Quest CCS Project
Learnings from the First Year of Operations

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Shell’s Response to the CO$_2$ Challenge

- Natural Gas
- Biofuels
- Efficiency
- Carbon Capture & Storage
Shell’s CCS/CCUS Project Portfolio

- **Industrial scale projects in operation**
- **Industrial scale projects in construction**
- **Involvement through Shell Cansolv Technology**
Quest Overview
Quest Project at a Glance

• **World First** – the first full-scale CCS project for oil sands

• **Who** – joint venture between Shell, Chevron and Marathon

• **Where** – capture at Scotford Upgrader; storage in saline aquifer: the Basal Cambrian Sands (at a depth of 2000m)

• **Impact** – 25 million tonnes of CO₂ captured over a 25 year period (1/3 of CO₂ from the Upgrader) – equivalent to the emissions of 250,000 cars

• **Technology** – syngas capture using amines
The Athabasca Oil Sands Project (AOSP)

- Muskeg River Mine
- Corridor Pipeline
- Scotford Upgrader
- Scotford Refinery (Shell only)
- Quest: CO₂ capture from 3 HMUs

Bitumen to Synthetic crude (255,000 bpd)

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**CO₂ Capture**

- The Hydrogen Unit combines steam and natural gas to produce high pressure steam and H₂ for use in the upgrader.
- The Amine Unit uses Shell technology to capture the CO₂ directly from the process.
- The process produces a 99% pure CO₂ output.
- Award winning integrated, modular construction (Fluor).
Transport

- CO$_2$ dehydrated and compressed to $>10$ MPa to keep the CO$_2$ in dense phase through entire pipeline
- 65 km pipeline with 6 block valves (every 4-15 km)
- Pipeline construction Oct 2013 – Aug 2014, with considerable stakeholder interaction
- Cleaning and preserved with nitrogen by October 2014
- First CO$_2$ into pipeline August 2015
Storage

3 well pads:

• Each pad has 1 injection well, 1 deep monitoring well and multiple shallow ground water wells
• Conventional drilling methods
• Multiple steel casings for injection wells, 3 in freshwater zone, all cemented to surface
• Comprehensive Measurement, Monitoring and Verification program
The Storage Complex

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)

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<th>Depth</th>
<th>Layer</th>
<th>Description</th>
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<td>Prairie Evaporite</td>
<td>Additional Seal</td>
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<tr>
<td>85m</td>
<td>Upper Lotsberg Salt</td>
<td>Ultimate Seal</td>
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<td>70m</td>
<td>Middle Cambrian Shale</td>
<td>Primary Seal</td>
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<td>40m</td>
<td>Basal Cambrian Sand</td>
<td>Storage Reservoir</td>
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<td>40m</td>
<td>PreCambrian Shield</td>
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Geology and Wells
Storage Complex Geology

**Basal Cambrian Sandstone (BCS)** – The injection zone.
Dominantly sandstones, with local thin - to very thin-bedded mudstones

**Lower Marine Siltstone (LMS)** – Impedes CO$_2$ migration.
Intermixed mudstones and sandstones

**Middle Cambrian Shale (MCS)** – The Primary Seal
Predominantly shale.
Deposited in an offshore environment as sea got deeper

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Reservoir Screening

BCS Thickness Map (1m contours)

Stratigraphic Cross-section

Upper Lotsberg

Lower Lotsberg

Seal Thickness Maps

After Grobe and Stewart, 2002

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Regional Correlations

Regional correlation of well data provides confidence in our depositional model and helps us predict how the reservoir will respond to CO₂.
Reservoir Modeling (Static, Dynamic)

- Well Correlations
- Structural Framework
- Facies Interpretation
- Regional Property Trends
- Upscaled Well Logs
## Development Scenario Modelling

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<tr>
<th>Expectation Case</th>
<th>Low Case</th>
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<td><img src="image1.png" alt="Map of Expectation Case" /></td>
<td><img src="image2.png" alt="Map of Low Case" /></td>
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### Charts

- **3 wells**
  - ![Chart 1](chart1.png)
  - ![Chart 2](chart2.png)
  - ![Chart 3](chart3.png)

- **5+3 wells**
  - ![Chart 4](chart4.png)
  - ![Chart 5](chart5.png)

- **3+2+3 wells**
  - ![Chart 6](chart6.png)
  - ![Chart 7](chart7.png)
Conceptual Storage Plan

![Conceptual Storage Plan Diagram]

**CO₂ Saturation**

**DeltaP (kPa)**

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Drilling Campaign

- 2 appraisal wells (~ 2 km MD, to BCS)
- 3 injection wells (~ 2 km MD, to BCS)
- 3 deep monitoring wells (~ 1.7 km MD, to top of seal)
- 9 groundwater monitoring wells (< 0.2 km MD, in GWP zone)
Well Pad Schematic

Freshwater

Colorado

CKLK

Lotsberg

UMS

MCS

LMS

BCS

Injection Well (IW)

Deep Monitoring Well (DMW)

Groundwater Monitoring Well (GMW)

Datalogger

(pH, Eh)

Geophone array (1 well only)

Fibre optic cable

~ 40m

~ 30m

~ 450m

~ 1750m

~ 30m

~ 750m

~ 180m

~ 5 9/16"

~ 1750m

~ 5 1/2"

~ 9 5/8"

~ 9 5/8"

~ 7"
Reservoir Model – Plume Predictions

- Based on pre-injection model
- Remaining uncertainty on relative permeability of CO₂ reduced in 2016 with model update and tuning to performance data.
- Current estimate of max plume lengths: 2.5 to 4.2 km
Measure, Monitor and Verify (MMV)
**Quest MMV Plan 2015**

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

- **Injection**
  - Time (years): 2010, 2015, 2020, 2025, 2030, 2035, 2040, 2045, 2050

- **Closure**

**Prominent Features**
- First of a kind – conservative approach
- Comprehensive: from atmosphere to geosphere
- Risk-based
- Site-specific
- Independently reviewed
- Combination of new and traditional technologies
- Baseline data collected before start-up
Atmosphere: LightSource

- LightSource system installed and functional at all injection sites prior to CO₂ injection
- Release testing very successful – all releases detected, quantified and located
- Confirmed as the technology for atmospheric monitoring at Quest
Hydrosphere: Groundwater Monitoring

• Continuous monitoring of Shell project wells (on well pads) – recently changed sensors to improve reliability
• Extensive field sampling campaign of landowner wells, many measurements taken
• Comprehensive baseline data
**Geosphere: Microseismic**

- Microseismic array installed in DMW 8-19 recording baseline MS activity in November 2014 – re-installed in April 2015.

- Three small ($M < -1$) locatable events have been detected through the end of 2016.
Geosphere: Time Lapse VSPs

• Baseline VSP acquired pre-injection in April, 2015 (no CO₂ is present in the reservoir).

• The first monitor VSP was recorded in March, 2016.

• Time lapse signal quite strong, consistent with modelled plume
Pulsed Neutron log was run in May 2015 prior to injection (Black line), and a repeat was run after 6 months of CO$_2$ injection. (Red line)

**Initial Observations**

- Change in the pulsed neutron response over the perforated (Red rectangle).
- No change in log response above or below the perforated interval or through the LMS member.

**Conclusions:**

- CO$_2$ is contained within the perforated interval and the BCS reservoir. (Red rectangle).
- The injected CO$_2$ is mainly within the high permeability streaks (Green Arrows).
Storage Operations
Quest – First 16 Months’ Performance

- Kept 8-19 steady initially to simplify pressure data at 5-35
- Capacity testing in February
- Well logging runs during Turn Around
- First million tonnes captured and stored by August, 2016
- Wells have not been a limiting factor
Reservoir Model – Pressure Forecasting

• Still too early for reliable history matching
• Reservoir properties looking more like our modelled high case scenarios
• (Far field) data from 5-35 considerably better than expected
• Pressure build-up in the BCS is still forecast to be less than 2 MPa ($\Delta P$) by the end of the project life
Quest Storage Learnings

**MMV:**
- MMV systems working well – no triggers
- Microseismic array has been very quiet
- VSPs can image CO$_2$ in the BCS, DAS working very well

**Wells:**
- Only 2 wells active – contributing to significant wells and MMV savings
- Pulse neutron logging confirmed that CO$_2$ is where it is supposed to be
- Important to keep water out of the wells, even the small amounts routinely used during logging

**Reservoir:**
- Excellent injectivity – comparable to high case scenarios
- After 25 years, we expect to use 5-7% of the available pore space
- Current estimate is that the $\Delta P$ at the end of the project may only be 2 MPa.
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