QUEST Carbon Capture and Storage

Risk-Based Measurement, Monitoring & Verification

Session 6: Monitoring Performance
IEAGHG Risk Network Meeting
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Shell Canada Energy
Quest Subsurface Team
The companies in which Royal Dutch Shell plc directly and indirectly owns investments are separate entities. In this presentation "Shell", "Shell group" and "Royal Dutch Shell" are sometimes used for convenience where references are made to Royal Dutch Shell plc and its subsidiaries in general. Likewise, the words "we", "us" and "our" are also used to refer to subsidiaries in general or to those who work for them. These expressions are also used where no useful purpose is served by identifying the particular company or companies. "Subsidiaries", "Shell subsidiaries" and "Shell companies" as used in this presentation refer to companies in which Royal Dutch Shell either directly or indirectly has control, by having either a majority of the voting rights or the right to exercise a controlling influence. The companies in which Shell has significant influence but not control are referred to as "associated companies" or "associates" and companies in which Shell has joint control are referred to as "jointly controlled entities". In this presentation, associates and jointly controlled entities are also referred to as "equity-accounted investments". The term "Shell interest" is used for convenience to indicate the direct and/or indirect (for example, through our 24% shareholding in Woodside Petroleum Ltd.) ownership interest held by Shell in a venture, partnership or company, after exclusion of all third-party interest.

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The United States Securities and Exchange Commission (SEC) permits oil and gas companies, in their filings with the SEC, to disclose only proved reserves that a company has demonstrated by actual production or conclusive formation tests to be economically and legally producible under existing economic and operating conditions. We use certain terms in this presentation, such as resources and oil in place, that SEC’s guidelines strictly prohibit us from including in filings with the SEC. U.S. Investors are urged to consider closely the disclosure in our Form 20-F, File No 1-32575, available on the SEC website www.sec.gov. You can also obtain these forms from the SEC by calling 1-800-SEC-0330.
Definitions and Cautionary Note

Reserves: Our use of the term "reserves" in this presentation means SEC proved oil and gas reserves for all 2009 and 2010 data, and includes both SEC proved oil and gas reserves and SEC proven mining reserves for 2008 data.

Resources: Our use of the term "resources" in this presentation includes quantities of oil and gas not yet classified as SEC proved oil and gas reserves or SEC proven mining reserves. Resources are consistent with the Society of Petroleum Engineers 2P and 2C definitions.

Organic: Our use of the term Organic includes SEC proved oil and gas reserves and SEC proven mining reserves (for 2008) excluding changes resulting from acquisitions, divestments and year-average pricing impact. To facilitate a better understanding of underlying business performance, the financial results are also presented on an estimated current cost of supplies (CCS) basis as applied for the Oil Products and Chemicals segment earnings. Earnings on an estimated current cost of supplies basis provides useful information concerning the effect of changes in the cost of supplies on Royal Dutch Shell’s results of operations and is a measure to manage the performance of the Oil Products and Chemicals segments but is not a measure of financial performance under IFRS.

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Quest is a Fully Integrated Saline Aquifer CCS Project

- Quest CCS Project - fully integrated CCS (capture, transport, storage & MMV)
- JV among Shell (60%); Chevron (20%); and Marathon (20%)
- Improves GHG performance of Oil Sands operations
- Capture at the Scotford Upgrader from 3 Hydrogen Units
- Capacity to capture over one million tonnes of CO₂ per year or up to 35% of Scotford Upgrader direct emissions
- CO₂ transported by pipeline
- Deep saline aquifer storage
Extensive Appraisal Data De-Risks Site Selection
BCS Storage Complex Provides Multiple Seals
MMV to Verify Safe CO2 Storage

- **Verify Storage Performance**
  - Validate, calibrate, update performance predictions
  - Adapt injection & monitoring to optimise performance
  - CO2 inventory reporting

- **Ensure Containment**
  - Verify absence of environmental effects
  - Detect early warning signs of any unexpected loss of containment
  - If necessary, activate additional safeguards
Iterative Design Process Reduces Risks

- **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

Source: Adapted from CO2Qualstore Report (DNV, 2009)
MMV will operate over a sufficient extent to include any potential impacts due to CO2 storage including the displacement of brine.
Multiple Independent Containment Safeguards In-Place

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

Numbers
- 34 Preventative safeguards
- 31 Corrective safeguards
## Systematic Evaluation of Passive Safeguards

- Evidence based using collective expert judgement
- Informed by appraisal data and site characterization studies
- Subject to independent expert review

### Table: Passive Safeguards Evaluation

<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>
</table>
| T6     | B6.1      | Select site with no natural seismicity | 1. No recorded seismicity within AOR  
2. Central Alberta is tectonically stable  
3. No faults seen in overburden  
4. Faults not critically stressed before injection | 1. Past may not indicate future seismicity | 0.6 | 0.2 |
|        | B6.2      | Select site away from known faults | 1. No faults through seals on 2D/3D seismic | 1. Not all faults (offsets<20m) identified  
2. Widespread basement faults; offsets<20m  
3. Reactivated fault may grow upwards | 0.3 | 0.3 |
|        | B6.3      | Select max injection pressure using geomechanics | 1. Inject at >14MPa below BCS fracture pressure  
2. Fault-normal stresses remain compressive  
3. Compressor & pipeline rated to 14.5MPa | 1. Injection induces shear stress on faults | 0.6 | 0.2 |
|        | B6.4      | Lower Lotsberg - Reseals fault | 1. Salt creep re-seals fault after slippage  
2. Expected salt thickness is 2-36 m | 1. Pinches out beyond the SW edge of AOI  
2. Salt creep may take years to re-seal fault | 0.2 | 0.4 |
|        | B6.5      | Upper Lotsberg - Reseals fault | 1. Salt creep re-seals fault after slippage  
2. Expected salt thickness is 53-91 m | 1. Salt creep may take years to re-seal fault | 0.3 | 0.3 |
How to Build an Active Safeguard

Detector | Decision Logic | Control Response

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?
### Many Independent Control Response Options Exist

<table>
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<tr>
<th>Preventative Controls</th>
<th>Corrective Controls</th>
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<tr>
<td><strong>Injection Controls</strong></td>
<td><strong>Well Interventions</strong></td>
</tr>
<tr>
<td>IC1 Re-distribute injection across existing wells</td>
<td>RM1 Repair leaking well by re-plugging with cement</td>
</tr>
<tr>
<td>IC2 Drill new vertical or horizontal injectors</td>
<td>RM2 Repair leaking injector by replacing completion</td>
</tr>
<tr>
<td>IC3 Extract reservoir fluids to reduce pressure</td>
<td>RM3 Plug and abandon leaking wells that cannot be repaired</td>
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<tr>
<td>IC4 Stop injection</td>
<td><strong>Exposure Controls</strong></td>
</tr>
<tr>
<td><strong>Well Interventions</strong></td>
<td>RM4 Inject fluids to increase pressure above leak</td>
</tr>
<tr>
<td>WI1 Repair leaking well by re-plugging with cement</td>
<td>RM5 Inject chemical sealant to block leak</td>
</tr>
<tr>
<td>WI2 Repair leaking injector by replacing completion</td>
<td>RM6 Contain contaminated groundwater with hydraulic barriers</td>
</tr>
<tr>
<td>WI3 Plug and abandon leaking wells that cannot be repaired</td>
<td>RM7 Replacement of potable water supplies</td>
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<tr>
<td><strong>Remediation Measures</strong></td>
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<tr>
<td>RM8 Pump and Treat</td>
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<td>RM9 Air Sparging or Vapour Extraction</td>
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<tr>
<td>RM10 Multi-phase Extraction</td>
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<td>RM11 Chemical Oxidation</td>
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<td>RM12 Bioremediation</td>
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<td>RM13 Electrokinetic Remediation</td>
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<td>RM15 Monitored Natural Attenuation</td>
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<td>RM16 Permeable Reactive Barriers</td>
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<td>RM17 Treat acidified soils with alkaline supplements</td>
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# Systematic Evaluation of Monitoring Technologies

- Evidence-based using collective expert judgement
- Informed by appraisal data and site characterization studies
- Subject to independent expert review

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<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 |
Technology Selection Based on Cost-Benefit Ranking

- Cost ranking based on estimated unit costs and schedule of monitoring
- Benefits ranking based on number of tasks supported weighted by the expected success rates
- Subject to regular re-evaluation based on performance
Diversified Monitoring Program Eliminates Dependence on any Single Technology

### Atmosphere
- Pre-Injection: Line-of-Sight CO2 Flux Monitoring
- Post-Closure: 

### Biosphere
- Pre-Injection: Remote sensing, Brine & CO2 Tracer Monitoring
- Post-Closure: 

### Hydrosphere
- Pre-Injection: Groundwater Monitoring Wells: Water Electrical Conductivity, pH, Brine & CO2 Tracer Monitoring
- Post-Closure: Landowner Water Wells: Brine & CO2 Tracer Monitoring

### Geosphere
- Pre-Injection: Time-Lapse 3D VSP
- Post-Closure: Time-Lapse 3D Surface Seismic, INSAR

### Wells: Monitors
- Pre-Injection: WPGS Observation Wells: Down-Hole Pressure & Temperature
- Pre-Injection: BCS Observation Well: Down-Hole Pressure & Temperature

### Wells: Injectors
- Pre-Injection: Injection Rate Metering, Tracer Injection
- Post-Closure: Down-Hole Pressure & Temperature, Distributed Temperature Sensing, Distributed Acoustic Sensing, Annulus Pressure Monitoring, Wellhead Pressure & Temperature, Wellhead CO2 sensor, Mechanical Well Integrity Testing, Operational Integrity Assurance

CBL, USIT
Based on collective expert judgement

Informed by appraisal data and feasibility studies

Risk Metric

Number of Safeguards

Passive safeguards
Active safeguards

Unacceptable
1 in $10^4$ per year

Tolerable
1 in $10^6$ per year

Broadly Acceptable
Summary

- **Quest is a fully integrated CCS Project**
  - Located in the Industrial Heartland of Alberta
  - Capacity to capture over 1 million tonnes of CO2 per year
  - Deep saline aquifer storage

- **Site Selection & appraisal completed**
  - Storage complex: Deepest permeable formation with three regional seals
  - CO2 injection locations maximize offset to abandoned wells
  - Sequestration lease area is 2,275 km²

- **MMV designed to demonstrate secure CO2 storage**
  - Risk-based
  - Site-specific
  - Adaptive
Acknowledgements

- Partners – Chevron Canada Limited & Marathon Oil Canada
- Government of Alberta, Department of Energy (DOE)
- Government of Canada, Natural Resources Canada (NRCan)
- Government of Alberta, Alberta Innovates