CARBON CAPTURE AND STORAGE
STORAGE RISK: ASSESSMENT AND
MITIGATION

IEAGHG Summer School
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Simon O’Brien
Quest Storage Manager
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The scale of the challenge

Contribution of technology area to global cumulative $\text{CO}_2$ reductions

<table>
<thead>
<tr>
<th>Year</th>
<th>Renewables</th>
<th>Energy efficiency</th>
<th>Fuel switching</th>
<th>Nuclear</th>
<th>CCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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<td>2020</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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<td>2030</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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<td>2050</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

The carbon intensity of the global economy can be cut by two-thirds through a diversified energy technology mix

http://www.iea.org/etp/etp2016/
Shell’s Response to the CO2 Challenge

Natural Gas

BIOFUELS

Efficiency

Carbon Capture & Storage
THE ATHABASCA OIL SANDS PROJECT (AOSP)

Muskeg River Mine

Corridor Pipeline

Scotford Upgrader

Scotford Refinery (Shell Only)

Quest: CO2 Capture from 3 HMUs

Bitumen

Bitumen to Synthetic crude (255,000 bpd)

H2
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 the end of June, 2016 is almost 900,000 tonnes.
The BCS Storage Complex

- Deep (~2km) saline aquifer
- Below potable water zones, zones with hydrocarbon potential
- Multiple thick, continuous seals (>150m within the complex)
- High quality (~17% porosity) sandstone reservoir
- Excellent permeability (~1000mD)

<table>
<thead>
<tr>
<th>Depth</th>
<th>Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>85m</td>
<td>Prairie Evaporite</td>
</tr>
<tr>
<td>85m</td>
<td>Upper Lotsberg Salt</td>
</tr>
<tr>
<td>10m</td>
<td>Lower Lotsberg Salt</td>
</tr>
<tr>
<td>70m</td>
<td>Upper Cambrian Shale</td>
</tr>
<tr>
<td>40m</td>
<td>Basal Cambrian Sand</td>
</tr>
<tr>
<td></td>
<td>PreCambrian Shield</td>
</tr>
<tr>
<td></td>
<td>BCS Storage Complex</td>
</tr>
</tbody>
</table>
QUEST SITE SELECTION

Sequestration Lease area = 3670 km$^2$

Selection based on many factors:
- Reservoir quality
- Seal placement
- Fractures/faults
- Predicted pressure response
- Stakeholder concerns
- Legacy wells ...
## CCS Site Selection: Screening Criteria

<table>
<thead>
<tr>
<th>Criterion Level</th>
<th>No.</th>
<th>Criterion</th>
<th>CO2 Storage Property or Attribute</th>
<th>Preferred or favourable</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Critical</strong></td>
<td>1</td>
<td>Reservoir Seal Pairs, extensive and competent barrier to vertical flow</td>
<td>Poor discontinuous, faulted and/or breached</td>
<td>Intermediate and excellent, many pairs (multi-layered system)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Pressure regime</td>
<td>Overpressure, pressure gradients greater than 14 kPa/m</td>
<td>Pressure gradients less than 12 kPa/m</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Monitoring potential</td>
<td>Absent</td>
<td>Present</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Affecting protected groundwater quality</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td><strong>Essential</strong></td>
<td>5</td>
<td>Seismicity</td>
<td>High</td>
<td>Moderate or less</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Faulting &amp; fracturing</td>
<td>Extensive</td>
<td>Limited to moderate</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Hydrogeology</td>
<td>Short flow systems or compaction flow. Saline aquifers in communication with protected groundwater acquifers</td>
<td>Intermediate and regional scale flow</td>
</tr>
<tr>
<td><strong>Desirable</strong></td>
<td>8</td>
<td>Depth</td>
<td>&lt;750-800m</td>
<td>&gt; 800m</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>Located within fold belts</td>
<td>yes</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>Adverse diagenesis</td>
<td>Significant</td>
<td>Low to moderate</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>Geothermal regime</td>
<td>Gradients &gt;35 degC/km and/or high surface temperature</td>
<td>Gradients &lt;35 degC/km and low surface temperature</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>Temperature</td>
<td>&lt;35 deg C</td>
<td>&gt;35 deg C</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>Pressure</td>
<td>&lt; 7.5 Mpa</td>
<td>&gt; 7.5 Mpa</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>Thickness</td>
<td>&lt; 20m</td>
<td>&gt; 20m</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>Porosity</td>
<td>&lt; 10%</td>
<td>&gt; 10%</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>Permeability</td>
<td>&lt; 20mD</td>
<td>&gt; 20mD</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>Caprock thickness</td>
<td>&lt; 10m</td>
<td>&gt; 10m</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>Well Density</td>
<td>High</td>
<td>Low to moderate</td>
</tr>
</tbody>
</table>

Ref: Bachu et al, 2003

**Pick the right site:** MINIMIZE YOUR RISK
Risk Analysis: The Full Project Lifecycle

Pre-Injection
- Site Selection
- Characterisation & Baseline data collection

Injection
- Monitor to Verify Site Performance

Closure
- Monitor to Inform Site Closure Process

Post-Closure
- Minor Project Monitoring May Be Needed

Ref: Benson, 2007
## Subsurface Risks and Uncertainties

<table>
<thead>
<tr>
<th>Risk Group</th>
<th>Risk Description</th>
<th>Key Uncertainty</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>
</tr>
<tr>
<td>Containment</td>
<td>LoC through the Subsurface</td>
<td>Structural interpretation Regional correlation of seals Geomechanics</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>
</tr>
<tr>
<td>Capacity</td>
<td>Low connected pore volume</td>
<td>Compartmentalisation Reservoir properties (h, N/G, phi &amp; cr)</td>
</tr>
<tr>
<td>MMV</td>
<td>Conformance risk</td>
<td>Unexpected plume migration Differentiation CO2 contamination Detectability</td>
</tr>
</tbody>
</table>
RISK REDUCTION: ITERATIVE DESIGN PROCESS

Risk-Based Decision making

- Identify risks
- Address uncertainty
  - Data collection & Analysis
  - Modelling
- Design safeguards
  - Passive (e.g. site selection)
  - Active (e.g. well remediation)
- Understand remaining uncertainty
- Decide whether further action required

Make Decision
Identify Risks
Implement Safeguards
Risk Evaluation

Risks reduced to ALARP
RISK & UNCERTAINTY MANAGEMENT FRAMEWORK

ALARP Risks
Bowtie Analysis

Uncertainty Management
TESLA

Risk Management
EASYRISK

- Evidence For
- Uncertainty
- Evidence Against

- Prevention & Recovery
- Barriers – Passive & Active
- Hardware or Processes

- Data Collection
- Analysis
- Understanding

- Workflow
- Modelling
- Engineering
MANAGING RISK – THE BOWTIE CONCEPT

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

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

THREATS

BARRIERS

UNWANTED EVENT

SCENARIO

Shell Canada Energy
July, 2016
BOW-TIE CCS STORAGE CONTAINMENT RISK EXAMPLE

**Passive safeguards:**
- Cement
- Completion design

**Active safeguards:**
- Monitoring
- Well repair/abandonment

**Unwanted Event:**
Loss of Containment
CO₂ migrates out of primary store

**Passive safeguards:**
- Seals above store
- Chem reactions

**Active safeguards:**
- Monitoring
- Barriers to protect groundwater

**Legend**
- Passive safeguards; these are always present
- Active safeguards, these are only present when a decision to intervene is made triggered by monitoring information
CCS SEQUESTRATION WORKFLOW (QUEST)

Communication and Consultation
Company, Government, Regulator, Landowners ….

Site Characterisation
- Evaluate Storage Feasibility
- Select Storage Site
- Evaluate Site-Specific Storage Risks
- Characterise Geological Safeguards
- Select Engineered Safeguards
- Evaluate these Initial Safeguards
- Storage Risks Suitable?

MMV Plan
- Establish Monitoring Requirements
- Select Monitoring Plans
- Establish Performance Targets
- Identify Contingency Monitoring
- Identify Control Measures
- Evaluate these Additional Safeguards
- Storage Risks Acceptable?

Performance Review & Site Closure
- Evaluate Monitoring Performance
- Adapt Monitoring Plans
- Storage Performance Acceptable?
- Evaluate Storage Performance
- Implement Control Measures
- Storage Performance Acceptable?
- Site Closure

Shell Canada Energy
July, 2016
## Site Selection: Risk Analysis & Mitigation

### Site Specific:
- **Risk Profile**
- **Uncertainty Profile**

### Capacity, Injectivity, Containment, MMV

<table>
<thead>
<tr>
<th>CO2 Storage</th>
<th>Advantages</th>
<th>Issues</th>
<th>Field Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>EGR &amp; EOR</td>
<td>Increases HC recovery &amp; economic gain</td>
<td>Timing</td>
<td>Weyburn</td>
</tr>
<tr>
<td></td>
<td>HC Seal Proven</td>
<td>Recycled CO2 injection profile</td>
<td>Salt Creek</td>
</tr>
<tr>
<td></td>
<td>Data &amp; knowledge rich area</td>
<td>Well count/integrity</td>
<td>K12B</td>
</tr>
<tr>
<td></td>
<td>Common Practise in O&amp;G industry</td>
<td>CO2 remains mobile</td>
<td>Denver unit</td>
</tr>
<tr>
<td>Depleted Fields</td>
<td>Production license period ended</td>
<td>Timing</td>
<td>In Saleh</td>
</tr>
<tr>
<td></td>
<td>HC Seal Proven</td>
<td>Well count/integrity</td>
<td>Peterhead/Goldeneye</td>
</tr>
<tr>
<td></td>
<td>Data &amp; knowledge rich area</td>
<td>Repressurisation pore collapse</td>
<td>Miller</td>
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<tr>
<td></td>
<td>Monitoring wells use legacy wells</td>
<td>Storage Capacity</td>
<td>LaBarge</td>
</tr>
<tr>
<td>Saline Aquifers</td>
<td>Timing</td>
<td>Data &amp; knowledge availability</td>
<td>Sleipner</td>
</tr>
<tr>
<td></td>
<td>Large Potential Storage Capacity</td>
<td>Sustained Injectivity</td>
<td>Snovt</td>
</tr>
<tr>
<td></td>
<td>Few wells acting as potential leak paths</td>
<td>Plume development &amp; Monitoring</td>
<td>Frio</td>
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<tr>
<td></td>
<td>Enhanced Residual &amp; Dissolution trapping</td>
<td>Seal extent/integrity</td>
<td>Otway</td>
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</tbody>
</table>
**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>Threat</th>
<th>Safeguard</th>
<th>Evidence For</th>
<th>Evidence Against</th>
<th>EF</th>
<th>EA</th>
</tr>
</thead>
<tbody>
<tr>
<td>T6</td>
<td>Induced stress re-activates a fault</td>
<td>Select site with no natural seismicity</td>
<td>1. No recorded seismicity within AOR&lt;br&gt;2. Central Alberta is tectonically stable&lt;br&gt;3. No faults seen in overburden&lt;br&gt;4. Faults not critically stressed before injection</td>
<td>1. Past may not indicate future seismicity</td>
<td>0.6</td>
</tr>
<tr>
<td>B6.1</td>
<td>Select site away from known faults</td>
<td>1. No faults through seals on 2D/3D seismic</td>
<td>1. Not all faults (offsets&lt;20m) identified&lt;br&gt;2. Widespread basement faults; offsets&lt;20m&lt;br&gt;3. Reactivated fault may grow upwards</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>B6.2</td>
<td>Select max injection pressure using geomechanics</td>
<td>1. Inject at &gt;14MPa below BCS fracture pressure&lt;br&gt;2. Fault-normal stresses remain compressive&lt;br&gt;3. Compressor &amp; pipeline rated to 14.5MPa</td>
<td>1. Injection induces shear stress on faults</td>
<td>0.6</td>
<td>0.2</td>
</tr>
<tr>
<td>B6.3</td>
<td>Lower Lotsberg - Reseals fault</td>
<td>1. Salt creep re-seals fault after slippage&lt;br&gt;2. Expected salt thickness is 2-36 m</td>
<td>1. Pinches out beyond the SW edge of AOI&lt;br&gt;2. Salt creep may take years to re-seal fault</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td>B6.4</td>
<td>Upper Lotsberg - Reseals fault</td>
<td>1. Salt creep re-seals fault after slippage&lt;br&gt;2. Expected salt thickness is 53-91 m</td>
<td>1. Salt creep may take years to re-seal fault</td>
<td>0.3</td>
<td>0.3</td>
</tr>
</tbody>
</table>
SAFEGUARD EFFECTIVENESS

MOST EFFECTIVE

Eliminate
- Eliminate the hazard

Substitute
- Use processes or methods with lower risk

Isolate/Separate
- Segregate hazards and/or targets

Engineer

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

Organization

Organisational Controls –
- Training, Competency, Communication

Procedures

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

PPE

Personal Protective Equipment –
- Protect the person

LEAST EFFECTIVE
PASSIVE SAFEGUARDS: RISK PROFILE

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

![Risk Profile Diagram]

- Risk Metric: Number of Safeguards
- 1 in 10^4 per year
- 1 in 10^6 per year

- Passive safeguards

- Tolerable
- Broadly Acceptable
- Unacceptable
MMV – RISK ANALYSIS & MITIGATION

Establish Monitoring Requirements
Select Monitoring Plans
Establish Performance Targets
Identify Contingency Monitoring
Identify Control Measures
Evaluate these Additional Safeguards

Storage Risks Acceptable?

no

yes

MMV Design
Identify Risks
Implement Safeguards
Risk Evaluation

Risks reduced to ALARP

- 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
### SYSTEMATIC EVALUATION OF MMV TECHNOLOGIES

- Evidence-based using collective expert judgement
- 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>Task</th>
<th>Technology</th>
<th>Indicator</th>
<th>Evidence For</th>
<th>Evidence Against</th>
<th>EF</th>
<th>EA</th>
</tr>
</thead>
</table>
| 6 Detect fault reactivation | DHPT | Down-hole pressure-temperature gauge in a WPGS observation well | Sustained Winnipegosis pressure increase detected by down hole pressure gauge | 1. Industry standard technology  
2. Continuous monitoring  
3. Early warning before brine or CO2 arrives  
4. Sensitive to low flux rates (1 ppm)  
5. Detection within 1-6 months | 1. Gauge drift may mask indicator  
2. Natural changes may mask indicator  
3. WPGS pressure barriers may mask indicator  
4. WPGS permeability may be insufficient | 0.8 | 0.1 |
| | DHMS | Down-hole microseismic monitoring | A sustained cluster of microseismic events located above the primary seal that migrates upwards with time | 1. Industry standard technology  
2. Continuous monitoring  
3. Detect magnitude -3 events up to 600m away  
4. Event location error c. 10-20 m | 1. Not all fault slip creates microseismic events  
2. Not all microseismic events are detectable | 0.7 | 0.2 |
| | INSAR | InSAR - Interferometric Synthetic Aperture Radar | Short spatial wavelength surface uplift anomaly around a potential fault | 1. Detects dilation of any shallow formation  
2. Sensitive to uplifts >1mm/year  
3. Monthly monitoring over entire AOR | 1. Natural monitoring targets maybe limited  
2. Cannot monitor through snow cover | 0.6 | 0.2 |
| | SEIS3D | Time-lapse surface 3D seismic | Appearance of an amplitude anomaly above the primary seal around a potential fault | 1. Areal coverage over entire CO2 plume  
2. Expect to image the CO2 plume  
3. Lateral resolution c. 25 m  
4. Vertical resolution c. 10 m | 1. No sensitivity expected to brine migration  
2. Acquisition noise may mask indicator  
3. Only monitor every few years  
4. Leak may go undetected for years  
5. Unable to detect CO2 leaks <10-60 ktonnes | 0.3 | 0.3 |
CONCEPTUAL MMV PLAN

**DOMAINS**

- **Atmosphere**
  - LoSCO$_2$
  - ESS
  - SPH
  - SSAL

- **Hydrosphere (Fresh)**
  - Tracers (artificial)
  - Tracers (natural)
  - CBL
  - Waterchem
  - WEC
  - WPH

- **Geosphere (brine)**
  - INSAR
  - 3D Seismic
  - 3D VSPs

- **Wells Injector Monitoring well**
  - CBL
  - DH microseis
  - DHPT
  - CBL
  - DAS/DTS
  - DHPT
  - MVT
  - Tracer
  - USIT
  - WHP, Q, CO$_2$
**QUEST MMV PLAN 2015**

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Injection</th>
<th>Closure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Atmosphere</strong></td>
<td>LightSource Laser CO2 Monitoring</td>
<td>Eddy Covariance Flux Monitoring</td>
<td>?</td>
</tr>
<tr>
<td><strong>Biosphere</strong></td>
<td>CO2 Natural Tracer Monitoring</td>
<td>CO2 Flux and Soil Gas</td>
<td>Remote Sensing (Brine &amp; NDVI)</td>
</tr>
<tr>
<td><strong>Hydrosphere</strong></td>
<td>Shell Groundwater Wells: Continuous EC, pH</td>
<td>Discrete Chemical and Isotopic Analysis on water and gas</td>
<td>Private Landowner Groundwater Wells (discrete chemistry and Isotopes on water and gas)</td>
</tr>
<tr>
<td><strong>Geosphere</strong></td>
<td>?</td>
<td>Time-Lapse Walkaway VSP Surveys</td>
<td>Time-Lapse 3D Surface Seismic</td>
</tr>
<tr>
<td><strong>Deep Monitoring Wells</strong></td>
<td>Downhole Pressure &amp; Temperature (DHPT) above Storage Complex (CKLK Fm)</td>
<td>Downhole Microseismic Monitoring</td>
<td>InSAR</td>
</tr>
<tr>
<td><strong>Injection Wells</strong></td>
<td>Injection Rate Metering, RST Logging, Temperature logging</td>
<td>DHPT, Well Head PT, Distributed Temperature and Acoustic Sensing, Annulus Pressure Monitoring, Wellhead CO2 Sensor, Mechanical Well Integrity Testing, Operational Integrity Assurance</td>
<td>CBL, USIT</td>
</tr>
</tbody>
</table>

Time (years):

- 2010
- 2015
- 2020
- 2025
- 2030
- 2035
- 2040
- 2045
- 2050
A sensor capable of detecting changes with sufficient sensitivity and reliability to provide an early warning

Decision logic to interpret the sensor data and select the most appropriate form of intervention

A control response to ensure continuing containment or to control any potential loss of containment

Is it fast enough, precise enough and big enough? Can we react to the changes detected?
## Preventative Controls

### Injection Controls
- **IC1** Re-distribute injection across existing wells
- **IC2** Drill new vertical or horizontal injectors
- **IC3** Extract reservoir fluids to reduce pressure
- **IC4** Stop injection

### Well Interventions
- **WI1** Repair leaking well by re-plugging with cement
- **WI2** Repair leaking injector by replacing completion
- **WI3** Plug and abandon leaking wells that cannot be repaired

## Corrective Controls

### Well Interventions
- **RM1** Repair leaking well by re-plugging with cement
- **RM2** Repair leaking injector by replacing completion
- **RM3** Plug and abandon leaking wells that cannot be repaired

### Exposure Controls
- **RM4** Inject fluids to increase pressure above leak
- **RM5** Inject chemical sealant to block leak
- **RM6** Contain contaminated groundwater with hydraulic barriers
- **RM7** Replacement of potable water supplies

### Remediation Measures
- **RM8** Pump and Treat
- **RM9** Air Sparging or Vapour Extraction
- **RM10** Multi-phase Extraction
- **RM11** Chemical Oxidation
- **RM12** Bioremediation
- **RM13** Electrokinetic Remediation
- **RM14** Phytoremediation
- **RM15** Monitored Natural Attenuation
- **RM16** Permeable Reactive Barriers
- **RM17** Treat acidified soils with alkaline supplements
ACTIVE SAFEGUARDS: RISK PROFILE

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

![Graph showing risk profile with passive and active safeguards]
## 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>3&lt;sup&gt;rd&lt;/sup&gt; Well 3&lt;sup&gt;rd&lt;/sup&gt; 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 CO&lt;sub&gt;2&lt;/sub&gt; injectivity</td>
<td>H&lt;sub&gt;2&lt;/sub&gt;O inj. test H&lt;sub&gt;2&lt;/sub&gt;O inj. test No, SCAL (core) HRAM, 2D, 3D CO&lt;sub&gt;2&lt;/sub&gt; 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.H&lt;sub&gt;2&lt;/sub&gt;O inj. test 3&lt;sup&gt;rd&lt;/sup&gt; well, core</td>
</tr>
<tr>
<td>MMV</td>
<td>Conformance risk</td>
<td>Unexpected plume migration Differentiation CO&lt;sub&gt;2&lt;/sub&gt; contamination Detectability</td>
<td>HRAM, 2D, 3D, 3&lt;sup&gt;rd&lt;/sup&gt; well Water sampling ........ MDT, sampling, INSAR</td>
</tr>
</tbody>
</table>
Performance Review & Site 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 reclamation
  - 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 – Reduction/elimination/isolation from risk
  • Site Characterization – Reduction in uncertainty and remaining risk
  • MMV/Injection – Risk monitoring and mitigation
  • Site Closure – 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 address all risks to ALARP
QUEST – 9 MONTHS PERFORMANCE

- Several minor start up hiccups
- Remarkably stable injection
- On target for a million tonnes in first year