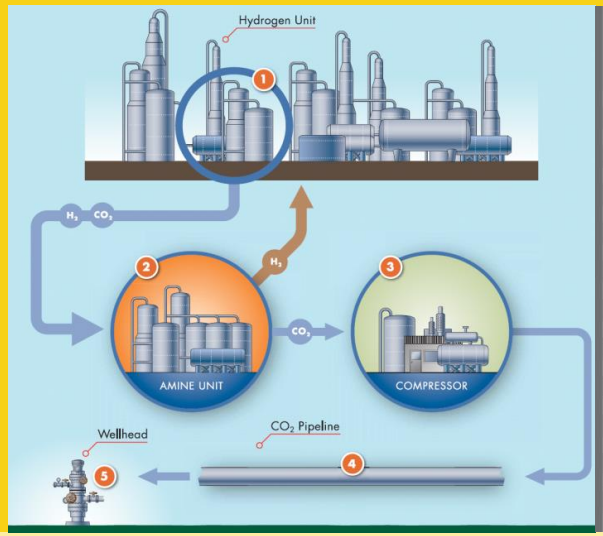
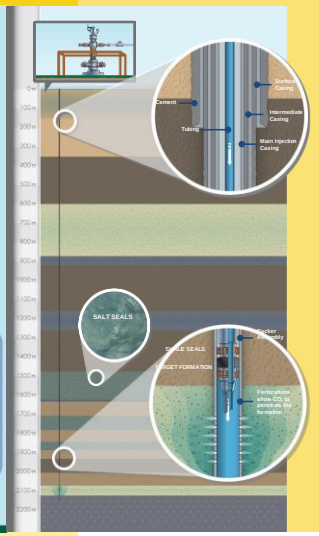
QUEST – MMV OVERVIEW

ARB Technical Discussion
Series: Monitoring

Sacramento – August, 2016





Dr. Simon O'Brien, Dr. Owain Tucker
Shell

CAUTIONARY STATEMENT

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 over which Royal Dutch Shell plc either directly or indirectly has control. Companies over which Shell has joint control are generally referred to "joint ventures" and companies over which Shell has significant influence but neither control nor joint control are referred to as "associates". In this presentation, joint ventures and associates may also be referred to as "equity-accounted investments". The term "Shell interest" is used for convenience to indicate the direct and/or indirect ownership interest held by Shell in a venture, partnership or company, after exclusion of all third-party interest.

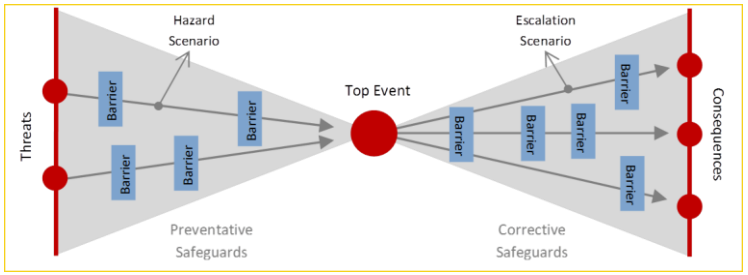
This presentation contains forward-looking statements concerning the financial condition, results of operations and businesses of Royal Dutch Shell. All statements other than statements of historical fact are, or may be deemed to be, forward-looking statements. Forward-looking statements are statements of future expectations that are based on management's current expectations and assumptions and involve known and unknown risks and uncertainties that could cause actual results, performance or events to differ materially from those expressed or implied in these statements. Forward-looking statements include, among other things, statements concerning the potential exposure of Royal Dutch Shell to market risks and statements expressing management's expectations, beliefs, estimates, forecasts, projections and assumptions. These forward-looking statements are identified by their use of terms and phrases such as ''anticipate'', ''believe'', ''could'', ''estimate'', ''expect'', ''goals'', ''intend'', ''may'', ''objectives'', ''outlook'', ''plan'', ''probably'', ''project'', ''risks'', "schedule", ''seek'', ''should'', ''target'', ''will'' and similar terms and phrases. There are a number of factors that could affect the future operations of Royal Dutch Shell and could cause those results to differ materially from those expressed in the forward-looking statements included in this presentation, including (without limitation): (a) price fluctuations in crude oil and natural gas; (b) changes in demand for Shell's products; (c) currency fluctuations; (d) drilling and production results; (e) reserves estimates; (f) loss of market share and industry competition; (g) environmental and physical risks; (h) risks associated with the identification of suitable potential acquisition properties and targets, and successful negotiation and completion of such transactions; (i) the risk of doing business in developing countries and countries subject to international sanctions; (j) legislative, fiscal and regulatory developments including regulatory measures addressing climate change; (k) economic and financial market conditions in various countries and regions; (l) political risks, including the risks of expropriation and renegotiation of the terms of contracts with governmental entities, delays or advancements in the approval of projects and delays in the reimbursement for shared costs; and (m) changes in trading conditions. All forward-looking statements contained in this presentation are expressly qualified in their entirety by the cautionary statements contained or referred to in this section. Readers should not place undue reliance on forward-looking statements. Additional risk factors that may affect future results are contained in Royal Dutch Shell's 20-F for the year ended December 31, 2013 (available at www.shell.com/investor and www.sec.gov). These risk factors also expressly qualify all forward looking statements contained in this presentation and should be considered by the reader. Each forward-looking statement speaks only as of the date of this presentation, 27 August 2014, Neither Royal Dutch Shell plc nor any of its subsidiaries undertake any obligation to publicly update or revise any forward-looking statement as a result of new information, future events or other information. In light of these risks, results could differ materially from those stated, implied or inferred from the forward-looking statements contained in this presentation.

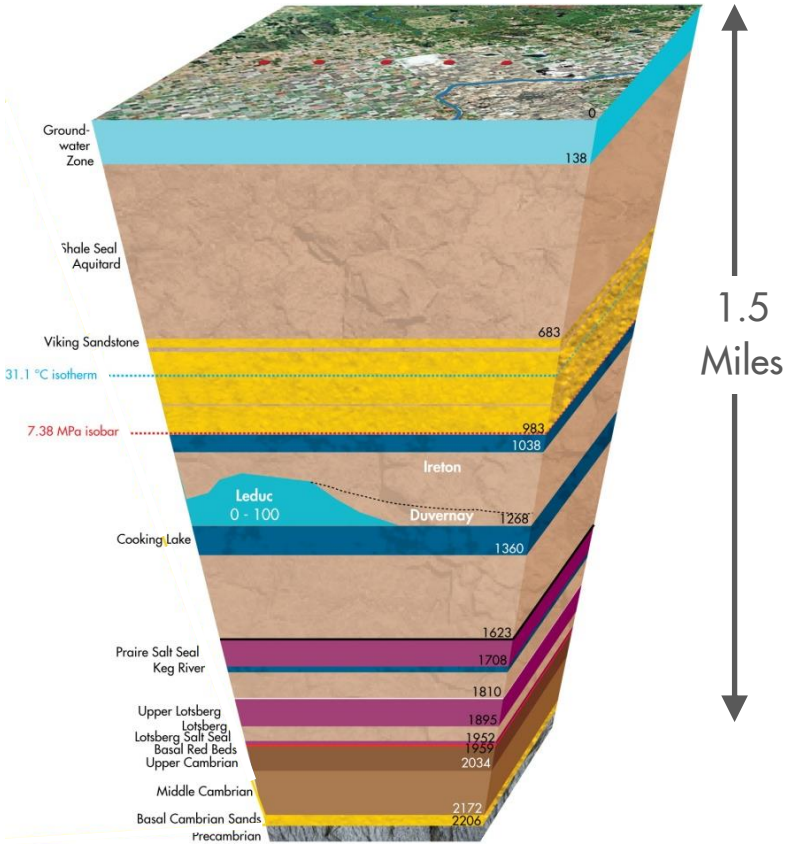
We may have used certain terms, such as resources, in this presentation that United States Securities and Exchange Commission (SEC) strictly prohibits us from including in our filings with the SEC. U.S. Investors are urged to consider closely the disclosure in our Form 20-F, File No 1-32575, available on the SEC website www.sec.gov. You can also obtain these forms from the SEC by calling 1-800-SEC-0330.

PRINCIPLES FOR CONSIDERATION

1) Presumption is zero leakage to atmosphere post-injection
   - Risk-based MMV
   - Good site selection is key
   - Revisit operational plans if migration is detected outside of primary store
   - Best engineering estimate to quantify leakage to atmosphere
   - Surface CO_2 flux can be highly variable (many factors influence) – assurance monitoring

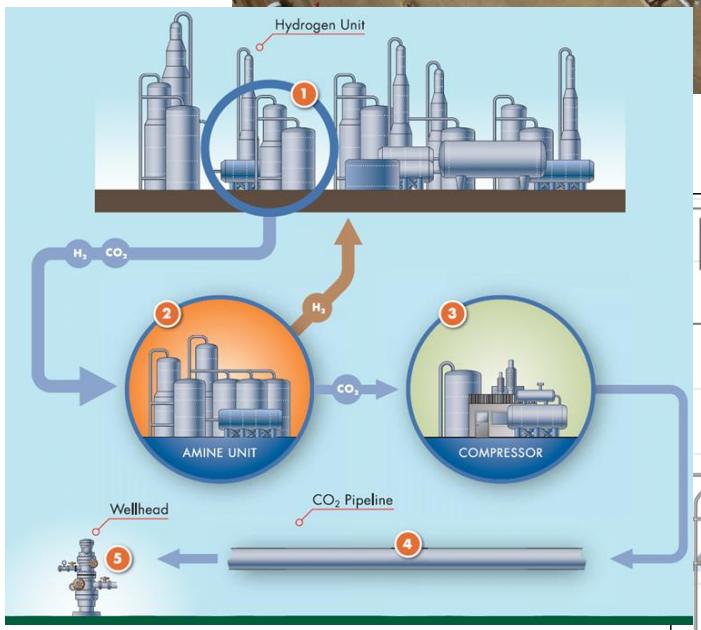
2) Fugitives in dense phase system would be readily visible. GHGRP fugitive emission factors not appropriate for CO_2 systems.

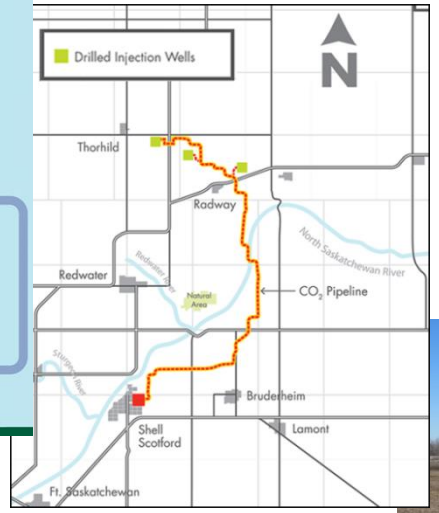




Copyright Shell Canada Limited
August, 2016

QUEST – INDUSTRIAL CAPTURE AND TRANSPORT



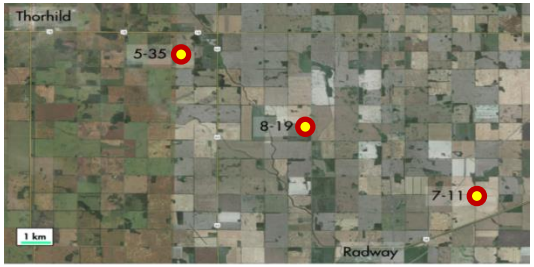


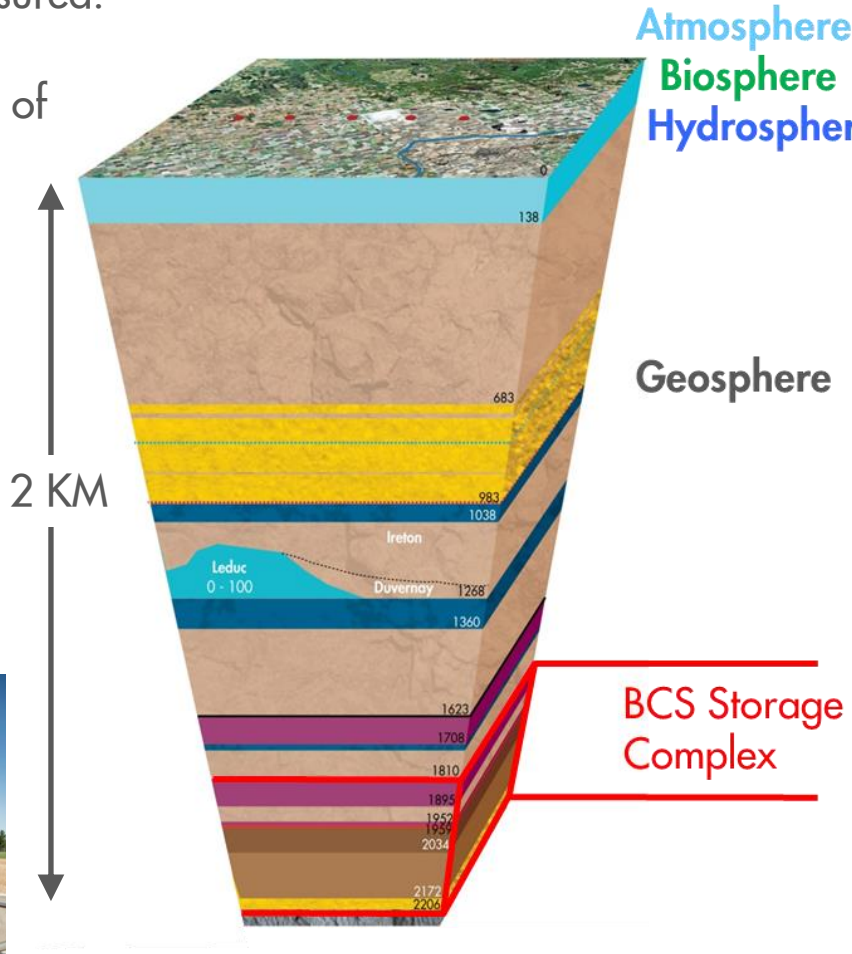
- Capture at the Scotford Upgrader: an Oil Sands facility that upgrades bitumen into synthetic crude
- CO_2 sources are 3 Hydrogen Manufacturing Units, captured using Shell amine technology
- Captures > 1 million tonnes per year (1/3 of the CO_2 emissions from the Upgrader) – equivalent to the emissions of about 250,000 cars
- CO_2 is dehydrated, compressed and transported in dense phase roughly 65 km to three well sites

Copyright Shell Canada Limited
August, 2016

QUEST – DEEP SALINE STORAGE

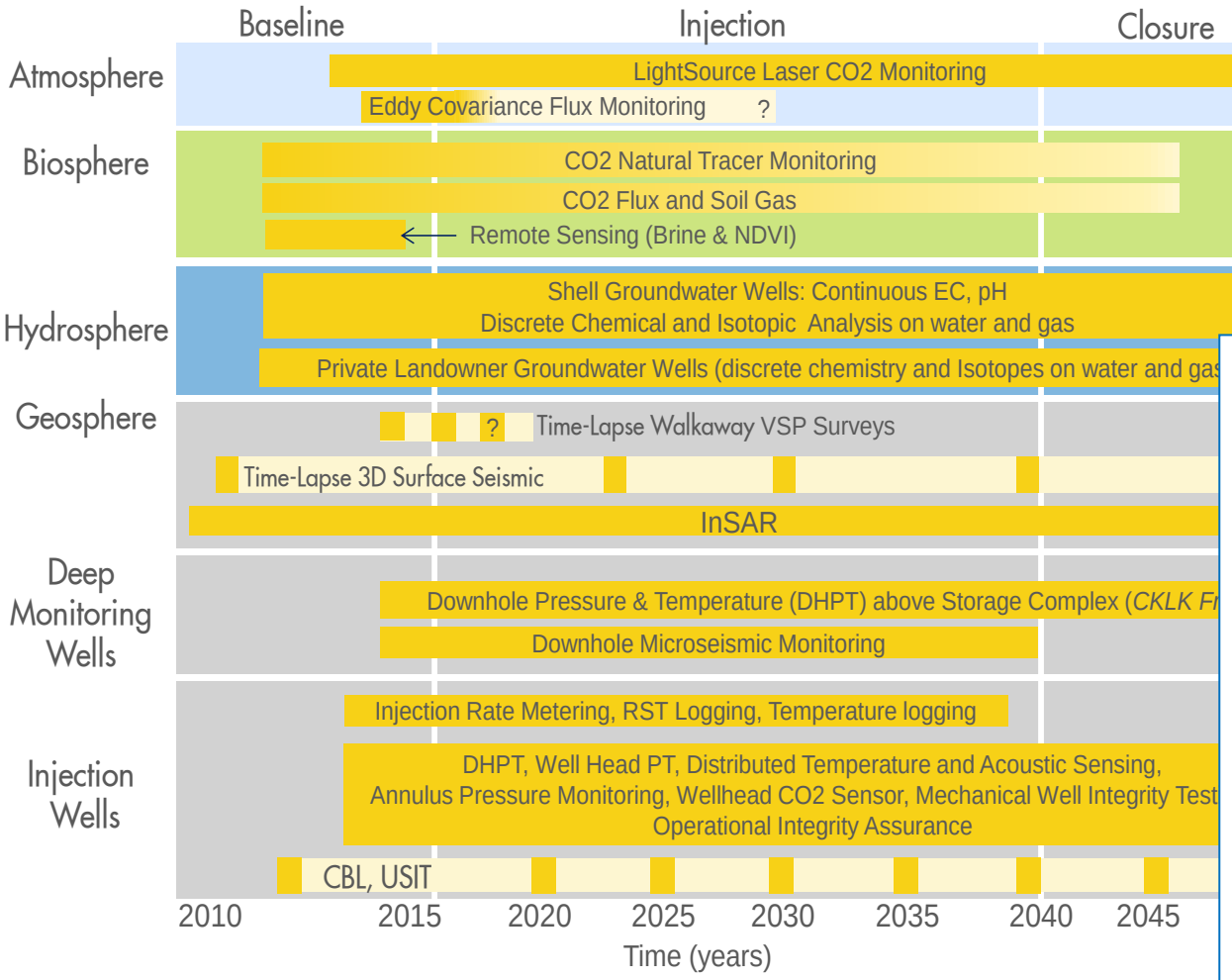
- **Storage Complex**
  - Carefully selected, characterized and externally assured: complete absence of natural migration pathways
  - Reservoir: High quality sandstone (BCS) at a depth of 2000 m
  - Seals: Multiple shale and salt layers (>200m)
- **Storage Facility consists of 3 well pads:**
  - Each pad has an injection well, a deep monitoring well and multiple shallow ground water wells
  - Conventional drilling methods
  - Multiple redundant engineered barriers: 3 steel casings in injection wells through freshwater zone, all cemented to surface
- **Comprehensive MMV program**





Copyright Shell Canada Limited
August, 2016

MMV (MEASURE, MONITOR AND VERIFY) PLAN



- 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.

The original Quest MMV plan is publicly available online:

http://www.energy.alberta.ca/CCS/MeasurementMonitoringandVerificationPlan.pdf

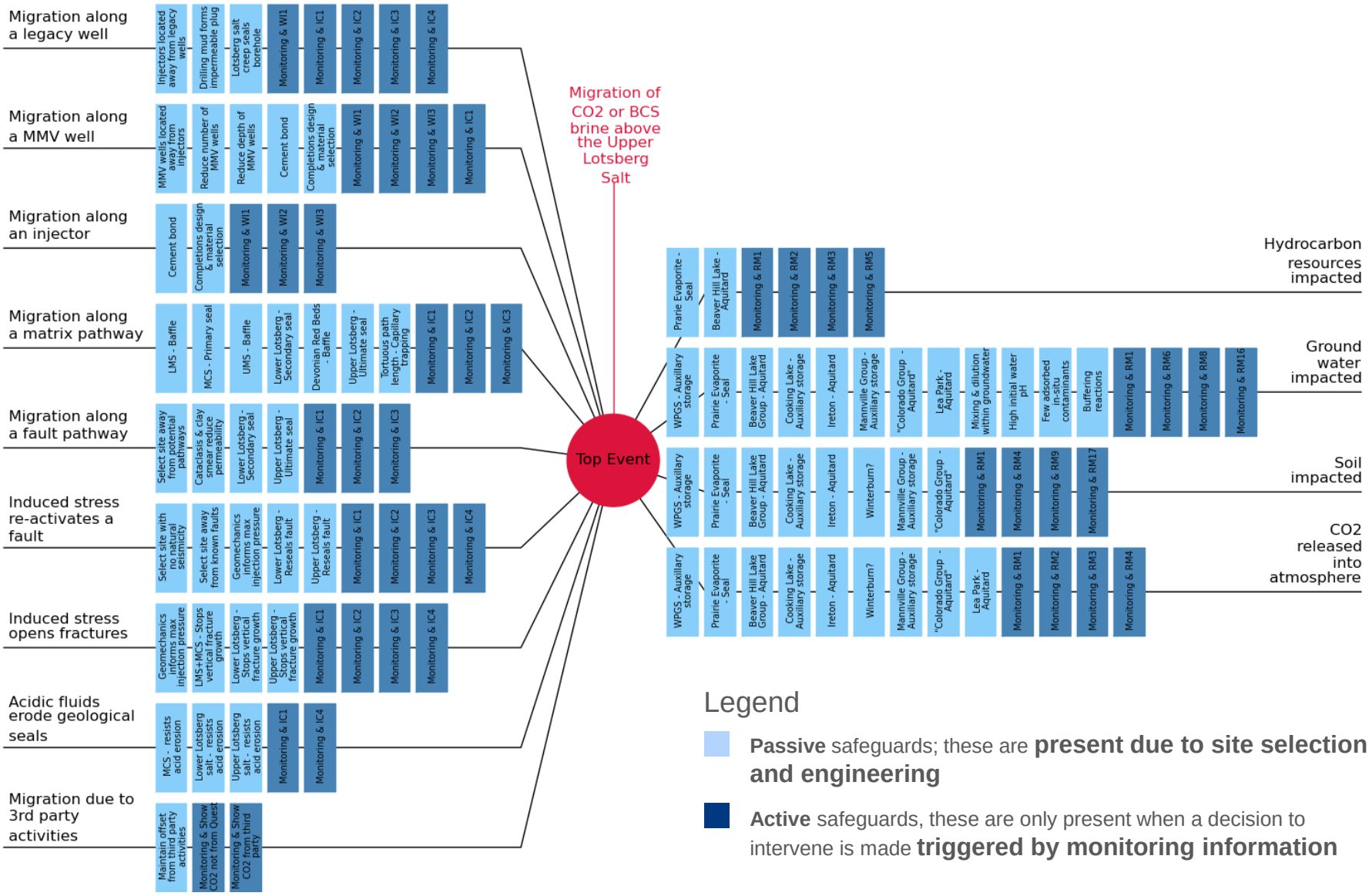
Copyright Shell Canada Limited
August, 2016

MMV CONSIDERATIONS

- System is designed and engineered not to leak – MMV technologies are not the primary barriers
- Three focus areas:
  - Containment (ensure CO_2 stays in zone)
  - Conformance (demonstrate we know where CO_2 is now and where it will be in the future)
  - Public/stakeholder confidence
- Timescales for action vary according to risk
  - Geologic movement very slow
  - Wells may potentially provide a faster path to the surface
  - MMV technologies must be appropriate to address the intended risk

Copyright Shell Canada Limited
August, 2016

BOW-TIE: CCS STORAGE CONTAINMENT RISK EXAMPLE



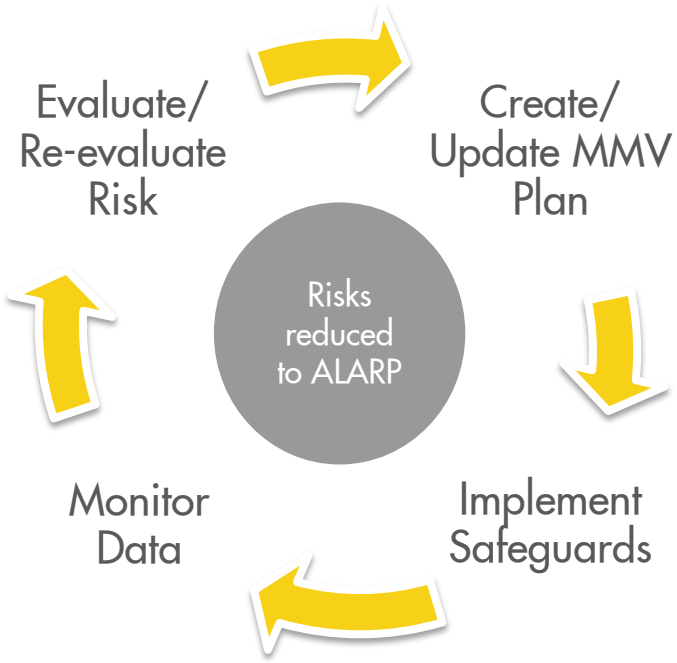
Legend

Passive safeguards; these are **present due to site selection and engineering**

Active safeguards, these are only present when a decision to intervene is made **triggered by monitoring information**

Copyright Shell Canada Limited
August, 2016

MMV DESIGN



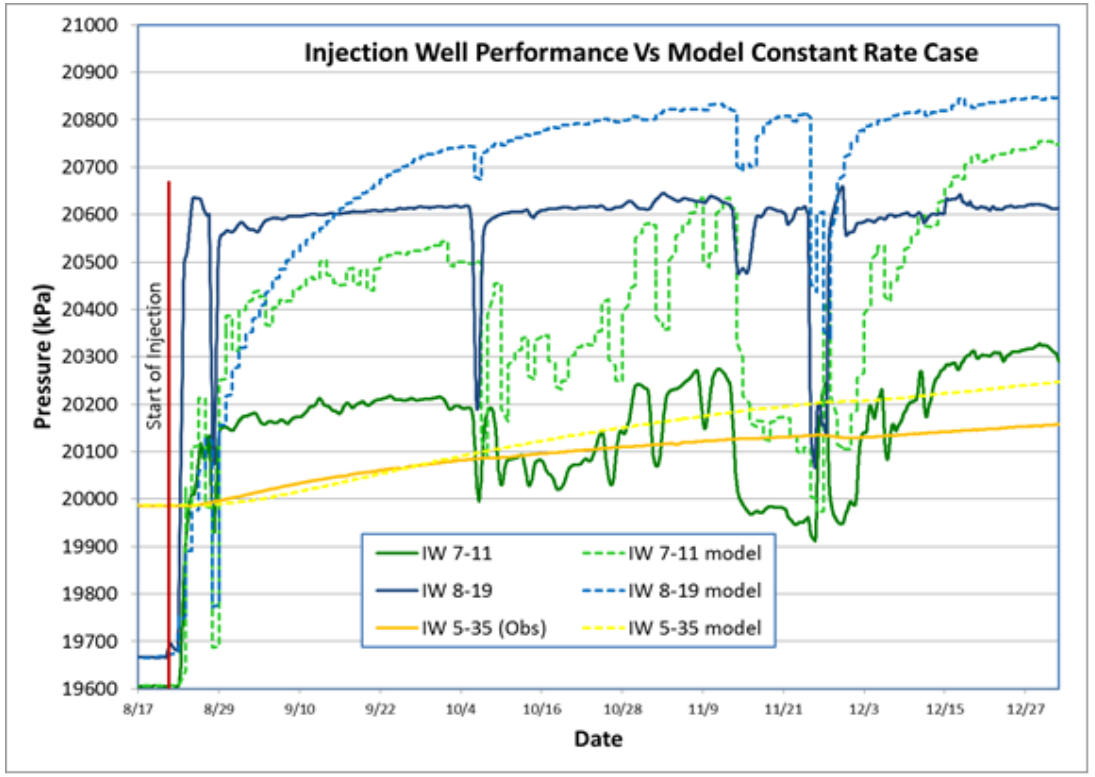
- Risk-Based
  - Verify geological & engineered safeguards
  - Reduce containment risk to ALARP
- Site-Specific
  - Choose monitoring technologies appropriate for each location
  - Informed by appraisal data
- Adaptive
  - Respond to observed performance
  - Contingency plans in place

Copyright Shell Canada Limited
August, 2016

RESERVOIR PRESSURE MONITORING

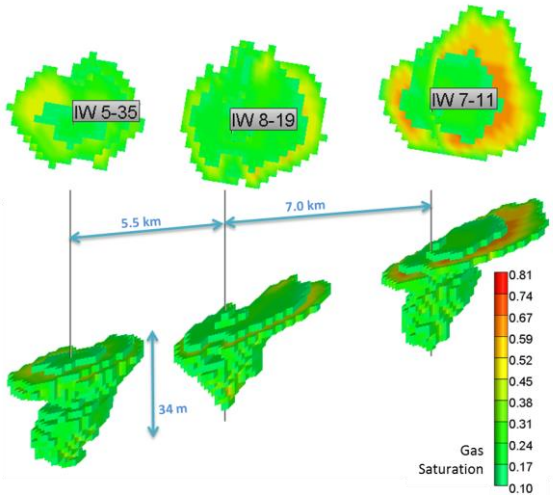
- Pressure build-up in the reservoir (BCS) is less than our mid-case forecast
- Reservoir properties appear to be better than expected
- Response at 5-35 to injection at 8-19 within a day or two
- Pressure build-up in the BCS is forecast to be less than 2 MPa (ΔP) by the end of the project life

➡ Can now update our suite of reservoir model forecasts using new data

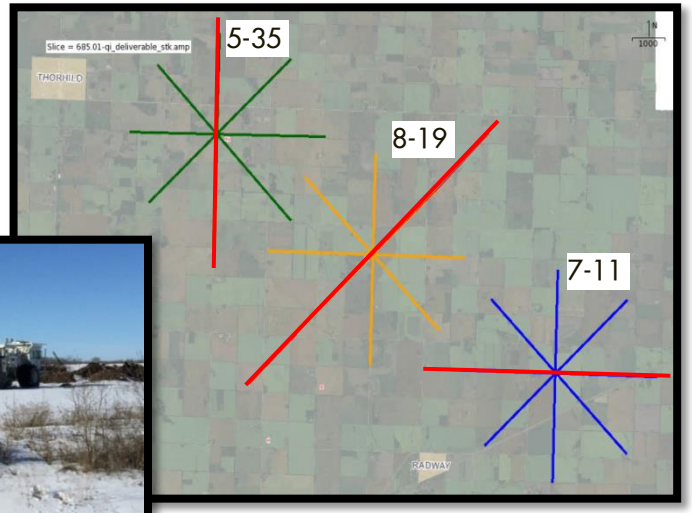


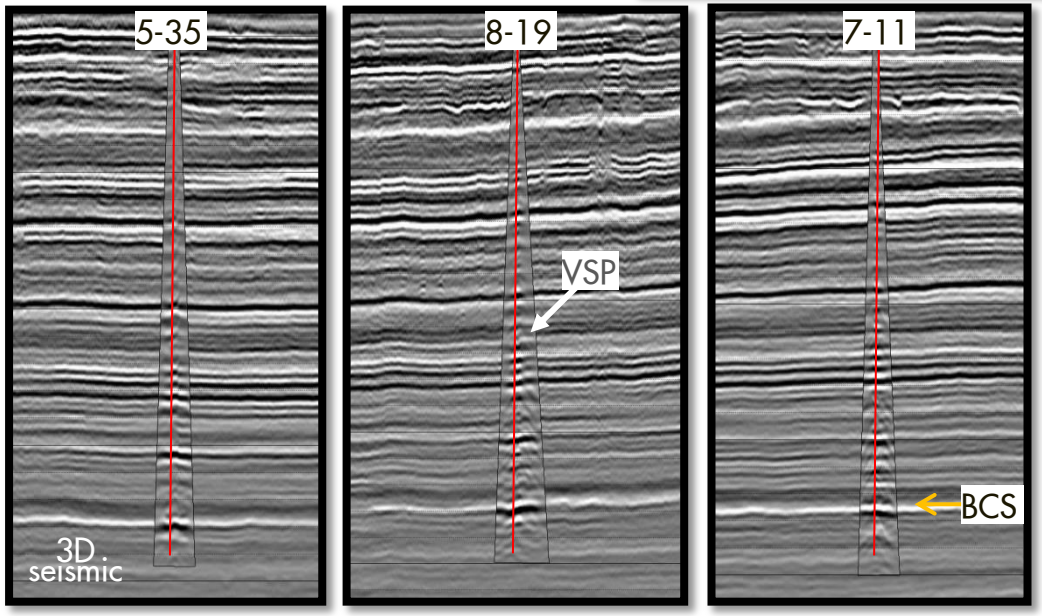
Copyright Shell Canada Limited
August, 2016

SEISMIC MONITORING – VERTICAL SEISMIC PROFILE (VSP)



Model of CO_2 Plume after injecting for 25 years

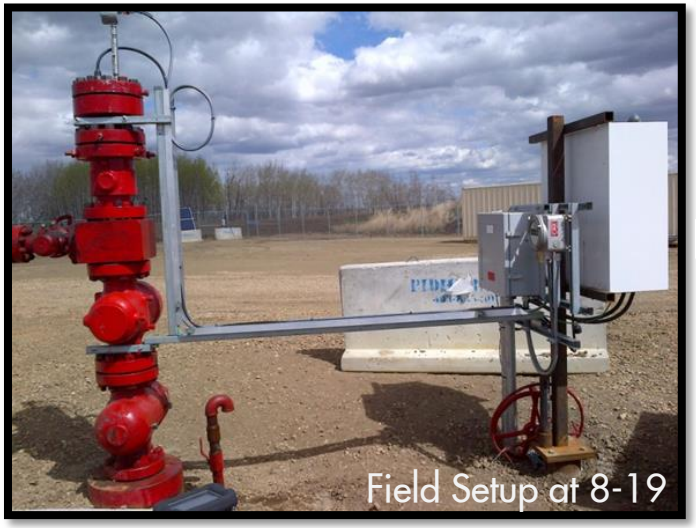


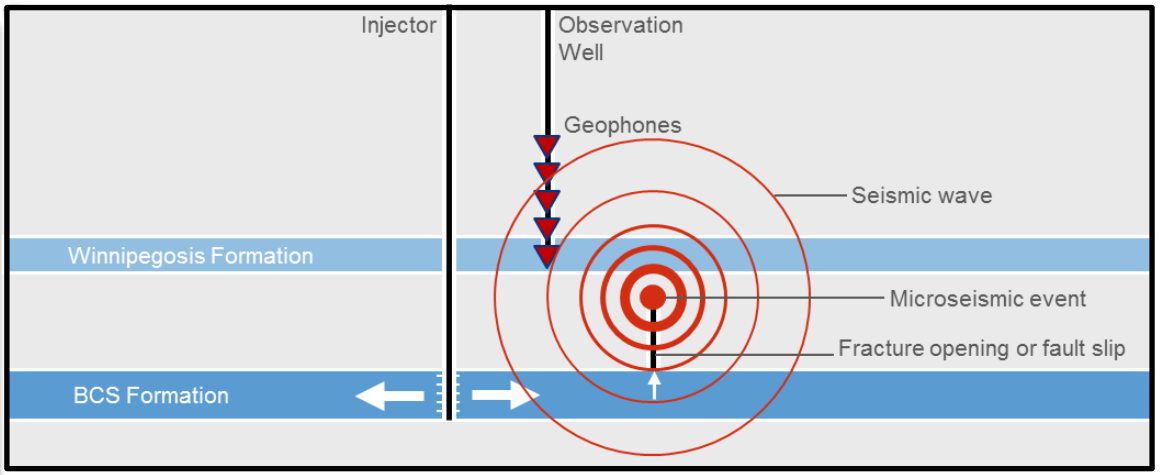


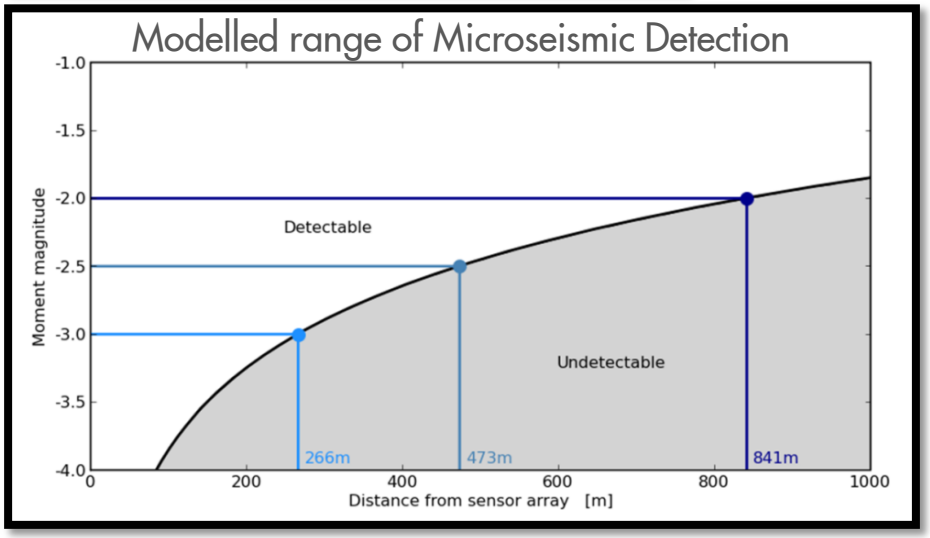
- Design change: from 3D VSP to radial walkaway 2Ds: significant cost savings
- Acquired baseline VSP in Feb, 2015 and the first monitor VSP in Feb, 2016.
- Processing is complete – still evaluating the results, but 4D response is strong

Copyright Shell Canada Limited
August, 2016

MICROSEISMIC MONITORING







- Microseismic array designed to detect events of magnitude -2.0 from a distance of ~840 m
- The array has been continuously recording since Nov 2014.
- Array is working well: numerous surface (human activity) and regional events triggered
- No locatable events yet detected

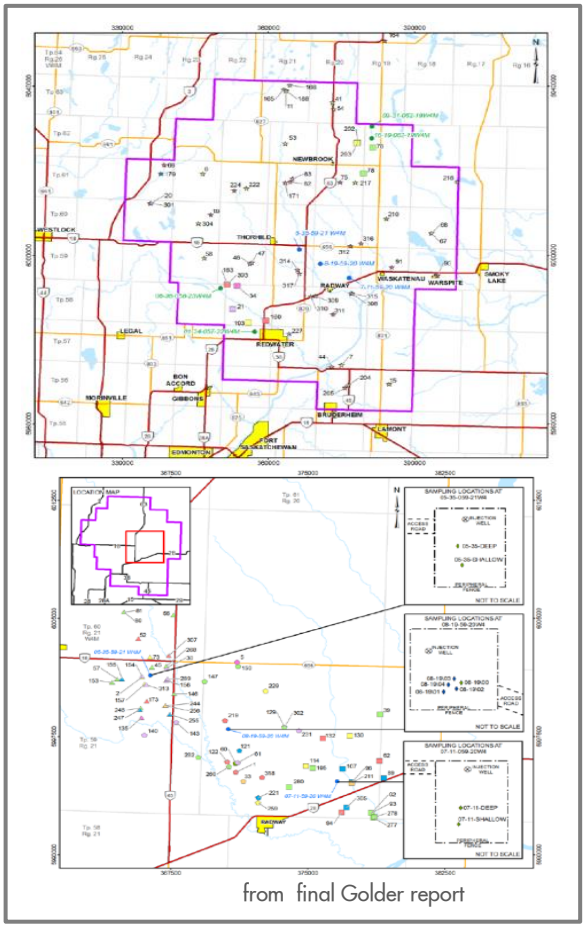
Copyright Shell Canada Limited
August, 2016

GROUNDWATER MONITORING

Discrete GW well sampling (Landowner & Project Wells)												
Sampling event	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Q4-2012											■	
Q1-2013			■									
Q2-2013						■						
Q3-2013								■				
Q4-2013										■		
Q1-2014		■										
Q2-2014					■							
Q3-2014								■				
Q4-2014										■		

Continuous GW well sampling (Project Wells only)												
Sampling event	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2013			■	■	■	■	■	■	■	■	■	■
2014	■	■	■	■	■	■	■	■	■	■	■	■

AITF study												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2013				■	■	■	■	■	■	■	■	■
2014	■	■	■	■	■	■	■	■	■	■	■	■



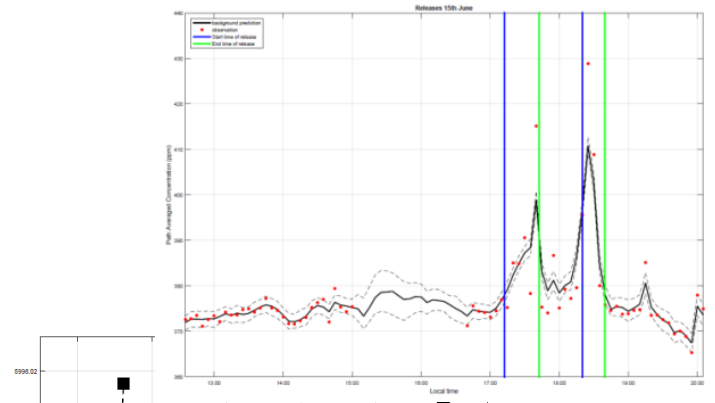
from final Golder report

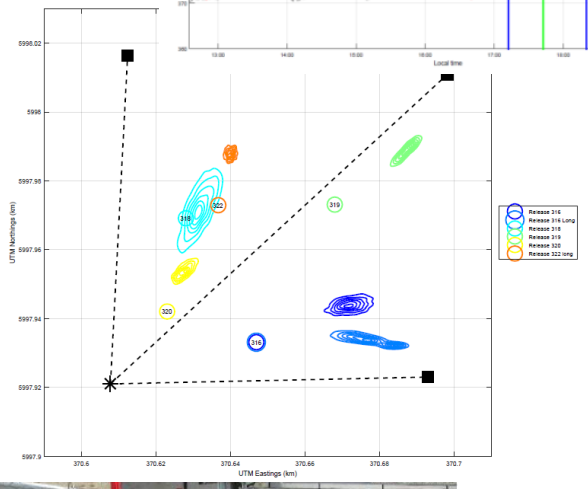
- Continuous monitoring of Shell project wells (on well pads)
- Extensive field sampling campaign of landowner wells, many measurements taken
- Comprehensive baseline data
- Working with regulator to optimize sampling

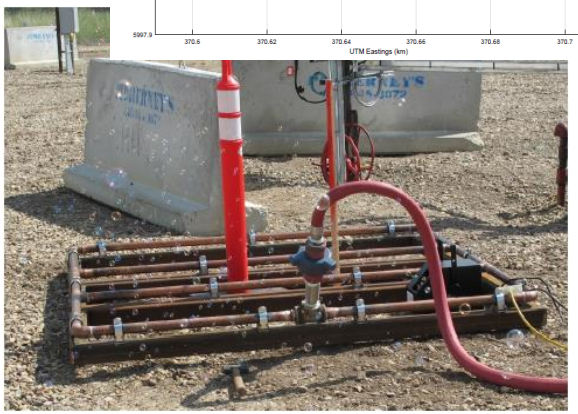
Copyright Shell Canada Limited
August, 2016

ATMOSPHERIC MONITORING

from Hirst et al. 2015







from Hirst et al. 2015

- The high variability of CO_2 levels in the atmosphere makes detecting small emissions difficult
- LightSource system installed and functional at all injection sites
- Release tests demonstrated we can detect and quantify CO_2 emissions on the well site
- **Confirmed as technology for atmospheric monitoring at Quest**

Copyright Shell Canada Limited
August, 2016

PERFORMANCE & CLOSURE

Closure Plan Outline
Intro
Project Overview
Storage Performance Tasks for Site Closure - CCS Targets from the Regulator
Storage Performance Data - Well inventory - CO_2 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

Post Injection MMV:

- Complements data collected during baseline and injection periods to demonstrate clear understanding of performance history
- Continues to validate the modelling of future CO_2 behaviour
- Assures decommissioning of the wells
- Facilitates the safe handover of liability, minimize future concerns
- Time frame is determined by assessment of remaining risk: site specific

Copyright Shell Canada Limited
August, 2016

MMV KEY POINTS

Important considerations for an MMV plan:

- Containment – risk based:
  - Thorough risk assessment required
  - Trigger based – each technology must contribute to specific barriers
  - Wellbore risks prior to abandonment generally higher than geologic risks, hence more intensive monitoring

- Conformance – confidence in storage security:
  - Model driven: need to acquire sufficient data to provide confidence in the model
  - Post-injection monitoring period dependent on site risk and operational performance

- Public/Stakeholder confidence
  - Perceived risks need to be treated seriously

➡ Site selection critical to risk assessment – MMV must be risk-based and site specific

Copyright Shell Canada Limited
August, 2016

ACKNOWLEDGEMENTS

- Government of Alberta, Department of Energy (DOE)
- Government of Canada, Natural Resources Canada (NRCan)
- Shell staff (Calgary, Houston, EU, Scotford and in the field)
- 3rd Party Contractors: Fluor, Golder Assoc., ESG, Boreal, Air Liquide, U. of C., U.B.C., U. Vic., et al.
- Partners: Chevron Canada Ltd & Marathon Oil Canada

Copyright Shell Canada Limited
August, 2016