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Reservoir Modelling and Geomechanics of Hydrogen Storage at the CO2CRC Otway International Test Centre

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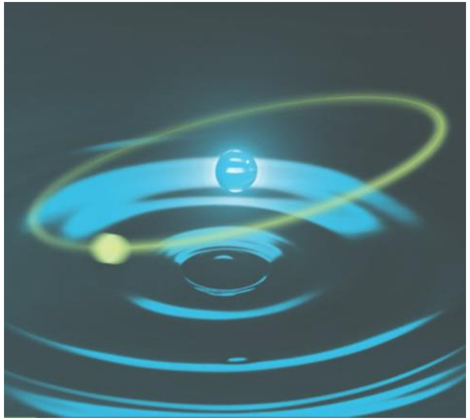

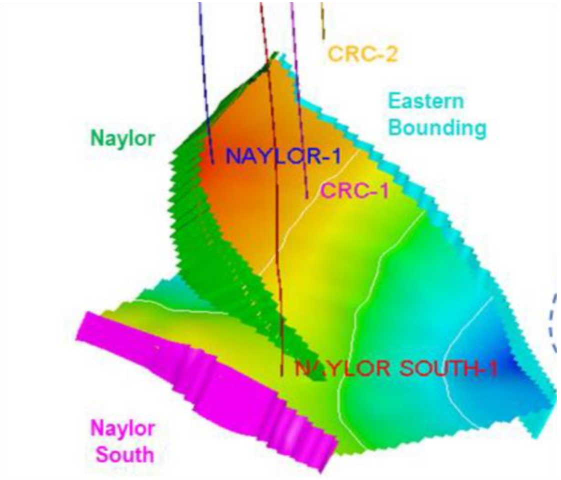

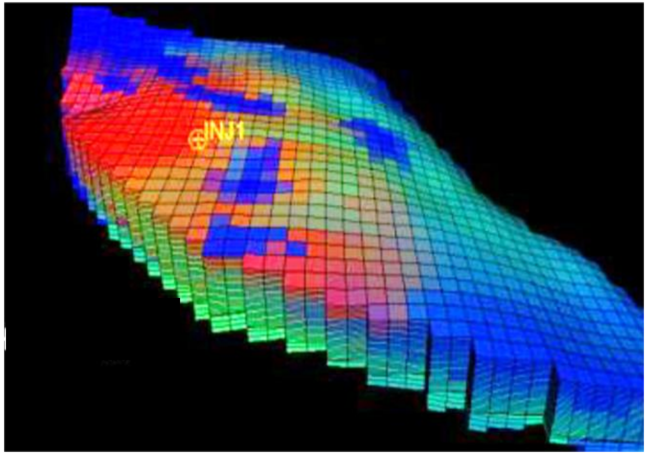

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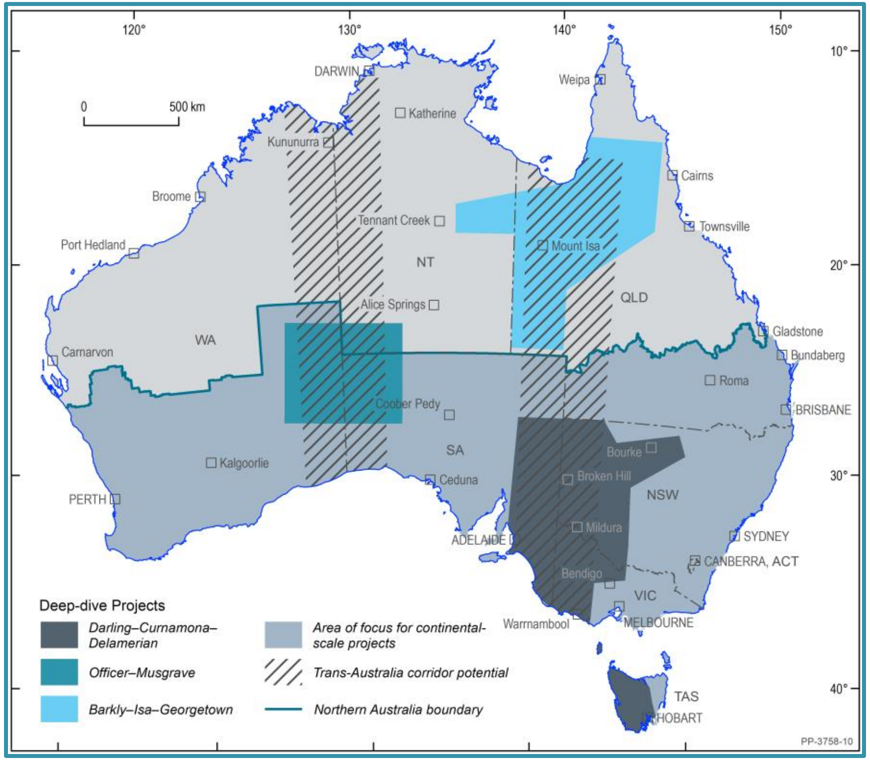
Exploring for the Future Programme and the Hydrogen Economy

- $124.5M Programme

Australia's Future Energy Resources:

A Project within EFTF to understand energy resource potential

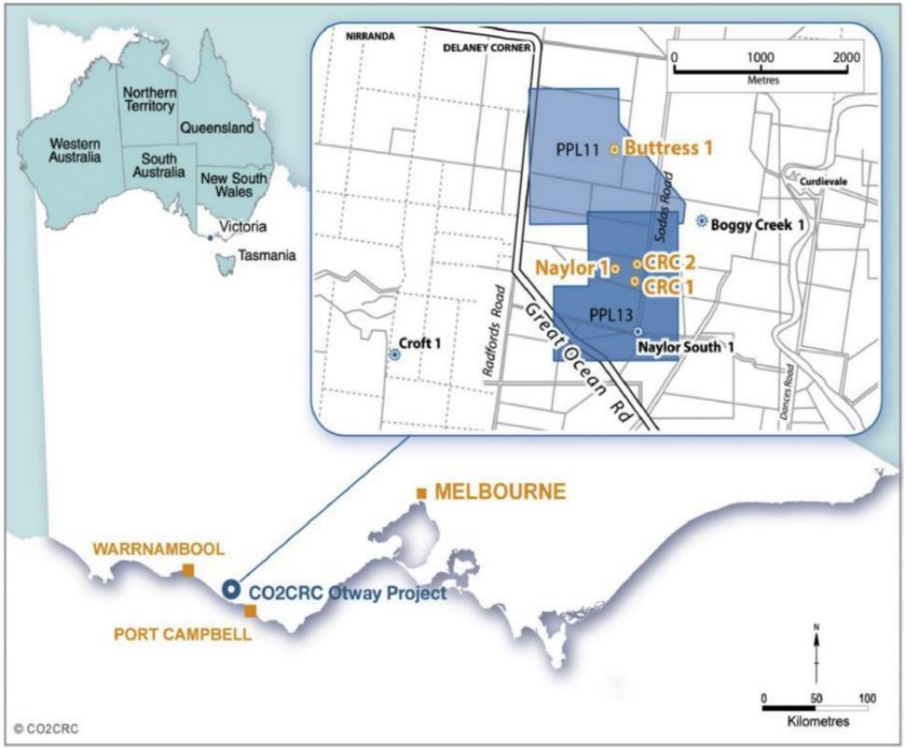
- Gas, oil, and CO_2 geological storage potential in underexplored basins
- **Hydrogen storage and sources**
- CO2-EOR in residual oil zones
- Basin inventory



www.ga.gov.au/eftf

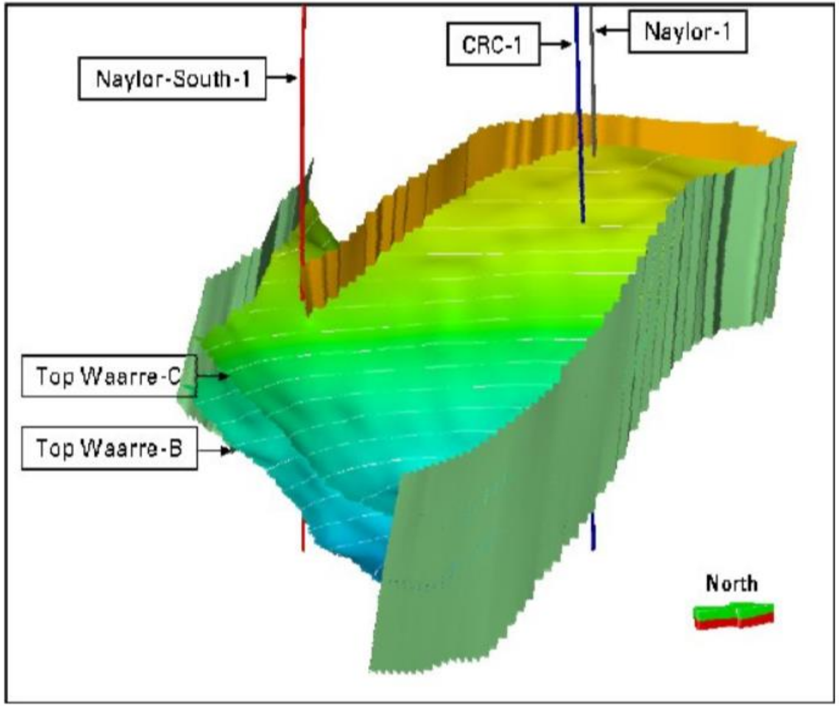
Aims of Otway H2 Storage Study

- Use the Naylor Field at the Otway International Test Centre as a template for reservoir and geomechanical modelling of H2 storage
- Model the multicyclic injection of hydrogen into a depleted gas field and identify any flow related or geomechanical risks
- Conduct extensive sensitivity analysis (cushion gas, diffusion, methanogenesis, temperature etc)
- Compare hydrogen injection to model runs using CO2 and methane to identify any key differences.



Naylor Field

- Fault-bound anticline, with sealing faults on 3 sides of the structure
- Gas field in production until 2003
- Used by the CO2CRC from 2007 as a CO2 storage pilot project
- Hydrogen injection and production in this study is conducted near crest of anticline
- ECLIPSE models constructed in 2006 by CO2CRC are the foundation for the H2 modelling

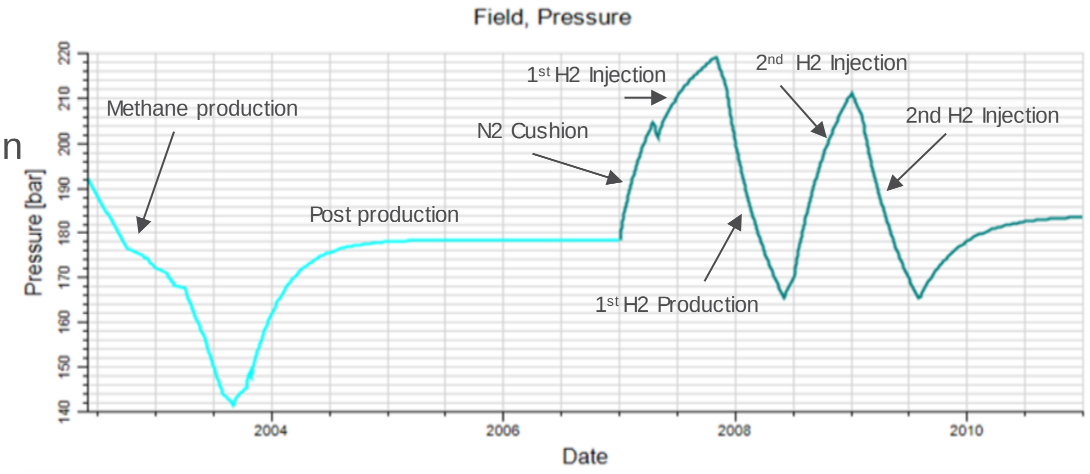


Berard et al., 2008

Initial Reservoir Simulations without Geomechanics

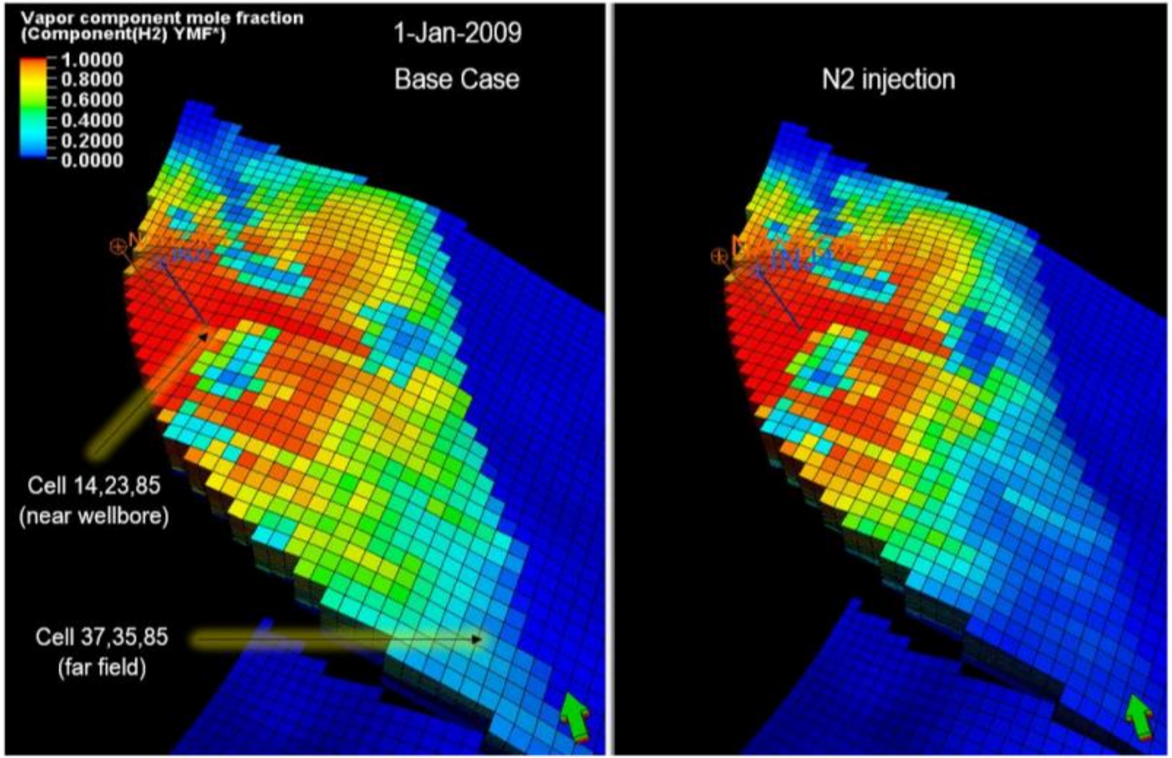
- Ensure modified grid performs close to reference grid
- Conduct sensitivity analysis for different parameters (cushion gas, diffusivity, dissolution, methanogenesis)

- Reservoir volumetric rate of 1500 m^3/d for both injection and production
- 2 injection production cycles
- 1 month shut in between
- 40 days N2 cushion gas



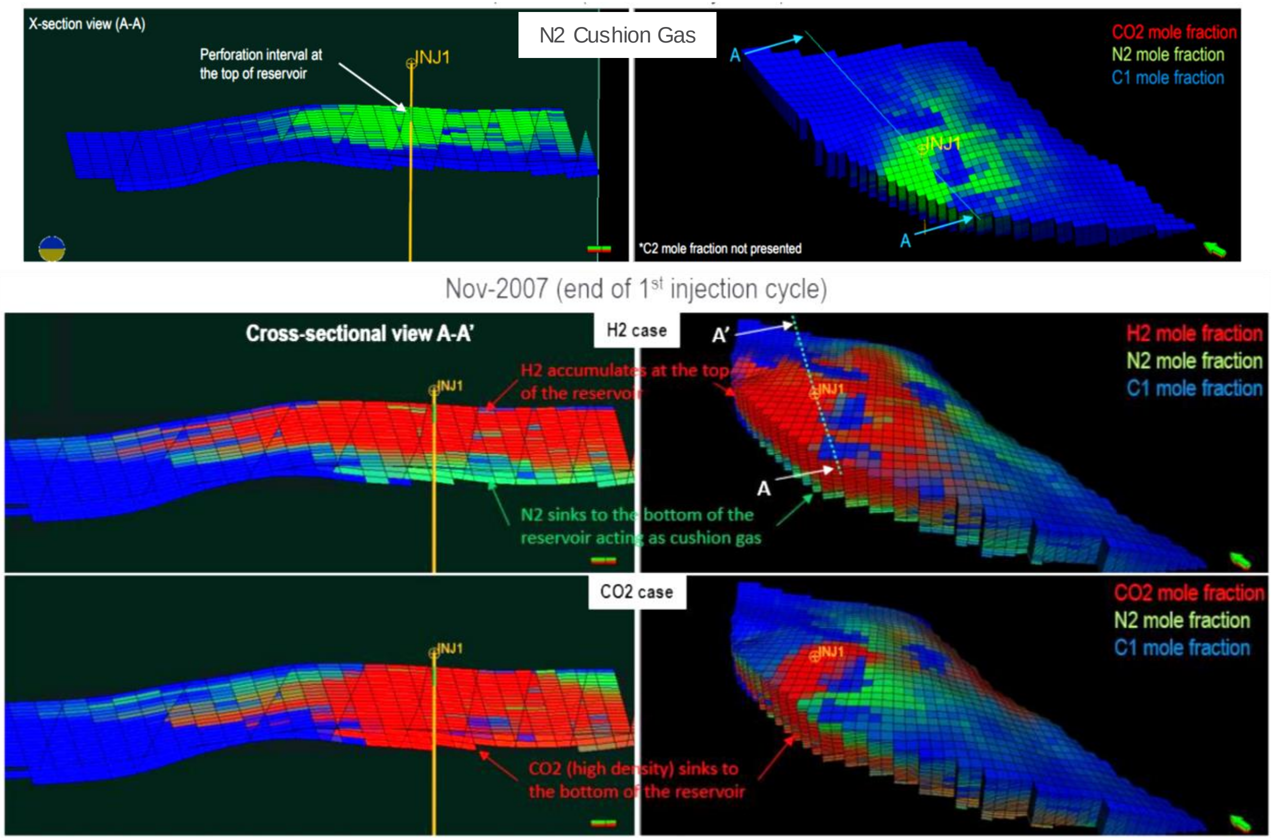
Importance of Cushion Gas

- N_2 cushion gas ensures efficient delivery of H_2 gas
- Constrains H_2 to crest of anticline
- Initial N_2 cushion gas is used for later geomechanical simulations



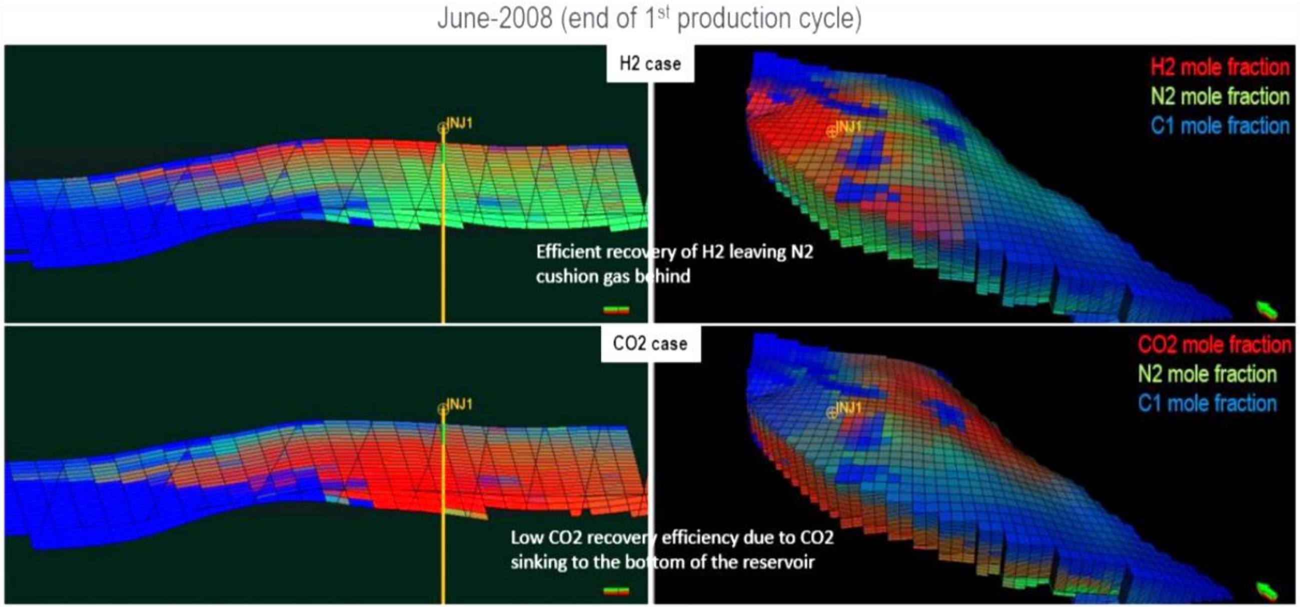
H2 Storage vs CO2 (Injection)

- N2 cushion gas initially fills crest of structure
- CO2 sinks to lower reservoir levels and displaces N2 laterally
- H2 remains at crest of structure



H2 Storage vs CO2 (Production)

- Little CO2 produced relative to H2 and significant cushion gas is extracted
- CO2 remains in lower portions of reservoir, which is favourable for CO2 storage
- H2 is produced very efficiently, with most cushion gas remaining in reservoir.



H2 Storage vs CO2 (Production)

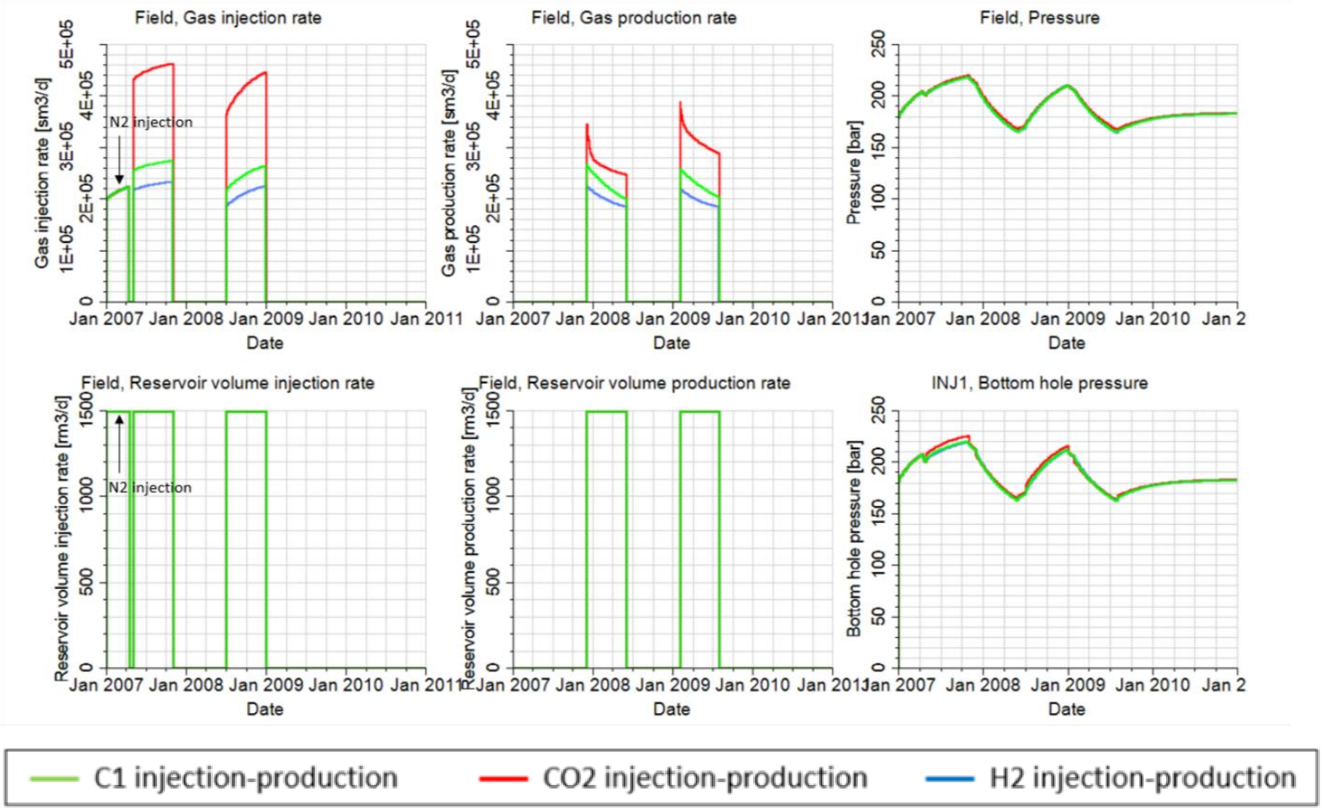
- Subsurface behaviour of CO2 and H2 result in large differences in gas recovery
- H2 recovery improves with successive cycles

Comparison of pressure and recovery of H2, CO2 and C1 injection-production cases with N2 as cushion gas

Component	1st Cycle					2nd Cycle				
	Total component injected (kg-mole 10^6)	Total component produced (kg-mole 10^6)	% injected component recovery	Max reservoir pressure (bar)	Max BHP (bar)	Total component injected (kg-mole 10^6)	Total component produced (kg-mole 10^6)	% injected component recovery	Max reservoir pressure (bar)	Max BHP (bar)
CO2	3.52	1.14	32%	221.5	228.1	3.26	1.93	59%	211.9	219.2
C1	2.08	1.46	70%	219.4	221.6	1.92	1.54	80%	211.2	213.8
H2	1.78	1.23	69%	219.7	220.7	1.65	1.30	79%	211.6	212.8

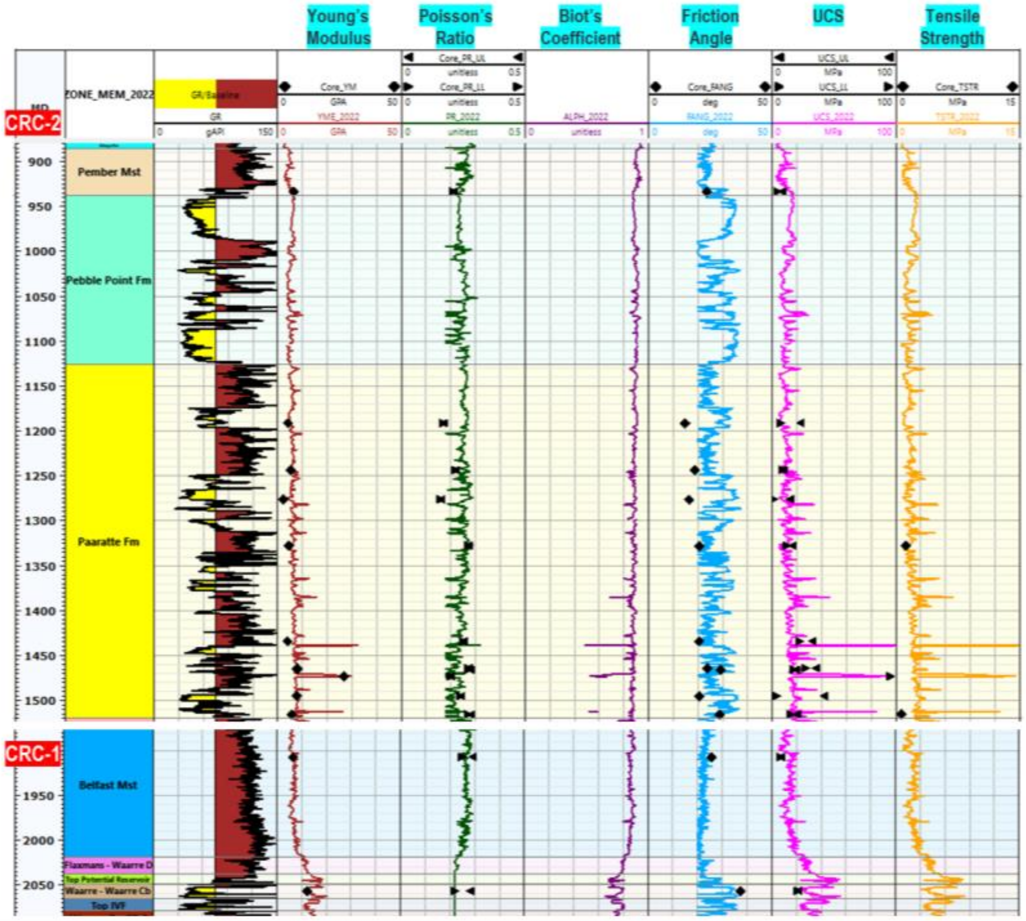
H2 Storage vs CO2 (Pressure differences)

- Injection and production rates for CO2 are highest due to greater density change
- Field pressures are the same for all 3 gases
- Bottom hole pressure for CO2 slightly larger due to greater viscosity



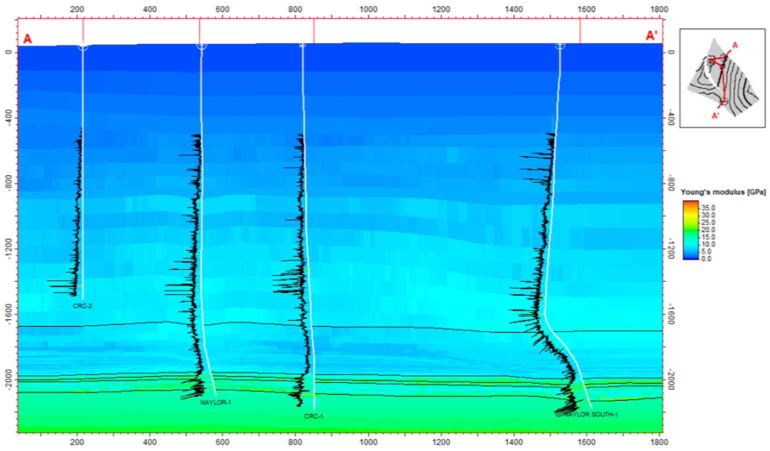
Geomechanical model

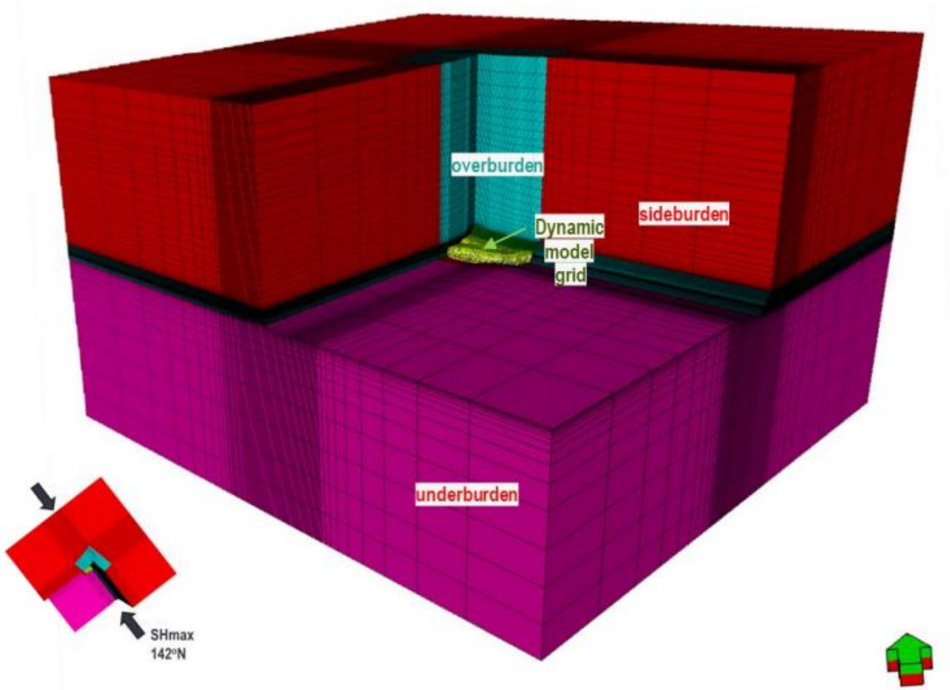
- Dynamic moduli using sonic and density logs
- Calibration of elastic properties using rock mechanical testing
- Stress orientations from previous mechanical studies
- Magnitude of maximum horizontal stress determined by iterative matching of synthetic borehole image to observed borehole features



Geomechanical Model Embedment

- Dynamic moduli using sonic and density logs
- Calibration of elastic properties using rock mechanical testing

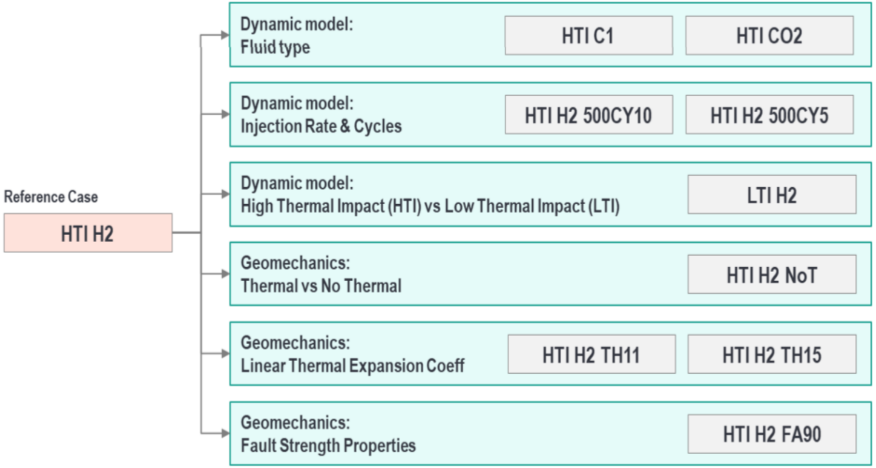




Dynamic Geomechanical Model Runs

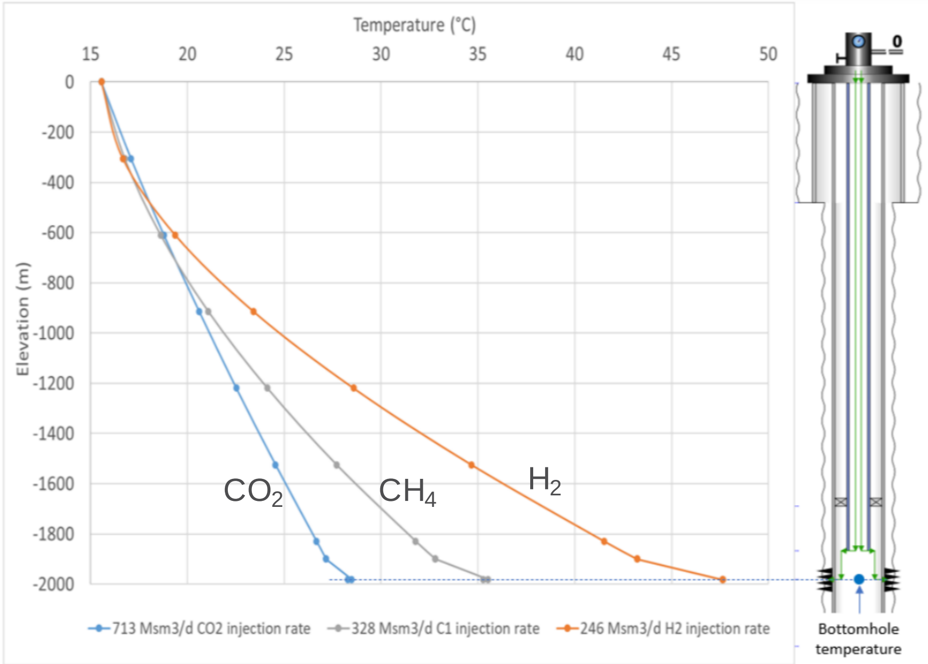
- Mostly run at standard injection and withdrawal rate
- More cycles than uncoupled reservoir modelling
- Other parameters varied: thermal properties, injection rate, fault properties, gas type

CASE ID	Fluid	Rate (m3d)	# Cycles	ECL thermal	VIS thermal	Fault Prop
HTI H2	H2	1500	10	HTI	13E-6	FA 75%
HTI C1	C1	1500	10	HTI	13E-6	FA 75%
HTI CO2	CO2	1500	10	HTI	13E-6	FA 75%
HTI H2 500CY10	H2	500	10	HTI	13E-6	FA 75%
HTI H2 500CY5	H2	500	5	HTI	13E-6	FA 75%
LTI H2	H2	1500	10	LTI	13E-6	FA 75%
HTI H2 NoT	H2	1500	10	HTI	No DT	FA 75%
HTI H2 TH11	H2	1500	10	HTI	11E-6	FA 75%
HTI H2 TH15	H2	1500	10	HTI	15E-6	FA 75%
HTI H2 FA90	H2	1500	10	HTI	13E-6	FA 90%



Temperature Effects

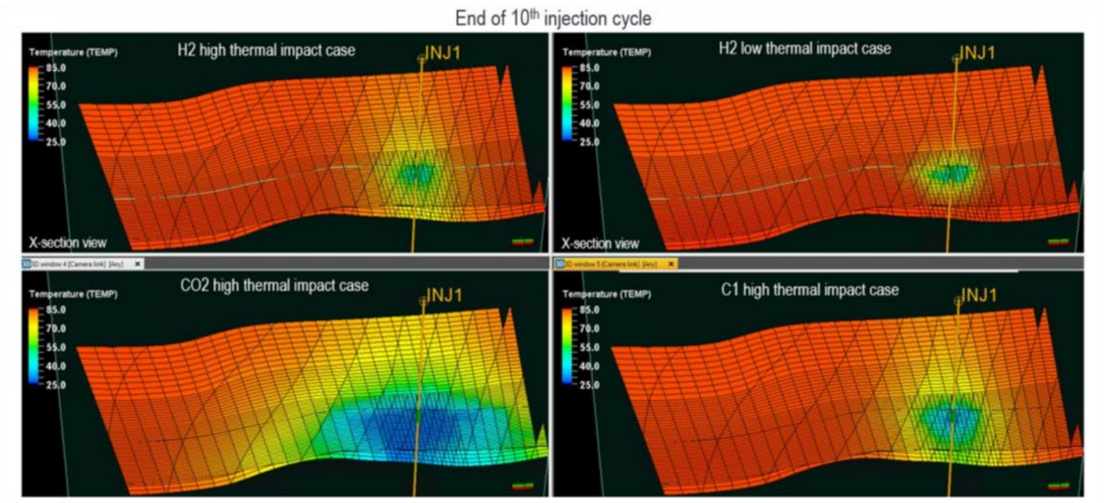
- Greatest geomechanical anomalies are driven by colder gases being introduced to a warm reservoir
- Different gas densities with depth lead to different thermal signatures for the different gases
- Injection rate for H2 is lower, therefore more equilibration with host rock
- CO2 requires high injection rate to meet 1500 m3/d flux at depth, therefore lower T at depth

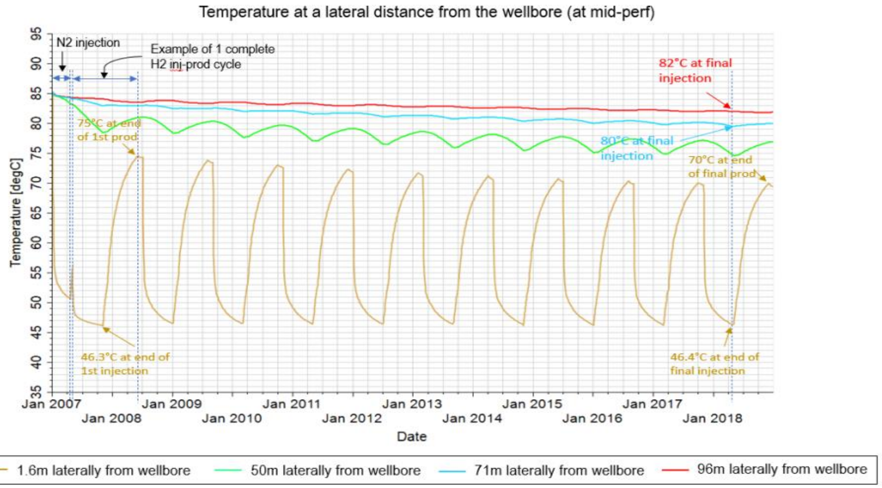


Injectant type	Reservoir volumetric injection rate (rm3/d)	Surface injection rate (sm3/d)	Bottom-hole pressure (bar)	Bottom-hole temperature (°C)
H2	1500	246,000	207.0	47.6
C1	1500	328,000	207.8	35.5
CO2	1500	713,000	210.7	28.5

Temperature Effects

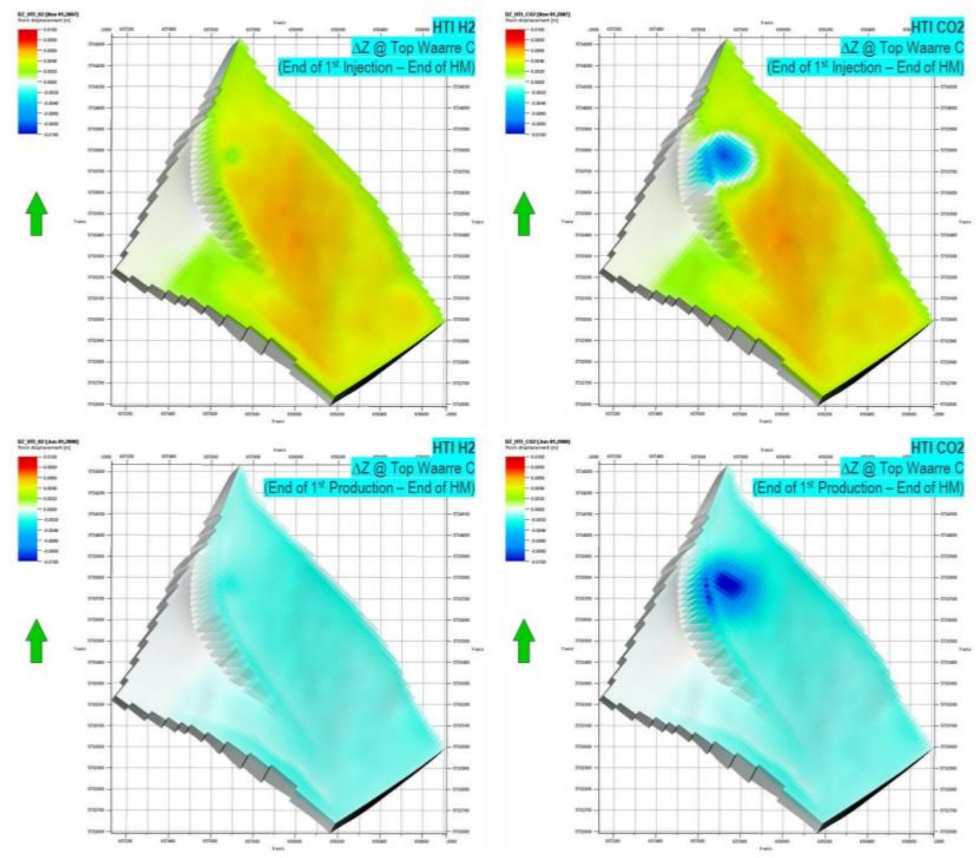
- Temperature change in reservoir is greatest for CO2 case
- H2 injection produces a smaller anomaly
- Thermal pulse propagates into the overlying caprock





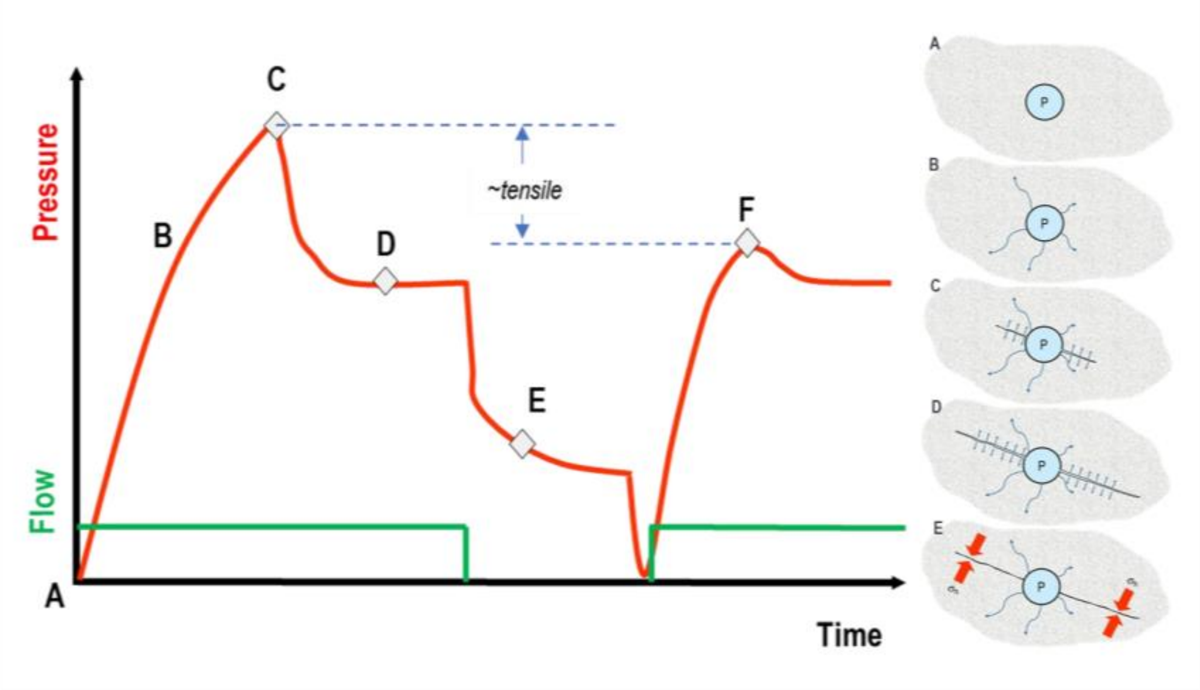
Reservoir Deformation

- Little reservoir deformation observed for H2 storage case
- Negative deformation occurs for CO2, even during pressurisation
- For CO2 thermal effects are stronger than the pressure effects



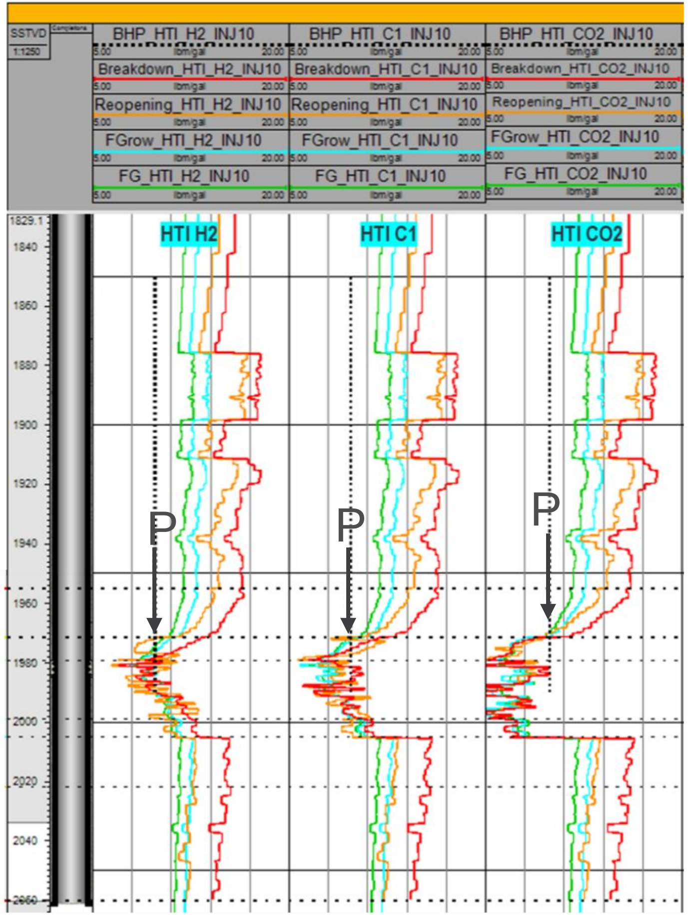
Impacts of Thermal Contraction on Fracture Pressure

- Fracture pressures depend on confining stress
- Cooling in wellbore region reduces confining stresses and facilitates fracturing.



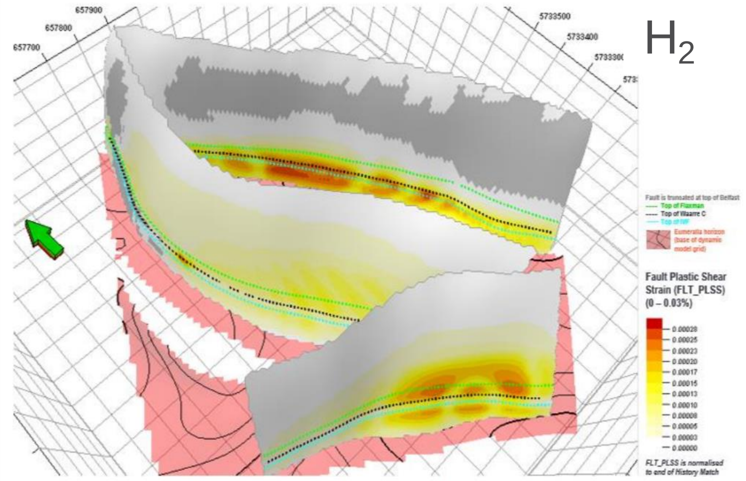
Thermally Induced Fracturing

- Thermal effects can depress fracture pressures below the wellbore pressure
- Effects are greatest for CO_2 models
- Fracture pressures are also depressed in transition zone and caprock
- Reducing injection and production rate significantly reduces thermal effects by allowing greater temperature equilibration



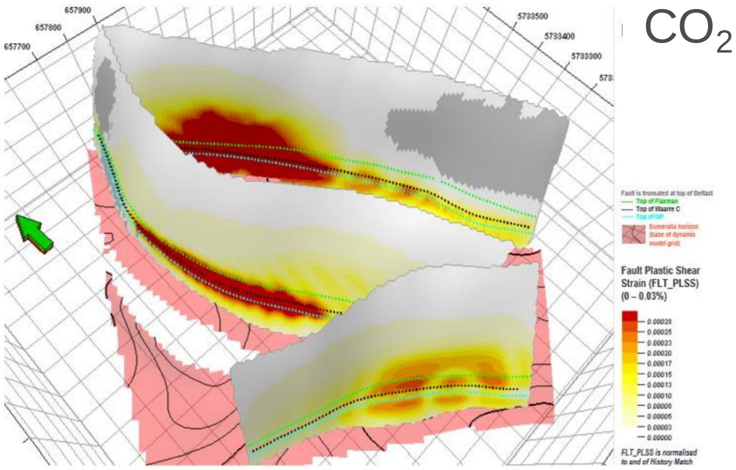
Fault Reactivation

- Thermal contraction and associated elastic relaxation results in plastic deformation along nearby faults
- Effects are much larger for CO2 than for H2
- Neither case reaches > 1% shear strain, which is empirically determined critical value



H_2

Figure 6-11: Fault Plastic Shear Strain at the end of Simulation for LTI H2 case



CO_2

Figure 6-9: Fault Plastic Shear Strain at the end of Simulation for HTI CO2 case

Key Observations

Geomechanics

- Model runs using CO_2 reach slightly higher pressures near the wellbore than H_2 and CH_4, for same injection rate at reservoir level
- H_2 exhibits least thermal cooling at reservoir level due to lower surface injection rates (highest formation volume factor)
- Thermally induced reservoir deformation is small for H_2 injection, relative to CO_2
- Thermal effects near well bore can reduce fracture pressures to critical levels
- Fracture pressures also modified in cap rock
- Reservoir deformation can also lead to plastic deformation on fault planes

Key Observations

Reservoir Simulations

- Presence of N_2 cushion gas is important; constrains H_2 to crest of anticline and improves deliverability
- Sensitivity models involving H_2 dissolution, diffusivity and methanogensis make insignificant difference
- H_2 and CH_4 remain near crest of anticline, while CO_2 sinks through N_2 cushion gas
- H_2 recovery rate from each injection-production cycle is approximately 70-80%
- Up to 56% of the N_2 cushion gas is produced by the 10^{th} cycle