
- Site Closure Certification
  - Post-closure monitoring
  - Transfer of infrastructure
- Reporting & Documentation
Summary

Risk & Uncertainty needs to be addressed at every phase of the project:

- Site Selection – Elimination/Isolation/Reduction from risk
- Site Characterization – Reduction in uncertainty and remaining risk
- MMV/Injection – Risk monitoring and mitigation
- Site Closure – Verification & Liability Transfer

Different stakeholders will focus on different risk elements

- Landowners – HSSE, Containment
- Government, Regulator – HSSE, Containment, Capacity and Long Term Liability
- Management – HSSE, Containment, Capacity, Long Term liability, Injectivity, Financially Sound

An Industrial Scale Integrated project needs to manage all risks to ALARP
A Final Thought

“Probability is not really about numbers; it is about the structure of reasoning”

………………Judea Pearl, Glen Shafer; 1983 - Defaults & Probabilities, Extensions & Coherence

“Perhaps the most important aspect is not the probability number, but the evidence and reasoning it summarizes”………Oliver North; 1995