The Quest Facility: Learning from 6 years of Operations

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Shell Scotford Complex

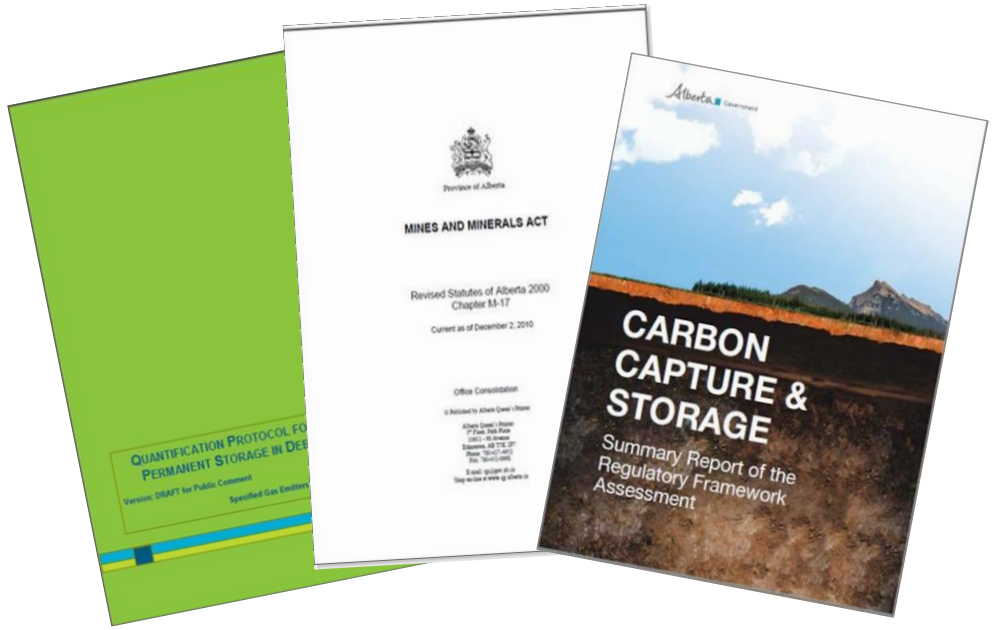
- Refinery (opened in 1984)
  - 100 kbpd nameplate capacity
- Chemicals plants (Styrene in 1984 and Glycols in 2000)
- Upgrader (opened in 2003 and expanded in 2011)
  - 255 kbpd nameplate capacity
- Quest Carbon Capture and Storage
  - 1 million tonnes CO2 capture/yr

Government Support for Quest

- Predicted total cost of Quest: $1.35B CAN (FEED, Capital + 10 years OPEX)
- The governments of Alberta and Canada contributed $745M and $120M respectively to Quest, for a total of $865M CAN
- Requirements – Quest will:
  - Only receive direct financial support until a net revenue threshold is reached
  - Adhere to stringent annual reporting with a comprehensive MMV plan
  - Conduct extensive knowledge sharing

Strong Regulatory Framework

- Carbon tax credits provide a long-term commercial incentive for capture and sequestration
- Pore space tenure – permission to inject CO_2 into the subsurface
- Requirements for monitoring, measurement and verification
- Quantification protocol – accounting scheme for injected CO_2
- Clarify long-term liability, closure planning

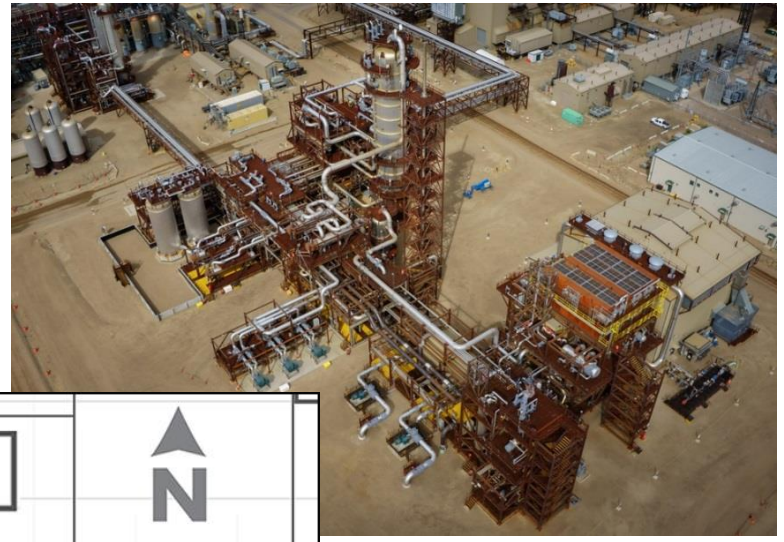


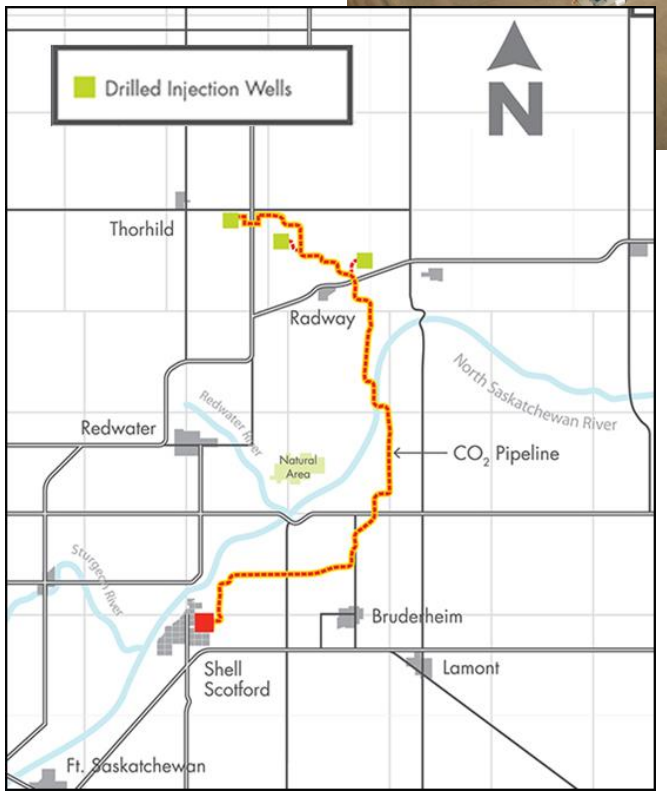
Community Perspective

- Community around pipeline and wells were new to Shell
- CCS/CO_2 pipelines were seen as "unknown"
- Thorhild County was announced as new location for regional dump
  - Right before Quest announcement
  - Divided community
  - We were seen as "dumping" our waste there as well
- Significant stakeholder engagement effort required

The Quest Facility

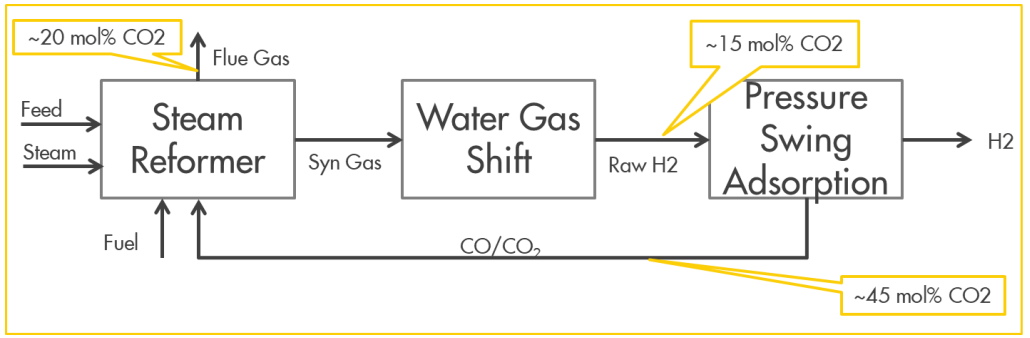
- Located at the Scotford Upgrader, north of Edmonton, Alberta (Canada)
- JV with Canadian Natural Upgrading and Chevron
- CO_2 capture from 3 hydrogen manufacturing units with rates up to 3600 tonnes/day.
- One million tonnes represents about 1/3 of the Upgrader's emissions – equivalent to the output of 250,000 cars!
- 65 km pipeline to storage facility north of Scotford
- Storage in secure saline reservoir – Basal Cambrian Sands (BCS)
- Started commercial operations in Oct, 2015

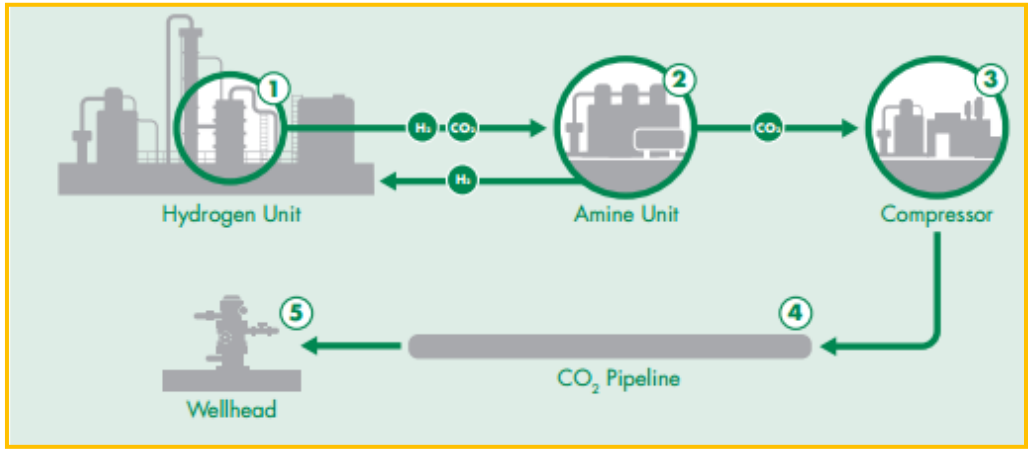




CO_2 Capture Facility

- Standard amine technology (Shell's ADIP-X) utilized for CO_2 removal from raw H_2
- CO_2 compression via an 8 stage, integrally geared compressor
  - 9-11 MPa discharge,
  - 12-16 MW power consumption: 1/3 of Quest emissions
- CO_2 dehydration via tri-ethylene glycol (TEG) to 4 lb H2O/MMScf water content spec
- Integrated facility design in excess of 1.2 Million tonnes per annum(Mtpa)



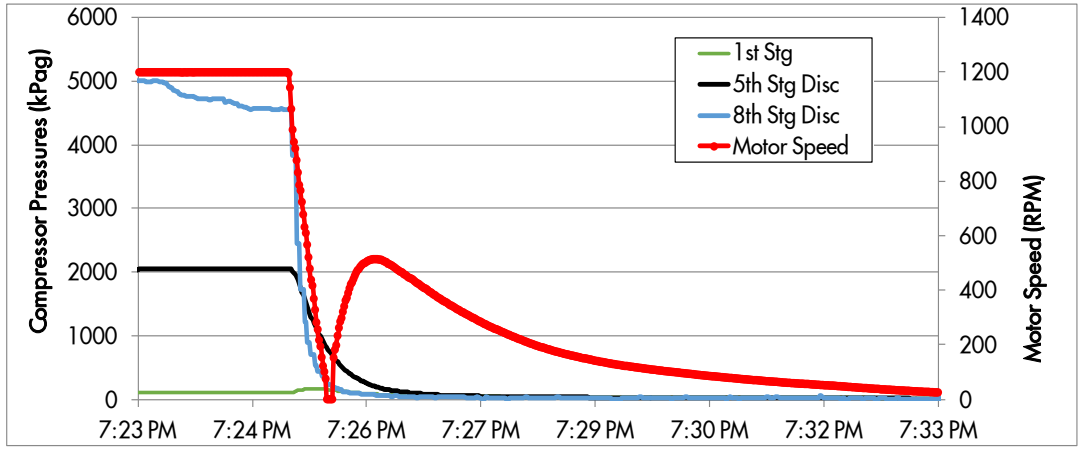


Facility Operations: Capture Unit and HMU

Capture Issues

Compressor Reverse Rotation

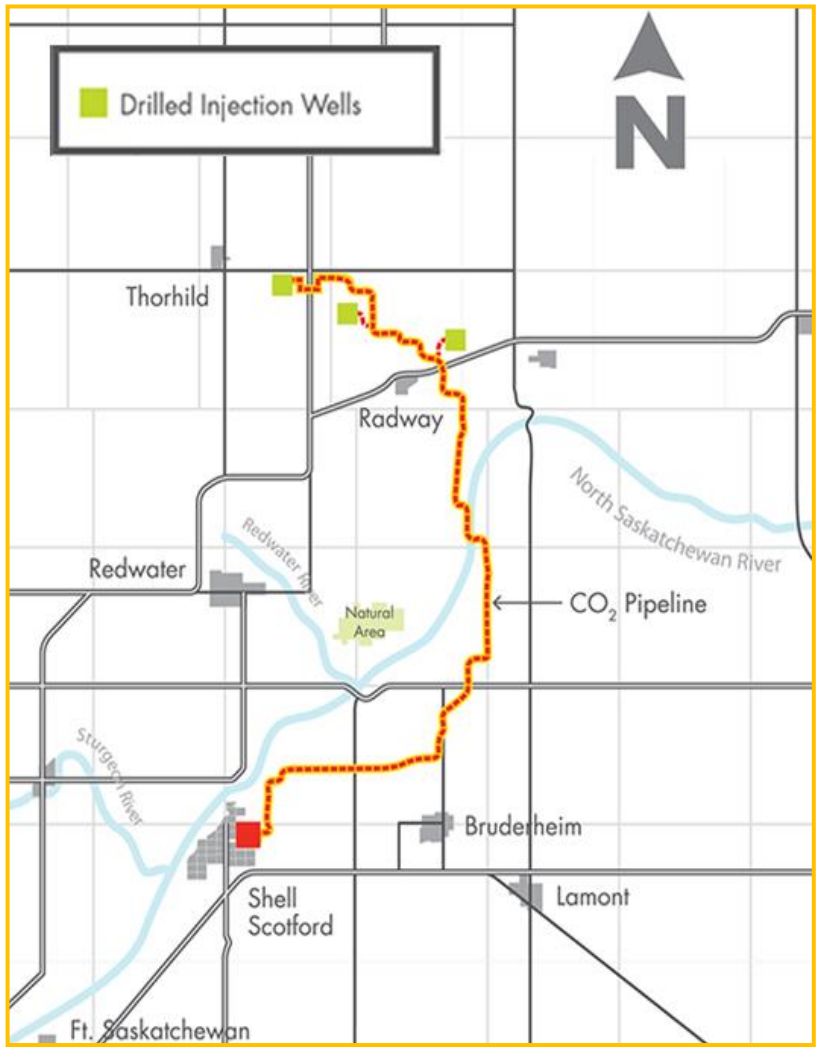
- First compressor shutdown in May 2015 resulted in reverse rotation up to 500 rpm after rapid deceleration
- Additional blow-off capacity added to 4th, 5th, and 6th compressor stages
- Successful test of the new blow-off arrangement in August 2015



Other Issues

- Some furnace issues on HMU3 limiting capture
- Carbon steel in low pH water service
- Discharge to water treatment not properly scoped
- Foaming/flooding in the amine absorbers tied to carbon filters

Quest Pipeline



- 65 km, 12" CO_2 pipeline with 6 block valves (every 4-15 km)
- Route selected to meet stakeholder requirements
  - Over 330 ROW crossings
  - 30+ re-routes to accommodate landowner input
- Design pressure: 14.8 Mpa
- Material – Z245.1 Carbon Steel
  - High strength and high toughness at low temperature to prevent long running ductile fracture

Pipeline Issues

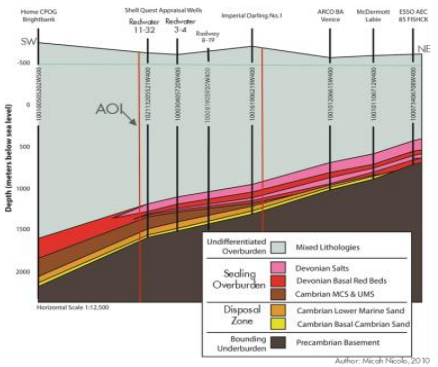
- Pipeline Pigging Receiver Design – not able to accommodate all pig sizes, including cleaning, maintenance and smart pigs for inspection.
- Pig Receiver Locations - only allow pigging up to LBV3 when the final wellsite is not in use
- Solar Panel Reliability - not functional during winter days with limited sunlight, required additional fuel cells
- Analyser reliability – created regulatory issue and required additional sampling

Quest Storage Site Selection

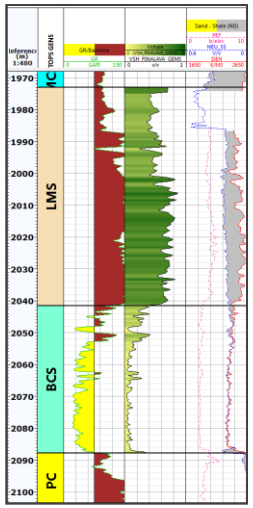
Table 3-1 Assessment of the BCS for Safety and Security of CO_2 Storage

Criterion Level	No	Criterion	Unfavourable	Preferred or Favourable	BCS Storage Complex
Critical	1	Reservoir-seal pairs; extensive and competent barrier to vertical flow	Poor, discontinuous, faulted and/or breached	Intermediate and excellent; many pairs (multi-layered system)	Three major seals (Middle Cambrian Shale [MCS], Lower Lotsberg and Upper Lotsberg Salts) continuous over entire CO_2 storage AOI. Salt aquicludes thicken up dip to NE.
	2	Pressure regime	Overpressured pressure gradients >14 kPa/m	Pressure gradients less than 12 kPa/m	Normally pressured <12 kPa/m
	3	Monitoring potential	Absent	Present	Present
	4	Affecting protected groundwater quality	Yes	No	No
Essential	5	Seismicity	High	≤ Moderate	Low
	6	Faulting and fracturing intensity	Extensive	Limited to moderate	Limited. No faults penetrating major seal observed on 2D or 3D seismic.
	7	Hydrogeology	Short flow systems, or compaction flow, Saline aquifers in communication with protected groundwater aquifers	Intermediate and regional-scale flow	Intermediate and regional-scale flow-saline aquifer not in communication with groundwater
Desirable	8	Depth	< 750-800 m	> 800 m	> 2,000 m
	9	Located within fold belts	Yes	No	No
Desirable (cont'd)	10	Adverse diagenesis	Significant	Low	Low
	11	Geothermal regime	Gradients ≥35°C/km and low surface temperature	Gradients <35°C/km and low surface temperature	Gradients <35°C/km and low surface temperature
	12	Temperature	<35°C	≥35°C	60°C
	13	Pressure	<7.5 MPa	≥7.5 MPa	20.45 MPa
	14	Thickness	<20 m	≥20 m	>35 m
	15	Porosity	<10%	≥10%	16%
	16	Permeability	<20 mD	≥20 mD	Average over AOI 20-500 mD
	17	Caprock thickness	<10 m	≥10 m	Three caprocks MCS 21 m to 75 m L. Lotsberg Salt 9 m to 41 m U. Lotsberg Salt 53 m to 94 m
	18	Well density	High	Low to moderate	Low

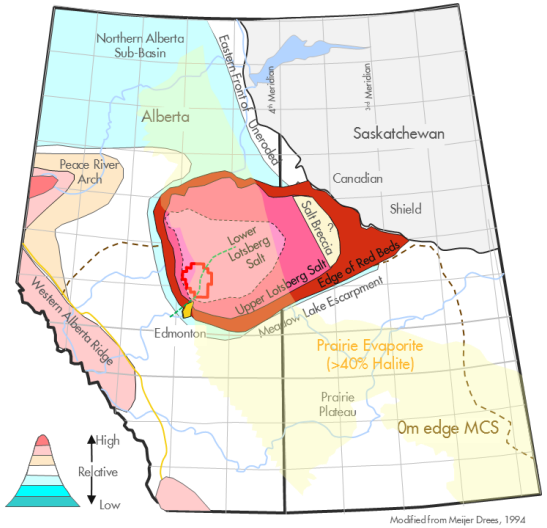
SOURCE: CCS Site Selection and Characterization Criteria – Review and Synthesis: Alberta Research Council, Draft submission to IEA GHG R&D Program June 2009.



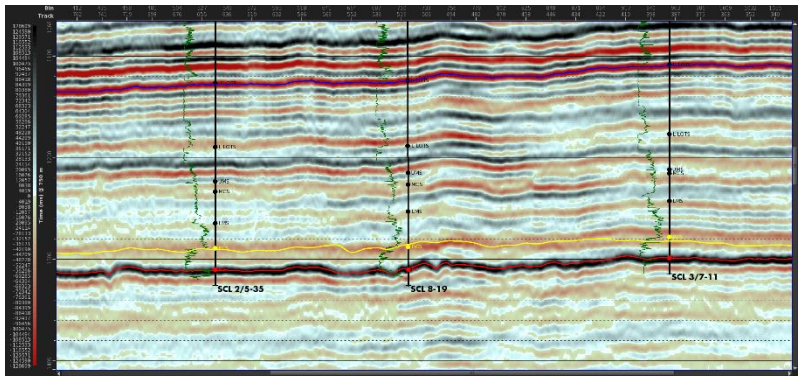
Stratigraphy



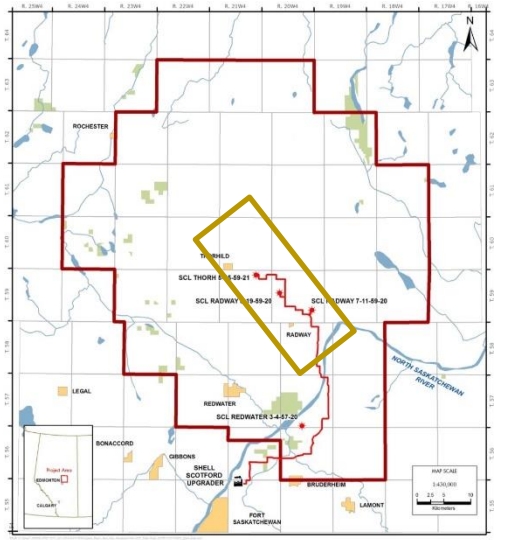
Reservoir Quality



Top Seals



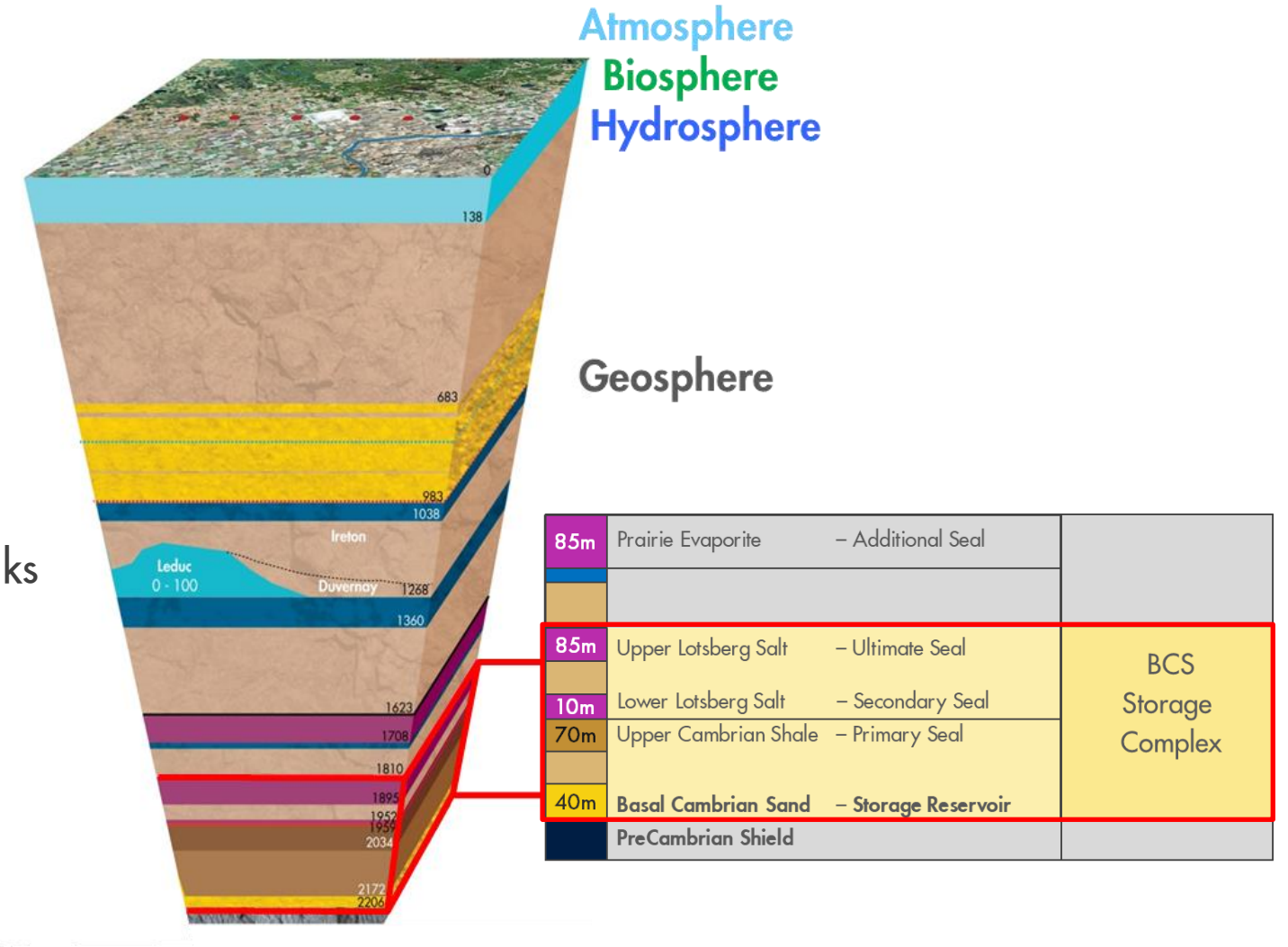
Fractures/faults



3rd Party Interference

Storage Geology

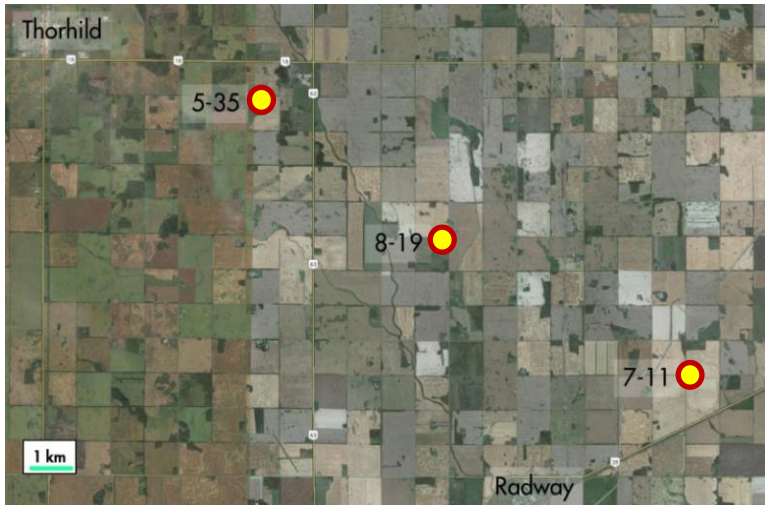
- High Quality Reservoir: Basal Cambrian Sands (17% porosity, 1000 mD permeability) at a depth of 2000 m
- Seals: thick, regionally extensive: Middle Cambrian Shale (70m) and Lotsberg Salts (100m)
- Existing fluid: saturated saline brine
- Very secure storage – the only possible leaks sites are at the wells
- Comprehensive Measurement, Monitoring and Verification (MMV) Plan

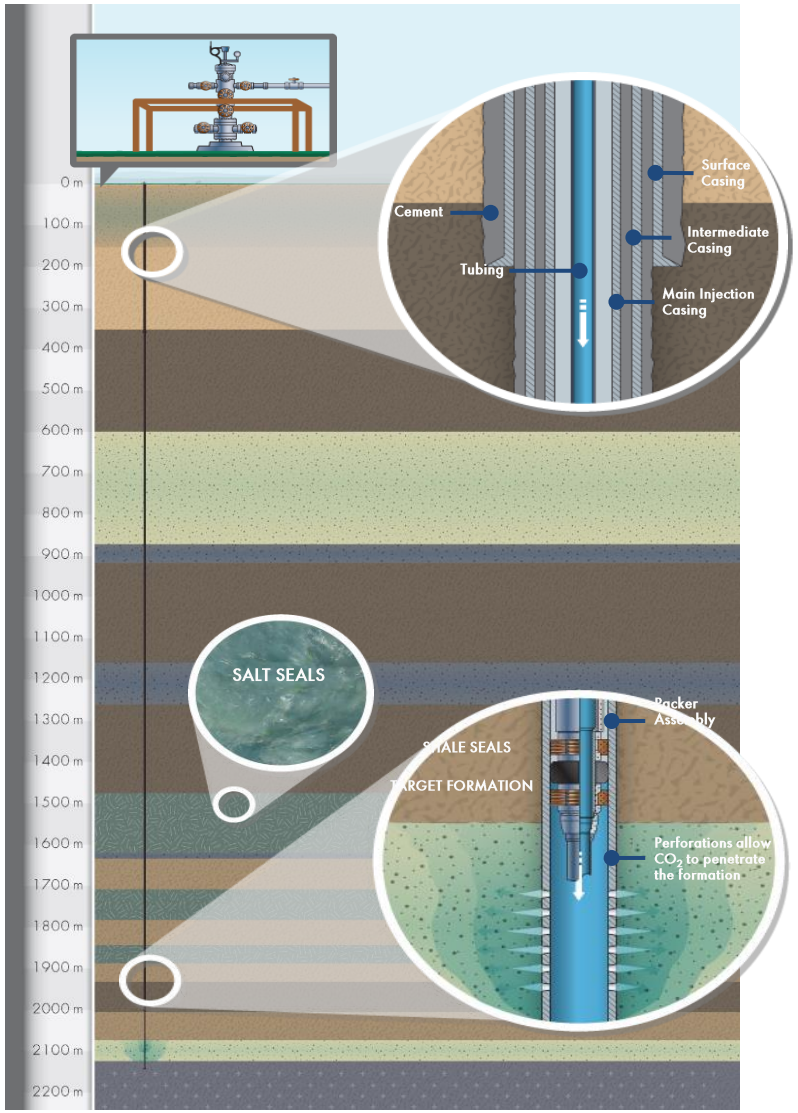


Wells and Drilling

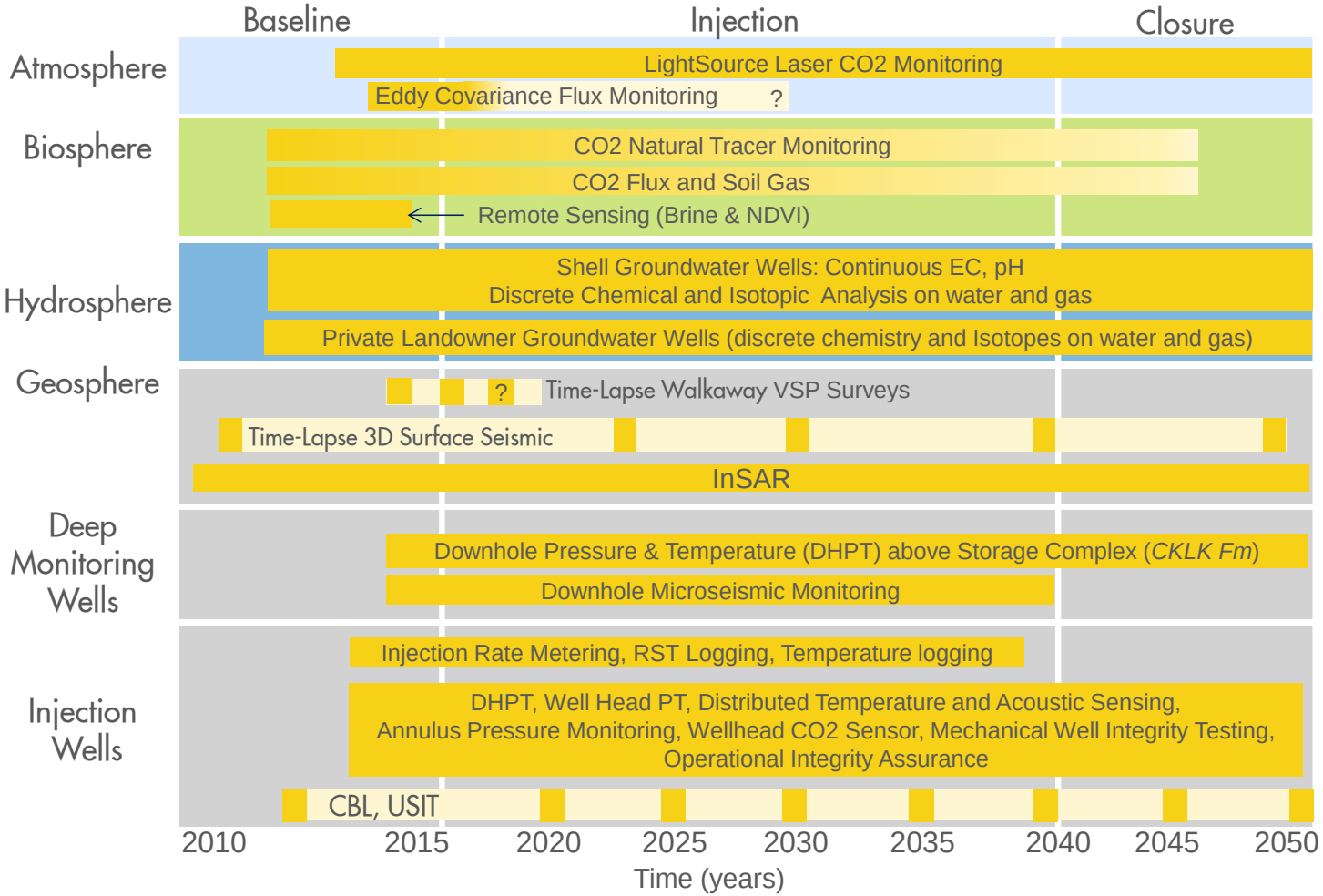
Storage Facility consists of three well pads:

- 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 the freshwater zone, all cemented to surface: very secure



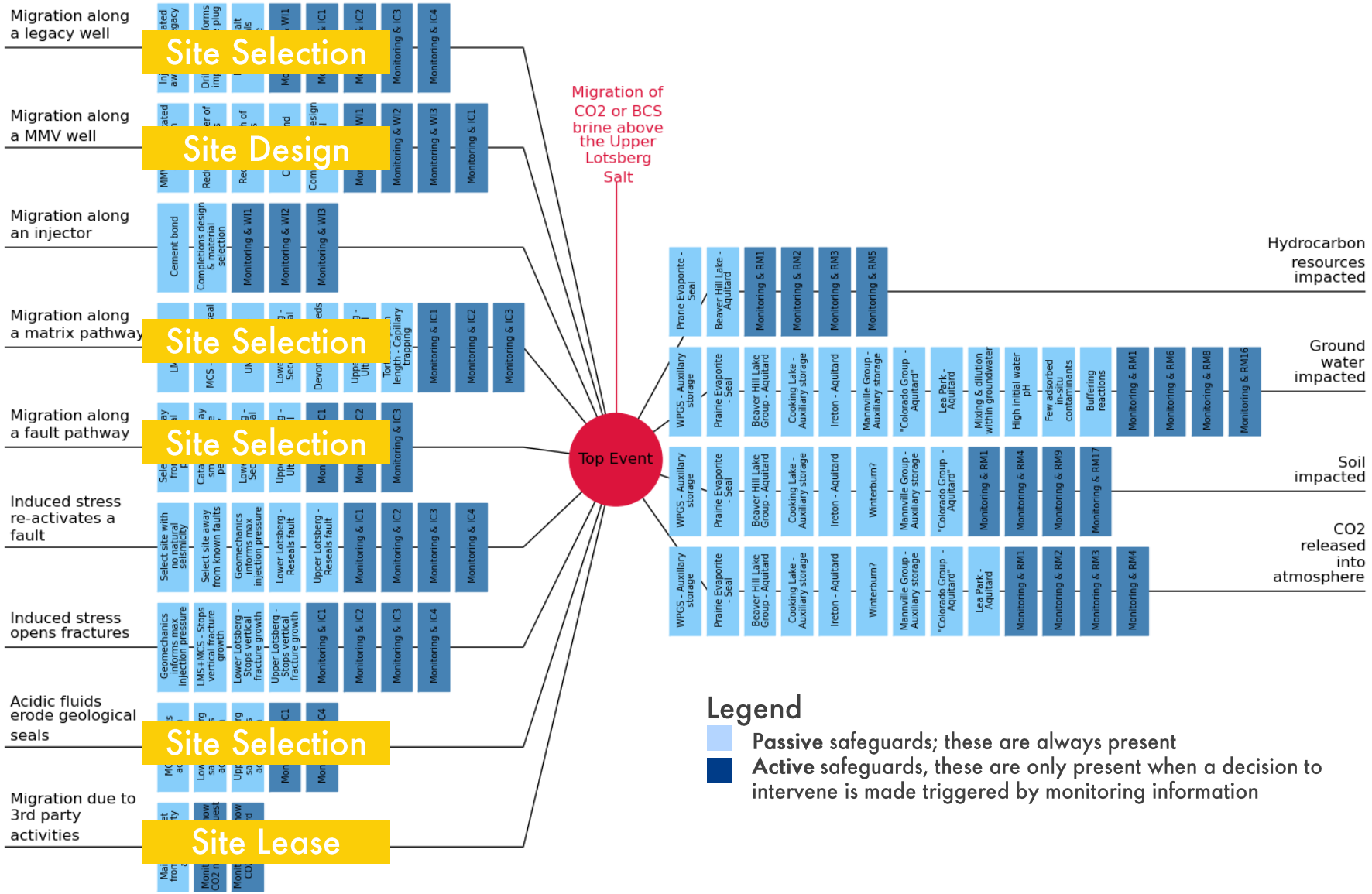


Quest MMV Plan 2015: Pre-injection

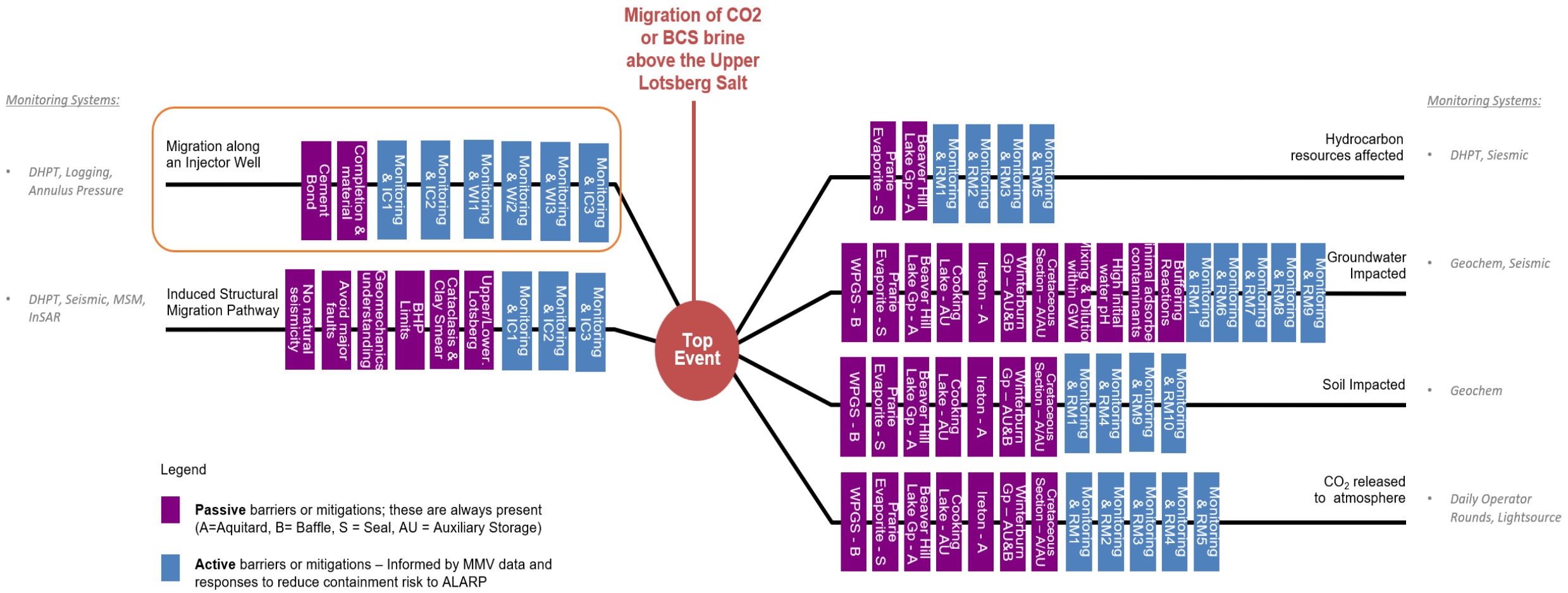


- Addresses Containment and Conformance
- First of a kind – conservative approach
- Comprehensive: from atmosphere to geosphere
- Risk-based, site-specific and independently reviewed
- Combination of new and traditional technologies
- Considerable baseline data collected before start-up
- Extensive: expensive
- Adaptive – updated every 3 years, learning from experience

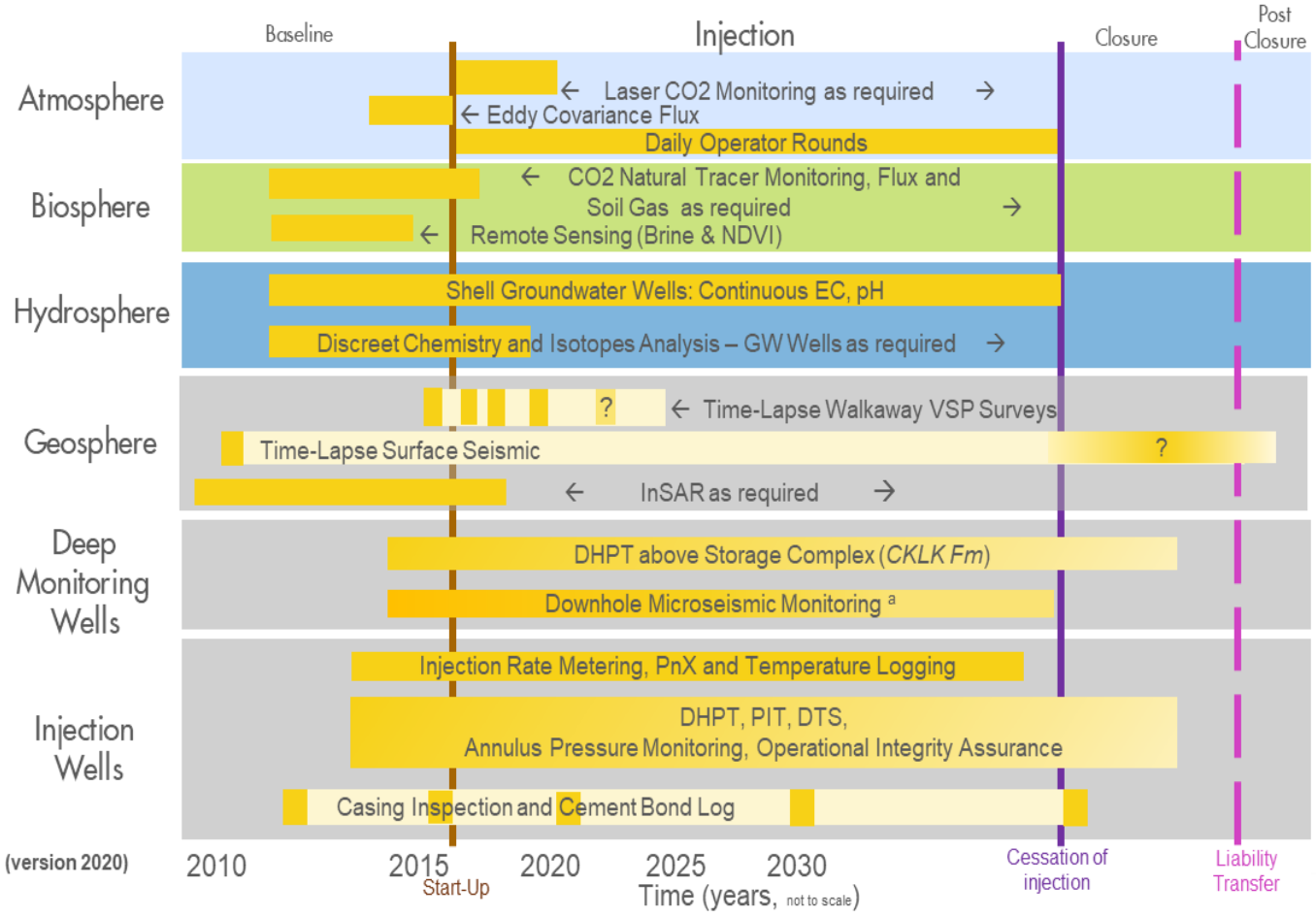
Pre-injection Containment Risk Bow-tie for Quest



Bow-tie: Quest Containment – 2020 MMV Plan



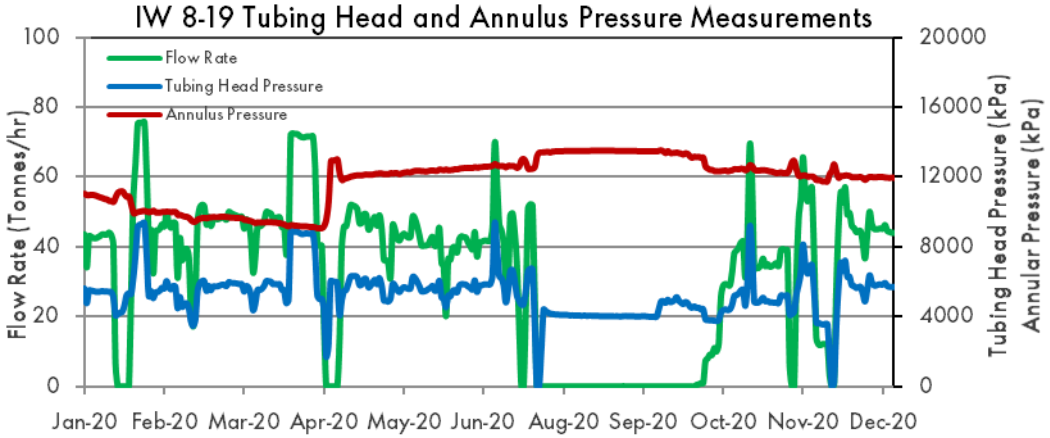
Measurement, Monitoring and Verification



- Focus on addressing key risks: drive towards ALARP
- Reduce or eliminate those technologies that do not drive decisions
- Focus on well integrity and near well-bore
- Tiered approach – much of the data analysis is on as needed basis:
  - Tier 1: early warning system – continuous monitoring near well-bore
  - Tier 2: periodic monitoring near well-bore
  - Tier 3: longer time-frame risks and contingent data that can be analysed in case of Tier 1/2 triggers

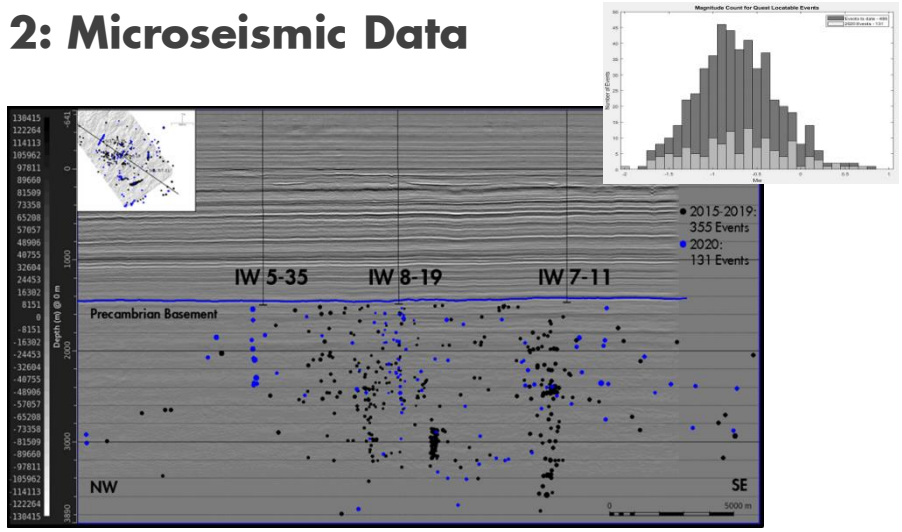
MMV Technology Examples

Tier 1: Tubing Head and Annular Pressures



- Essential well integrity monitoring
- Production casing by tubing annulus contains Drillsol with a nitrogen (N2) cushion above
- Stable pressures and Drillsol levels confirm annular integrity

Tier 2: Microseismic Data

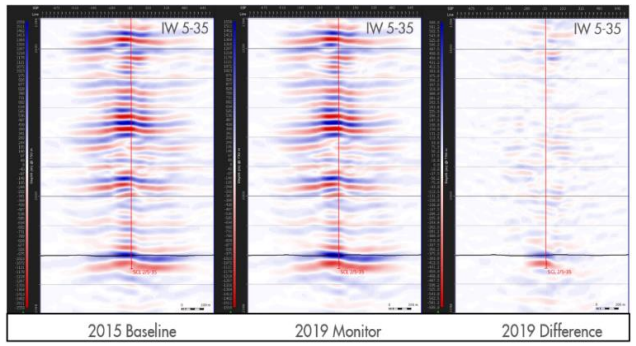


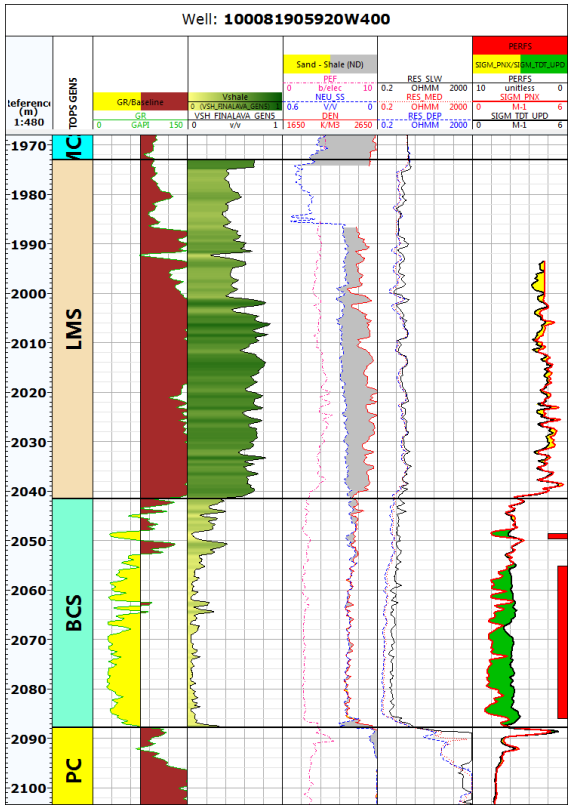
Distribution of microseismic events in depth, 2016-2020

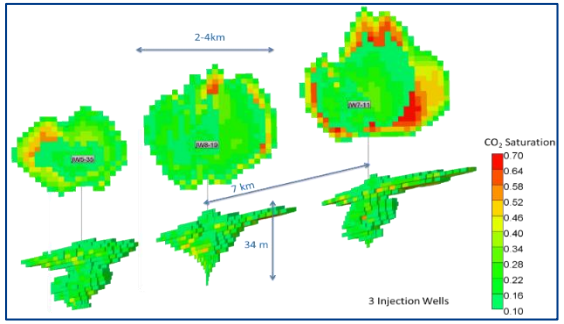
- Geophone array in monitoring well
- Continuous recording, daily analysis and reporting
- Event locations in the basement and small magnitudes confirm no risk to containment

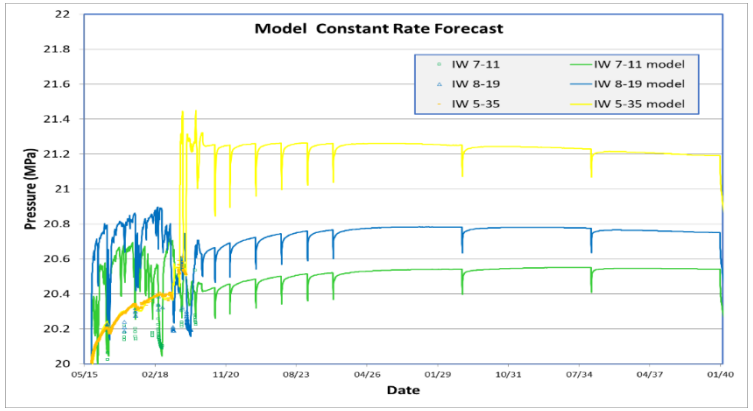
Conformance Monitoring – Modelling

- Time lapse Vertical Seismic Profiles used to image the change in lateral extent of the CO_2 plume over time
- Pulse Neutron Logs used to verify the vertical distribution of CO_2 in the reservoir
- Model has been refined with improved reservoir properties – good history match achieved
- Pressure build-up (ΔP) in the BCS forecast to be less than 2 MPa over the life of the project



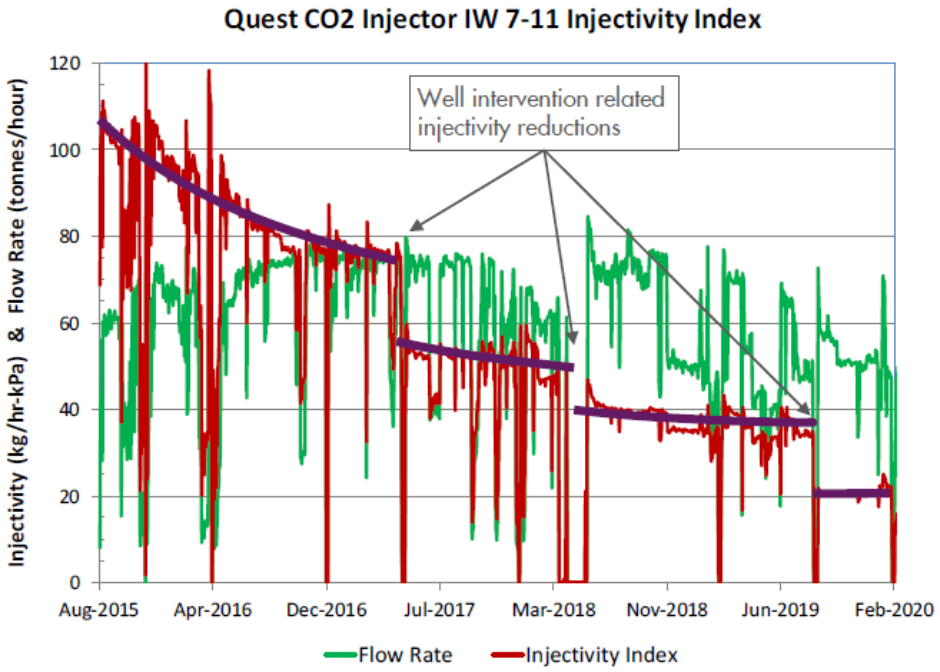


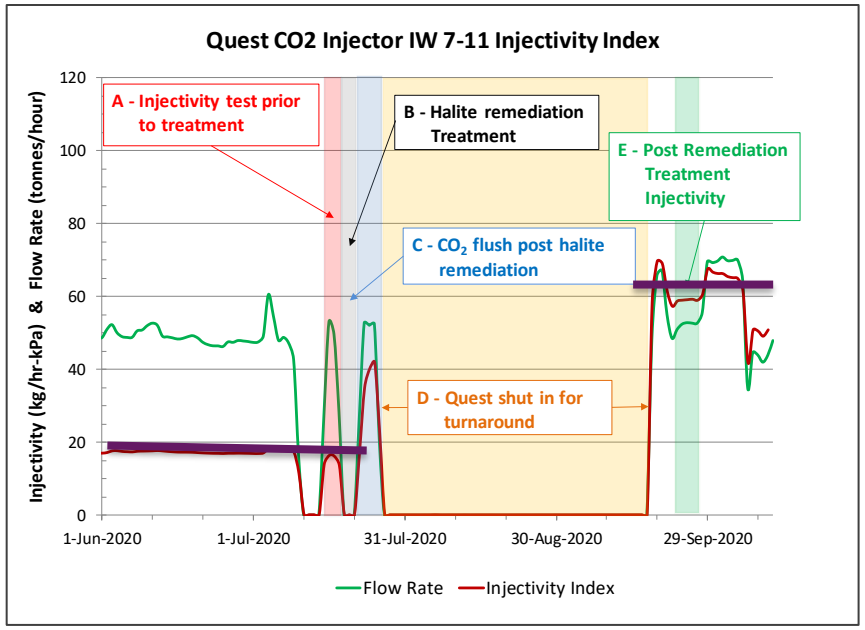




Storage Issues – Injectivity Decline

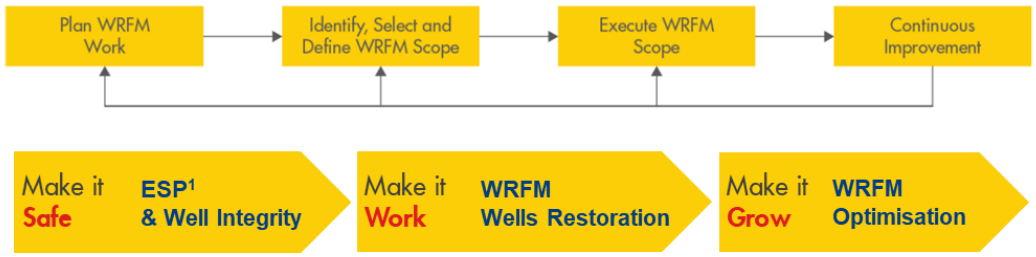
- Declining injectivity due to halite precipitation: Notable drops following well interventions
- Not a concern for first four years of injection
- Remediation with water flush successfully reversed decline in 2019
- Remediation with water flush successfully reversed decline in 2019 > 250% increase in injectivity!
- Subsequently applied to all 3 wells – all had excellent results





Storage Issues

- Hydrate formation during first post-injection logging operation, caused operational delays
- "CO_2 compatible" elastomers swelled during depressurization, making retrieval difficult
- Weeping well head seals - looks like possible issues with material coatings or grease compatibility



- Subsurface operational processes were new to Downstream – getting them established was difficult
- Onboarding wells/MMV technologies to a DS site was very challenging
- Seismic imaging/monitoring below multiple coals and salt took several iterations

Quest – Six Years of Operations

- Operations are continuing smoothly: >98% reliability
- Capture and monitoring costs well below expectations
- Amine and TEG recycle has been very high
- Well performance has been good, more than enough capacity with 3 wells running
- Measuring Monitoring and Verification system working well – well logging and seismic confirm CO_2 plume developing as expected
- **Through the end of 2021, Quest has captured and safely stored more than 6.5 M tonnes of CO_2**