Building a low emissions future

CO2CRC Otway Project

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Senior Manager – Technology Development

Carbon Sequestration Leadership Forum
June 13–14, 2023, Warsaw, Poland

CO2CRC is a world leader in applied CCUS research

We do research and commercially relevant demonstrations in CCUS applications.

We build and operate first of a kind plant and equipment.

We develop industry led technology options to accelerate commercial deployment.

We own and operate the Otway International Test Centre in South-West Victoria, Australia.

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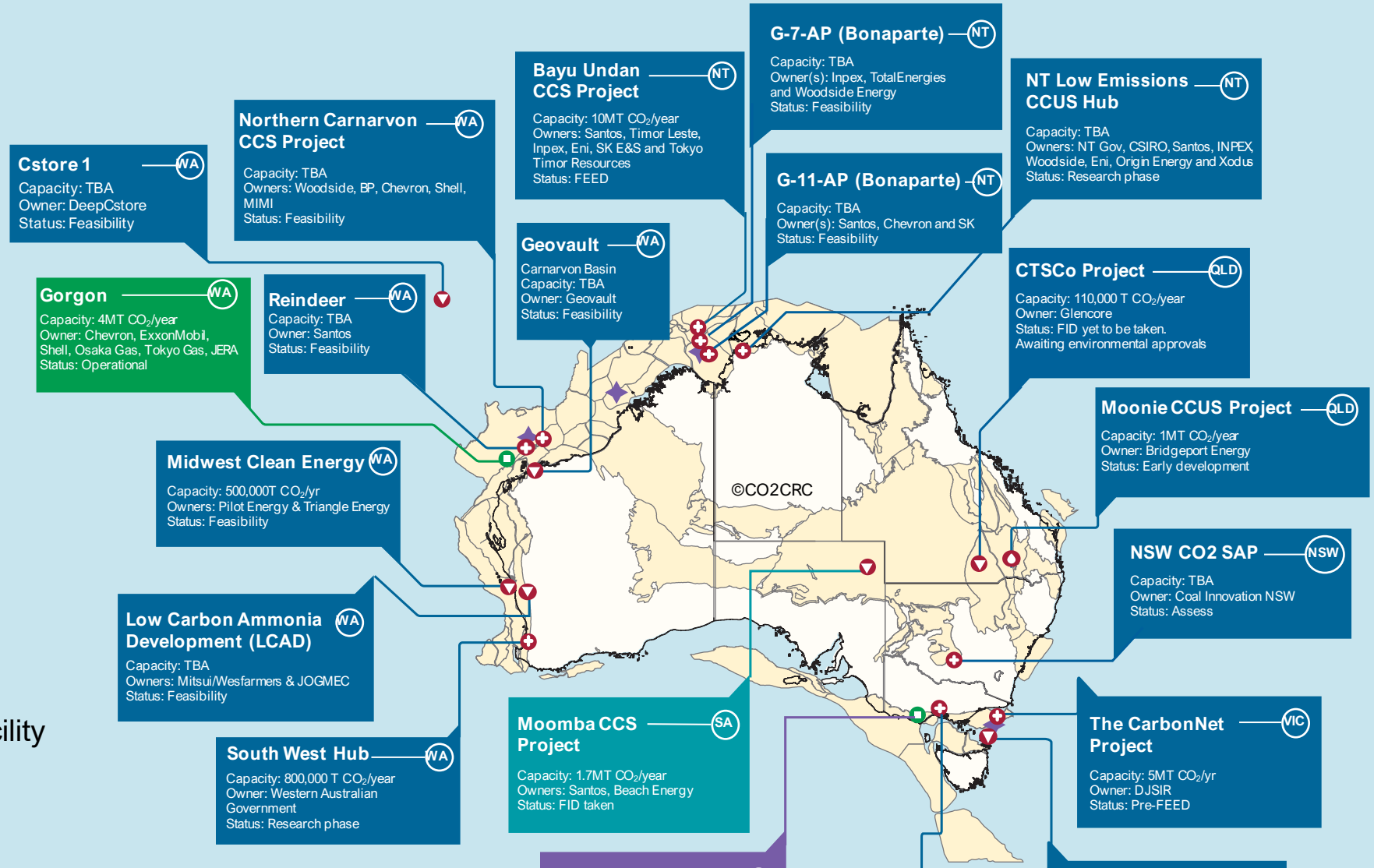
CCUS Projects in Australia 2023

- 1 Operational project
- 1 Final investment decision taken
- 17 Projects in feasibility
- 1 Pilot and demonstration facility



Cstore 1 (WA)
Capacity: TBA
Owner: DeepCstore
Status: Feasibility

Northern Carnarvon CCS Project (WA)
Capacity: TBA
Owners: Woodside, BP, Chevron, Shell, MIMI
Status: Feasibility

Bayu Undan CCS Project (NT)
Capacity: 10MT CO_2/year
Owners: Santos, Timor Leste, Inpex, Eni, SK E&S and Tokyo Timor Resources
Status: FEED

G-7-AP (Bonaparte) (NT)
Capacity: TBA
Owner(s): Inpex, TotalEnergies and Woodside Energy
Status: Feasibility

NT Low Emissions CCUS Hub (NT)
Capacity: TBA
Owners: NT Gov, CSIRO, Santos, INPEX, Woodside, Eni, Origin Energy and Xodus
Status: Research phase

Gorgon (WA)
Capacity: 4MT CO_2/year
Owner: Chevron, ExxonMobil, Shell, Osaka Gas, Tokyo Gas, JERA
Status: Operational

Reindeer (WA)
Capacity: TBA
Owner: Santos
Status: Feasibility

Geovault (WA)
Carnarvon Basin
Capacity: TBA
Owner: Geovault
Status: Feasibility

G-11-AP (Bonaparte) (NT)
Capacity: TBA
Owner(s): Santos, Chevron and SK
Status: Feasibility

CTSCo Project (QLD)
Capacity: 110,000 T CO_2/year
Owner: Glencore
Status: FID yet to be taken. Awaiting environmental approvals

Moonie CCUS Project (QLD)
Capacity: 1MT CO_2/year
Owner: Bridgeport Energy
Status: Early development

Midwest Clean Energy (WA)
Capacity: 500,000T CO_2/yr
Owners: Pilot Energy & Triangle Energy
Status: Feasibility

NSW CO2 SAP (NSW)
Capacity: TBA
Owner: Coal Innovation NSW
Status: Assess

Low Carbon Ammonia Development (LCAD) (WA)
Capacity: TBA
Owners: Mitsui/Wesfarmers & JOGMEC
Status: Feasibility

Moomba CCS Project (SA)
Capacity: 1.7MT CO_2/year
Owners: Santos, Beach Energy
Status: FID taken

The CarbonNet Project (VIC)
Capacity: 5MT CO_2/yr
Owner: DJSIR
Status: Pre-FEED

South West Hub (WA)
Capacity: 800,000 T CO_2/year
Owner: Western Australian Government
Status: Research phase

CO2CRC Otway International Test Centre (VIC)
Capacity: Research facility
Owner: CO2CRC
Status: Research project

Otway CCS Hub (VIC)
Capacity: 200,000 T CO_2/year
Owner: Beach Energy
Status: Feasibility

The SEA CCS Hub (VIC)
Capacity: 2MT CO_2/yr
Owner: ExxonMobil & Woodside
Status: FEED

Legend

- Operational
- CO2-EOR
- CCS
- Storage hub
- Offshore CCS permits
- Geological Basins

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Otway International Test Centre

CO2CRC's Otway International Test Centre enables field scale research and development of CCUS & H_2 storage technologies for commercial deployment.

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Otway International Test Centre

Key Success Factors

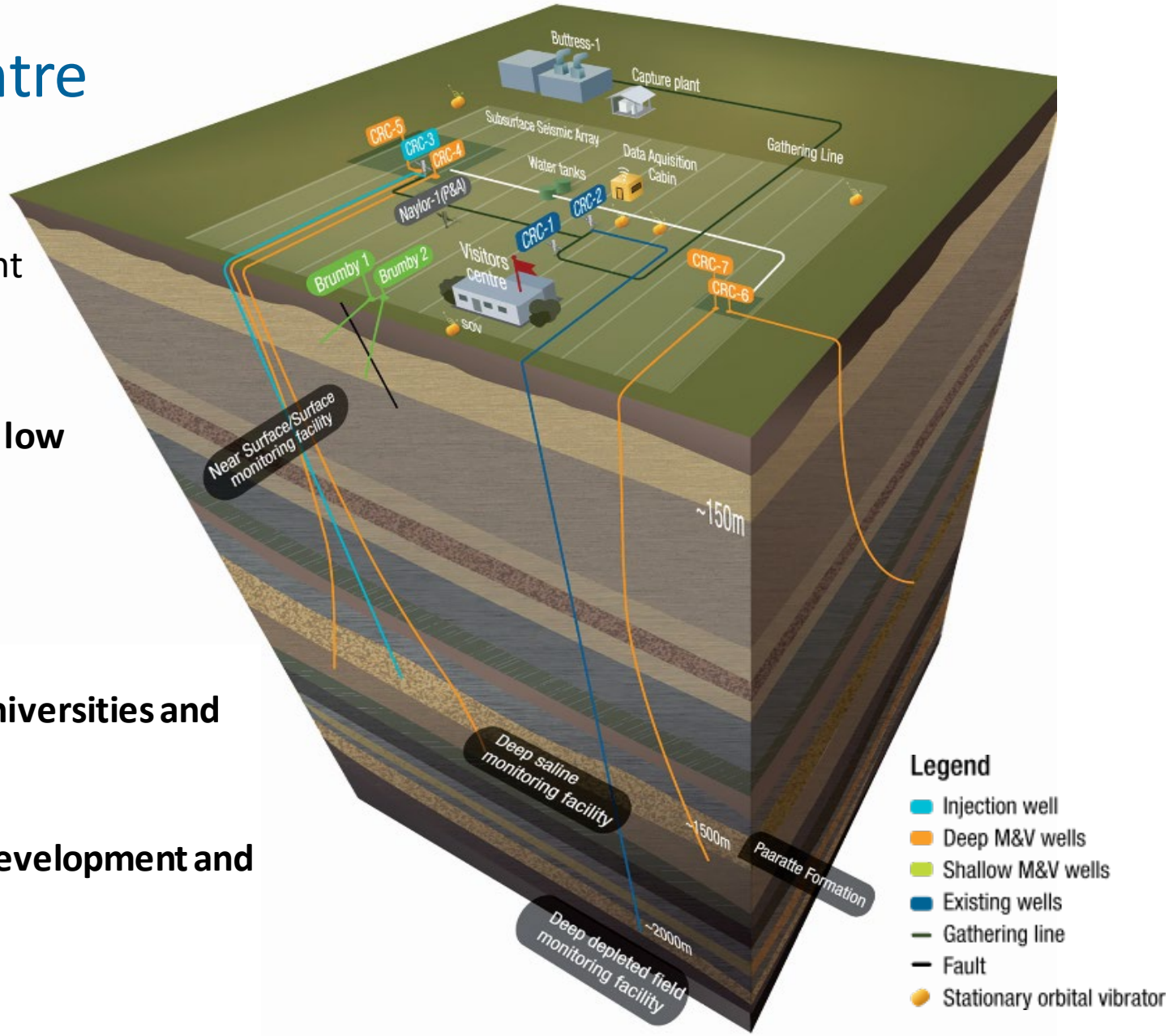
At scale investment - Long term Government and Industry funding

Focused on **accelerating the transition to a low emissions future**

Industry led Research

Well-established **collaboration between universities and industry**, nationally and internationally

Globally unique test centre to **accelerate development and commercial deployment** of technologies



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Otway International Test Centre

Otway Stage 1 (Concept): 2004 – 2009

- ✓ Demonstrated safe CO_2 storage into a depleted gas reservoir

Otway Stage 2 (Risk Reduction): 2009 – 2019

- ✓ Demonstrate safe injection of CO_2 into a saline formation
- ✓ Stage 2B – Near well residual & solution trapping characterisation
- ✓ Stage 2C – Minimum detection, 4D M&V & Plume stabilisation

Otway Stage 3: 2015 - 2022

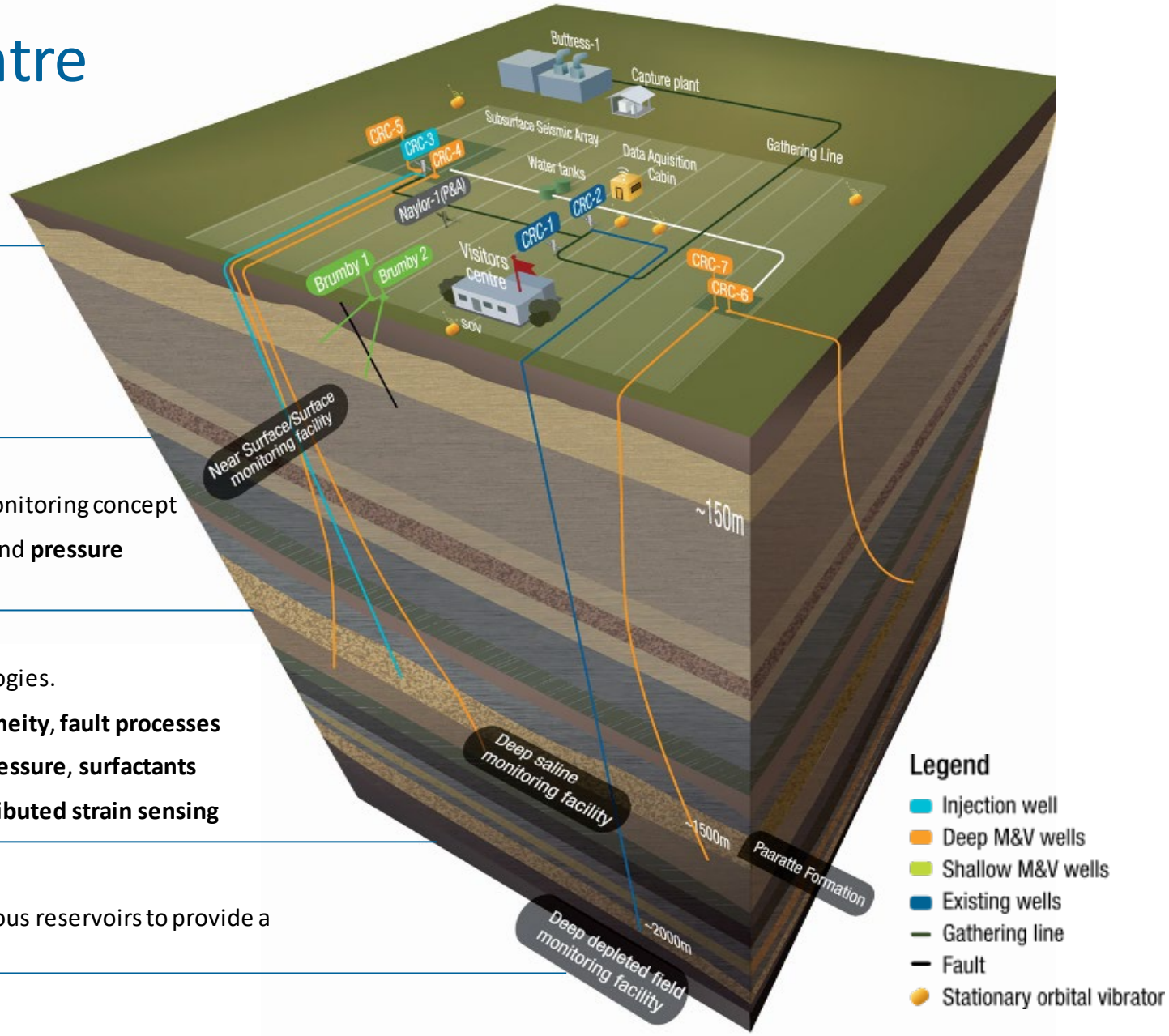
- ✓ Develop and test an "**on-demand", sub-surface and permanent** monitoring concept
- ✓ Two primary technologies - **sub-surface seismic data acquisition** and **pressure tomography** (4 new monitoring wells)

Otway Stage 4: 2019 – 2026

- Demonstrate commercially-focused **reservoir management** technologies.
  - Improved modelling workflows – Role of **fine scale heterogeneity**, **fault processes**
  - CO_2 storage optimisation – **Microbubble**, **pulsed injection pressure**, **surfactants**
  - Performance monitoring – CO_2 saturation from **seismic**, **distributed strain sensing**

Underground Hydrogen Storage Demonstration: 2021 – 2028

- ❖ Field scale demonstration of underground hydrogen storage in porous reservoirs to provide a platform for technology development.



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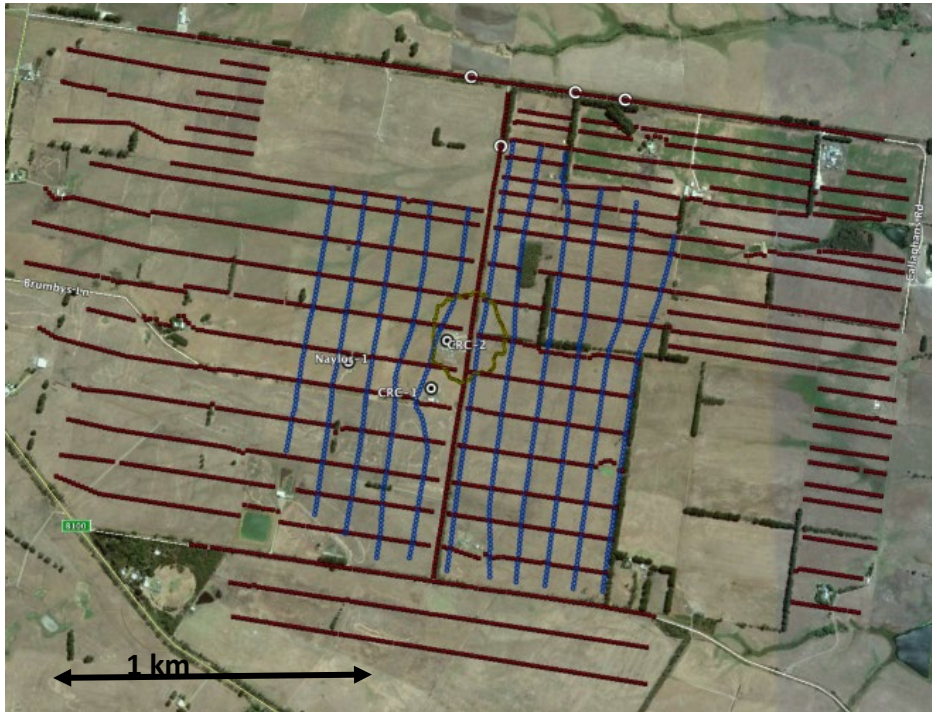
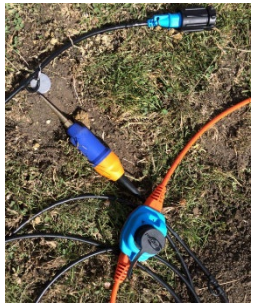
Otway's Breakthrough Technologies

Seismic Monitoring Example

In order to see, the industry needed:

Otway's Evolving Seismic Monitoring Program





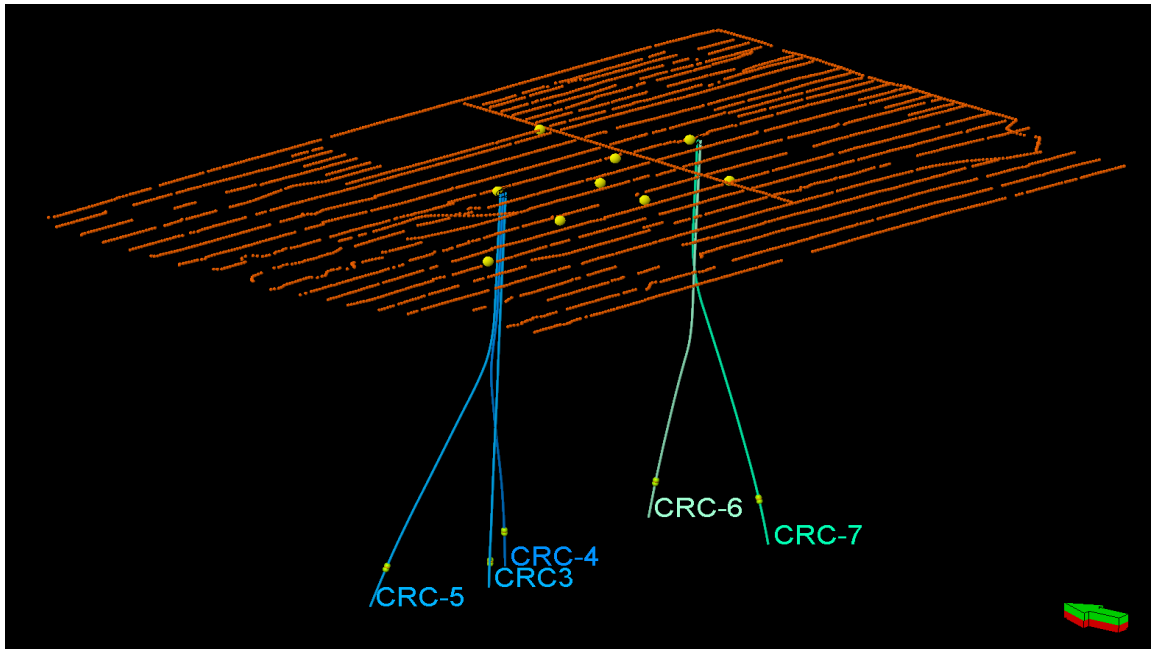
Geophones

Fibre optic cable

F/O Deployed in Trench

Vibroseis

Stationary Orbital Vibrators



F/O Deployed Downhole

DE-RISKING THE STORAGE OF CO2 IN SALINE FORMATIONS

Saline formations have the greatest potential for CO_2 storage globally. Their utilisation will be necessary to ensure we remain within the COP21 2C target.

2015–2019

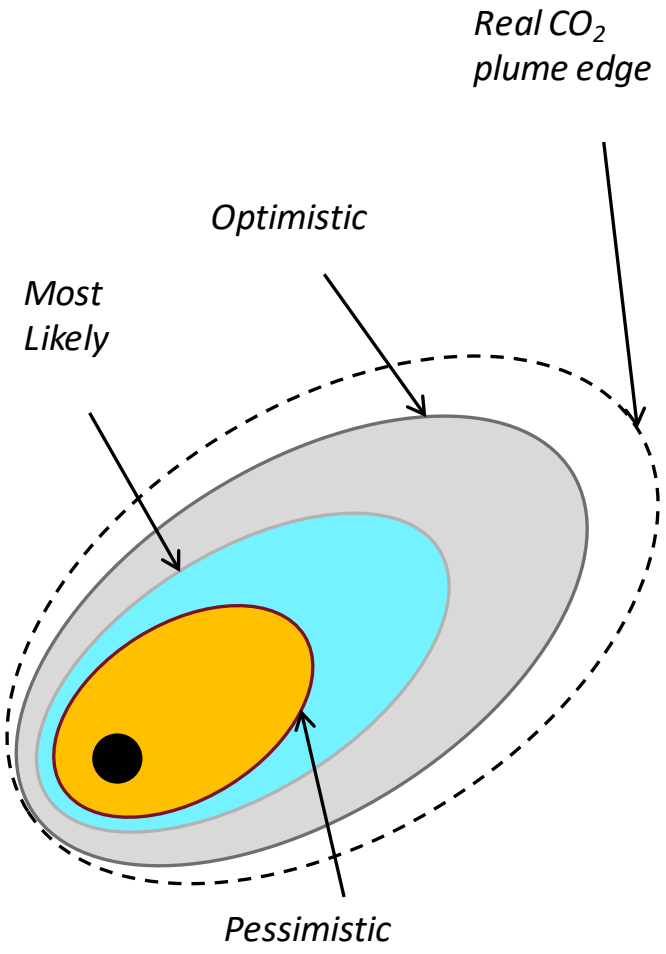
THROUGH THE MONITORING AND VERIFICATION OF 15,000 TONNES OF INJECTED CO2 WE WILL VALIDATE SALINE ROCK FORMATIONS FOR CARBON CAPTURE AND STORAGE BY:

A VALIDATING THE ACCURATE MODELLING OF CO2 STABILISATION AND TRAPPING IN A SALINE FORMATION

B UNDERSTANDING THE SAFE STORAGE CAPACITIES OF THIS RESOURCE

C DEMONSTRATING THE MINIMUM DETECTION LEVEL OF CO2

Otway Stage 2 Objectives



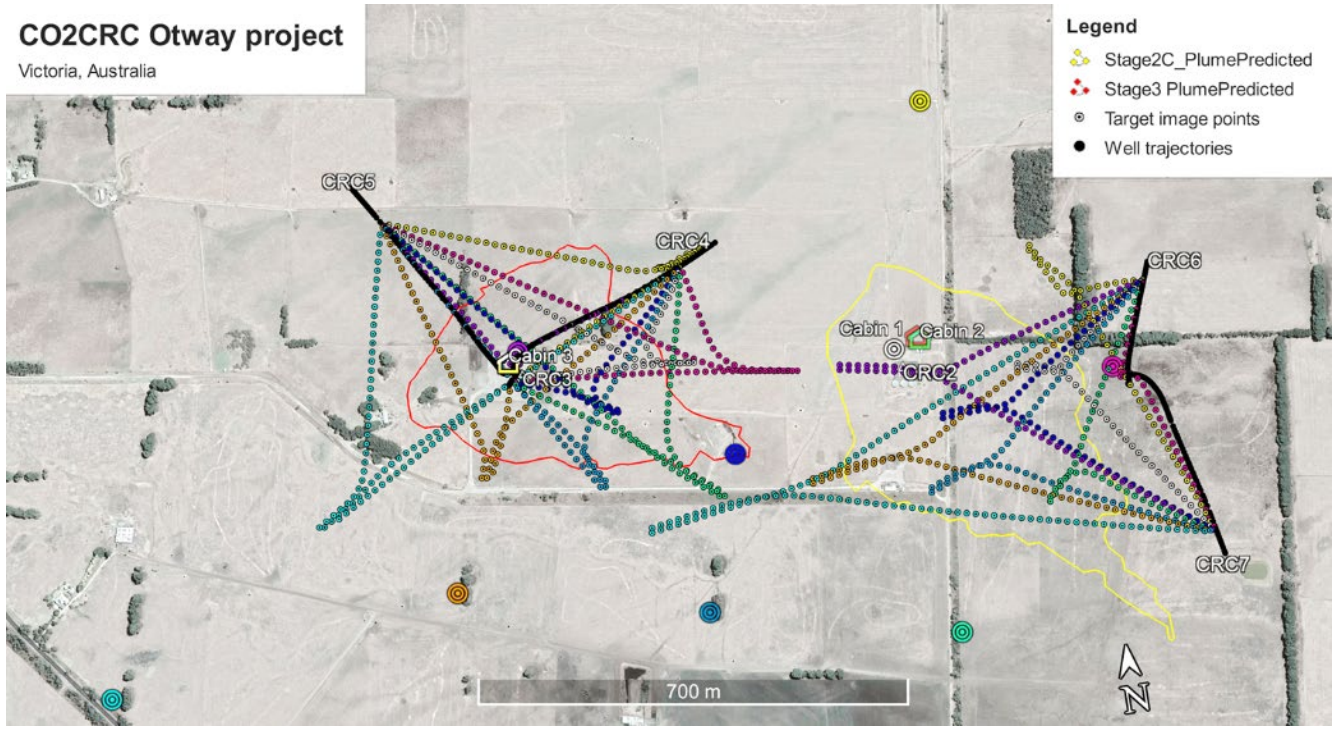
Demonstrated safe saline formation storage and characterised the trapping processes' role in CO_2 migration and stabilisation

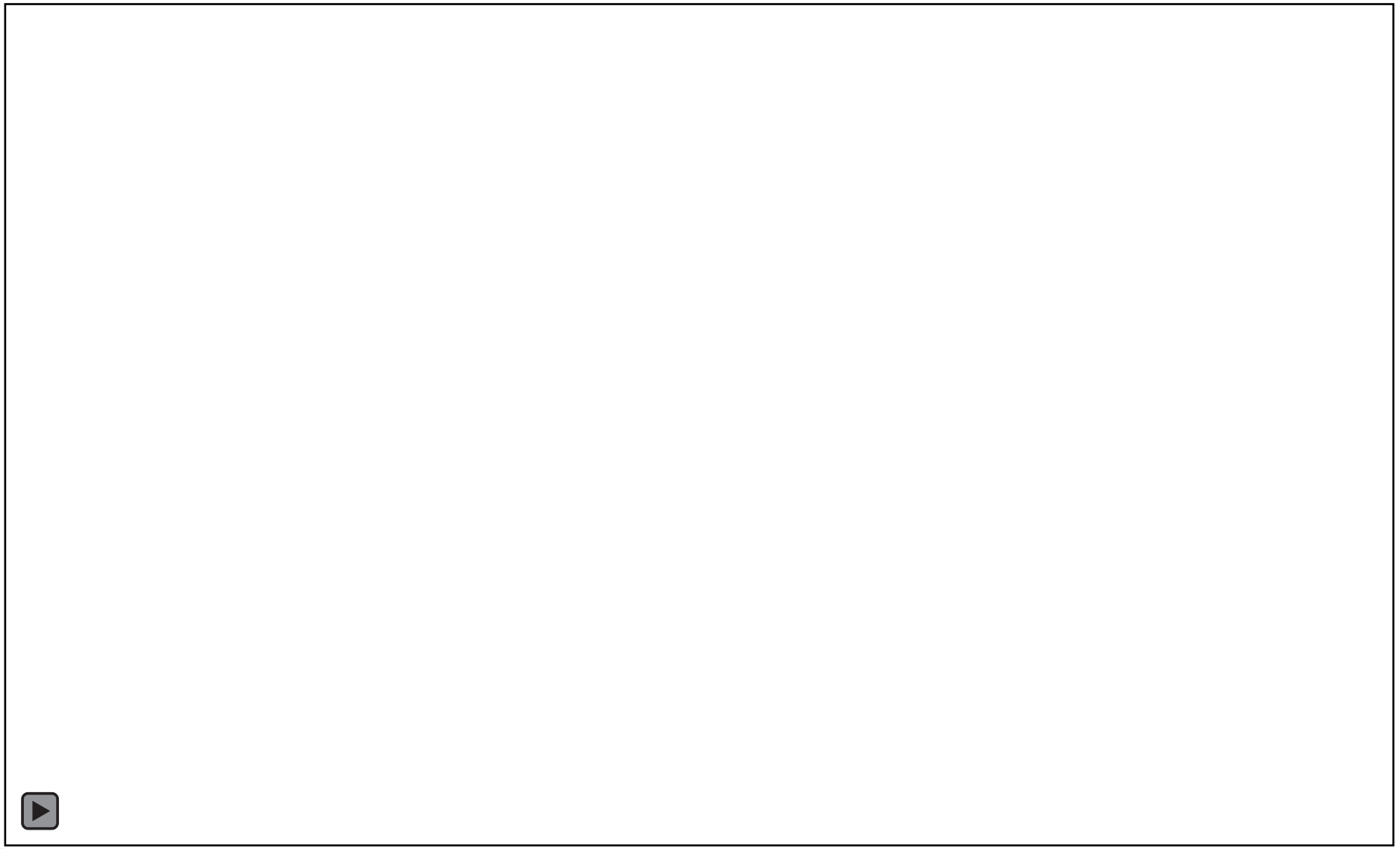
Main outcomes:

- Detected injected CO_2 and established a 5,000 tonne minimum detection threshold
- Observed gas plume development in time lapse
- Verified stabilisation of the injected plume

Otway Stage 3 - Risk based M&V through downhole seismic and SOV/DAS

- Deployed permanent sources and in well fibre optics receiver system to provide multiple transects to monitor plume evolution.
- On-demand system configured to provide a new image of the site every 2 days.
- First detected the gas plume on the 2nd day of injection with ~300 tonnes injected.





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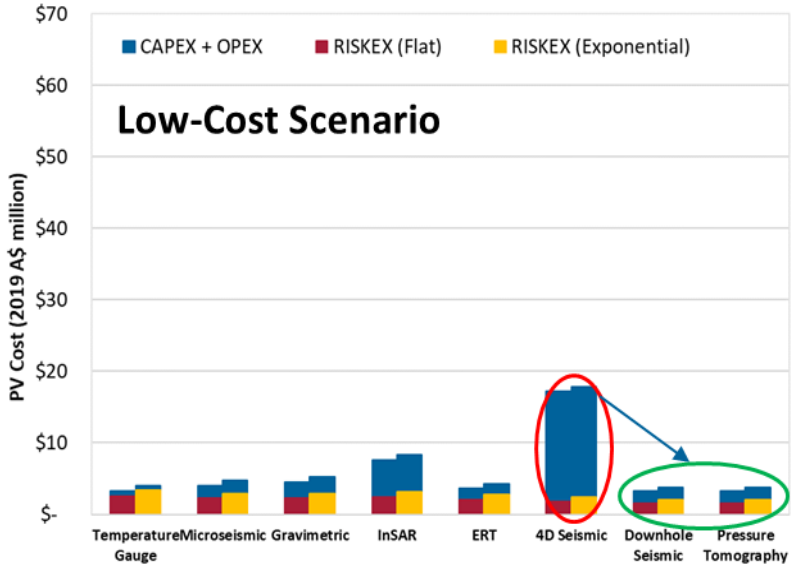
Development of cost-effective monitoring technologies

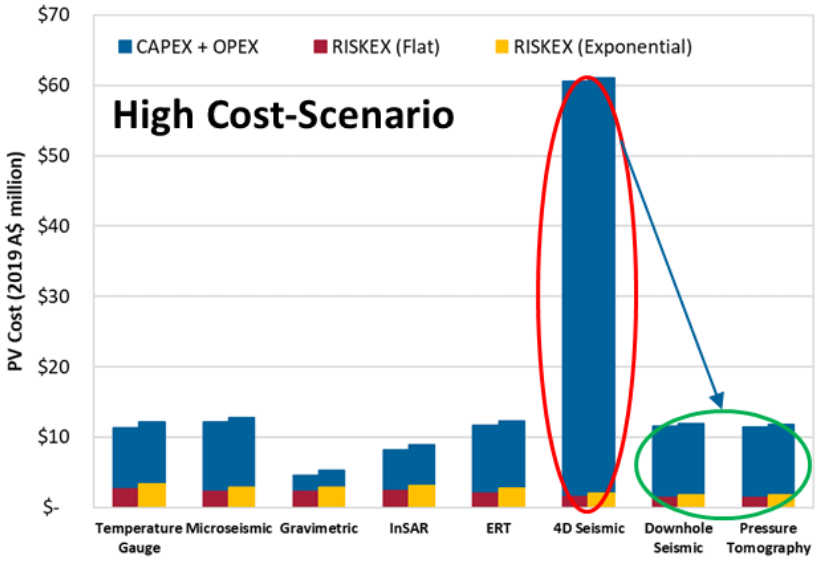
- CO2CRC has trialled cost effective monitoring technologies as part of Otway Stage 3 project.
- Both probabilistic and risk-based methodologies were deployed to perform techno economic analysis
- The analysis shows the CO2CRC technologies can save up to 85% of the monitoring cost

85%



- Using existing wells as monitoring wells
- 3D seismic is required every 5 years
- A baseline 3D seismic does already exist

75%



- New monitoring wells are required to be drilled
- 3D seismic is required every 2 years
- A baseline 3D seismic needs to be acquired

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Next Activities at Otway: Otway Stage 4

Optimisation and Reservoir Management

Otway Stage 4

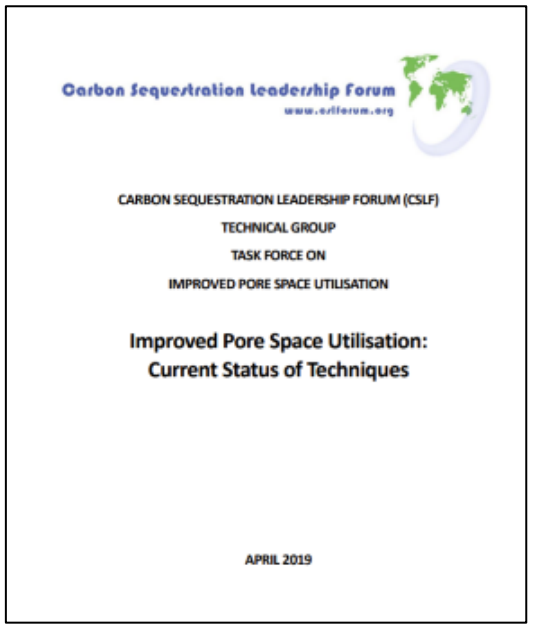
Goal: Demonstrate commercially-focused reservoir management technologies to improve injection, storage and monitoring efficiencies, and thereby materially lower project costs.

Classification	CO2 storage resource (Gt) Project and no project	CO2 storage resource (Gt) Project specified
Stored	0.043	0.043
Capacity	0.211	0.211
Sub-Commercial	577	66.3
Undiscovered	13377	30.0
Aggregated	13954	96.6

OGCI CO_2 Storage Resources Catalogue (2022)

Outcomes:

- Provide a suite of technologies and workflows that can be selected to create bespoke solutions which optimise the use of CO_2 storage capacity while minimising capital and operating costs.
- **Optimisation**
  - Provide a minimum 20% increase in CO_2 storage efficiency for commercial storage.
  - Unlock poorer quality storage systems' capacity for commercial CO_2 storage.
- **Modelling**
  - Improve modelling workflow, with a predictive capacity to support performance-based site operation and closure decisions.
- **Monitoring**
  - Develop storage 'performance' monitoring which is fit-for-purpose and low cost.



CSLF (2019)

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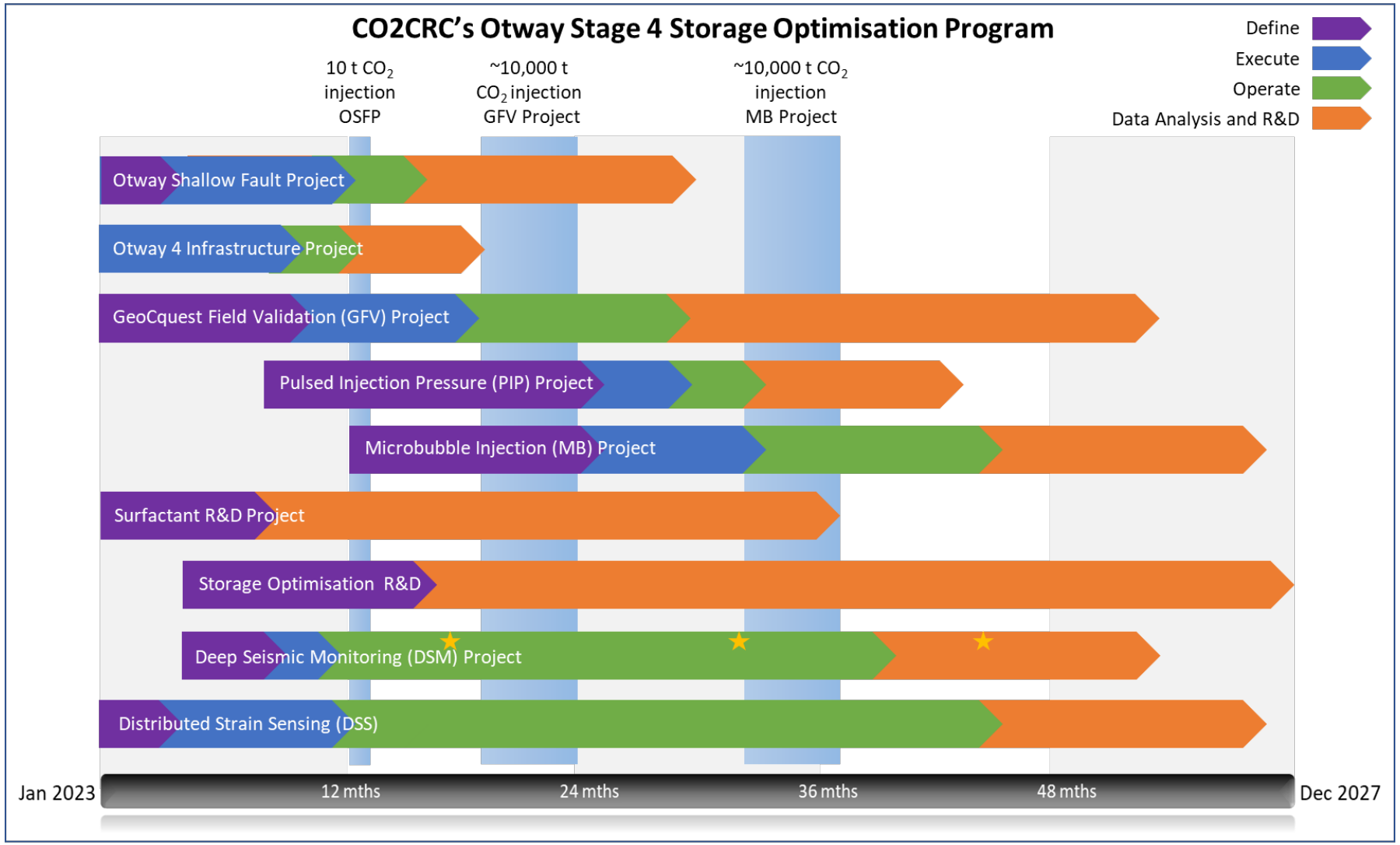
The Otway Stage 4 Project Schedule



★ 4D VSP acquisitions

The Otway Stage 4 schedule has a sequenced project approach. Firstly, a comparative benchmark will be formed. This will then be used to assess technologies that:

- Improve injectivity, and storage efficiency
- Enable effective monitoring of storage performance,
- Reduce CO_2 storage cost, risk and uncertainty.
- Data and facilities can and will be used to support further R&D with member organisations.

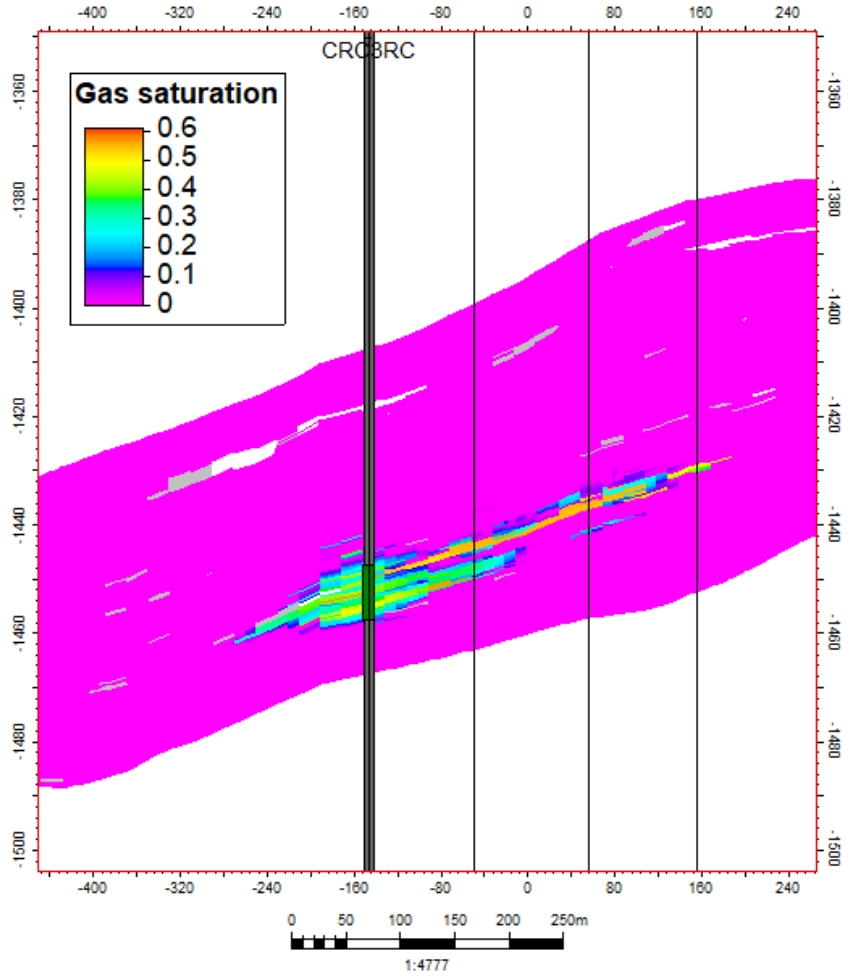
GFV Objectives

Goal

Obtain and utilise a unique dataset to comprehensively quantify the role of fine-scale geological heterogeneity and secondary trapping for limiting injected CO_2 mobility, validate an advanced characterisation and modelling workflow for reliable prediction of CO_2 storage, and use this knowledge to develop solutions for storage optimisation.

Objectives

1. Acquire a 'benchmark' dataset of CO_2 saturation & fluid chemistry during plume migration and trapping within a saline formation.
2. Investigate the role of fine-scale heterogeneity on CO_2 flow dynamics and capillary & dissolution trapping.
3. Validate and refine GeoCquest's advanced reservoir characterisation and modelling workflow to predict CO_2 migration & trapping along the plume migration path.
4. Develop a set of performance-based protocols for defining site closure & liability transfer and solutions to best utilise geological heterogeneity and secondary trapping for project risk reduction & storage optimisation.



Modelled CO_2 saturation @ end injection

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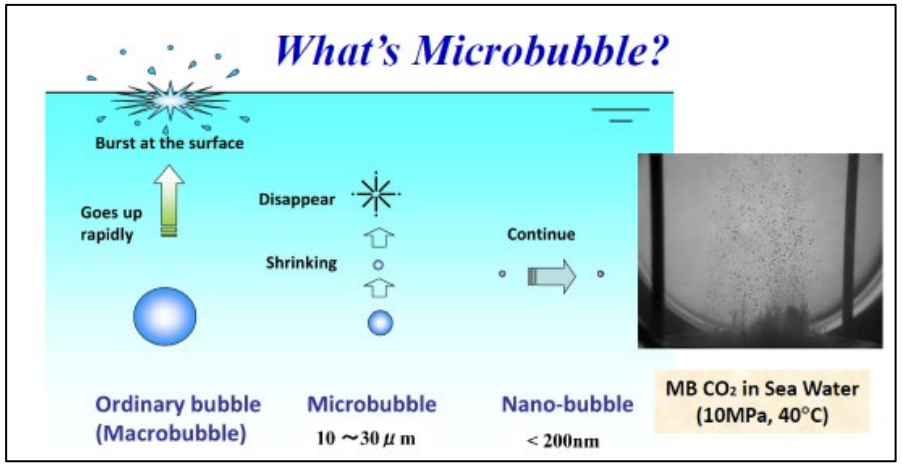
Stanford University

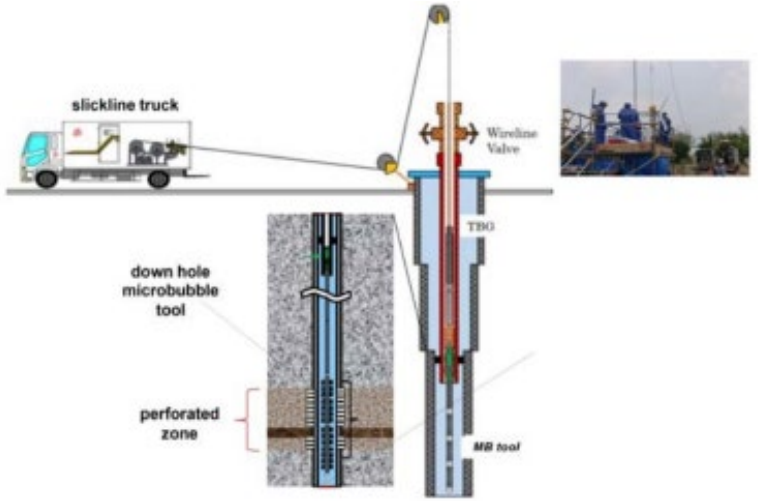
UNIVERSITY OF CAMBRIDGE

THE UNIVERSITY OF MELBOURNE

Microbubble (MB) Injection Project

- **Background**: CO_2 Microbubbles (MB) injection technology, developed by RITE, has previously been tested in lab and through a small scale EOR trial, demonstrating MB value for:
  - Effective penetration into low perm layers (e.g. improved sweep), and delayed breakthrough
  - Higher dissolution, and therefore increased secondary trapping
  - Lower injection pressure (or higher injection rate)
- **Objective**: To test the effectiveness of MB as a CO_2 storage optimisation technique at the OITC. The injection trial will inform the feasibility of employing microbubbles for large-scale CO_2 storage.
- **Intent**: Utilising Otway infrastructure and GFV monitoring plan, undertake a fair comparison between normal and MB injection, measuring injection pressure, plume distribution, saturation & dissolution, both near well and far field.

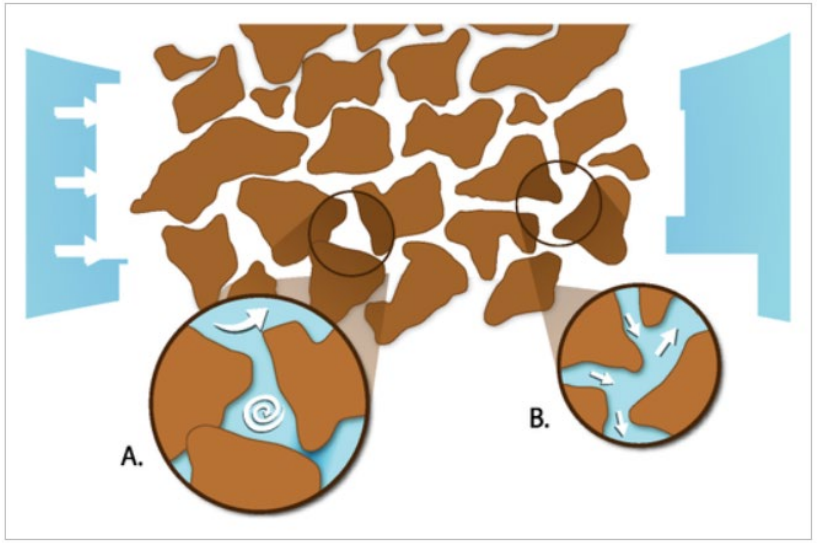




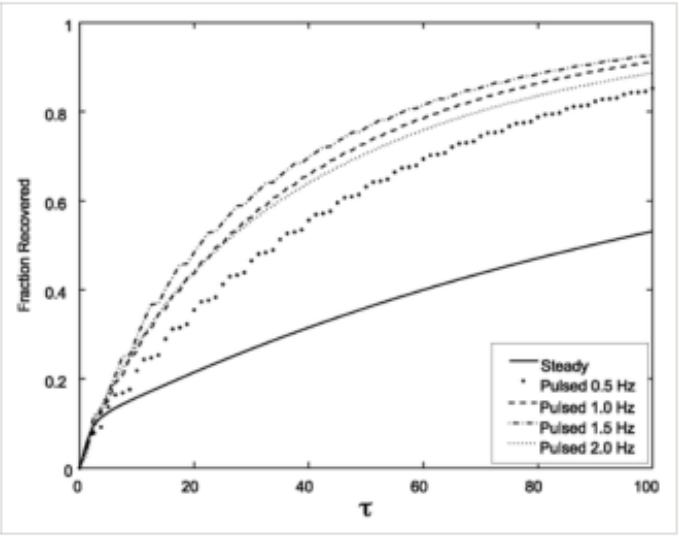
Schematic for microbubble injection (Xue et al 2021)

Pulsed Injection Pressure (PIP) Technology (Pre-define)

- **Background**: Uneven fluid distribution can bypass or underutilise sections of the storage system. PIP, developed by Strathclyde and Edinburgh Universities, addresses this through micro-pulsing the injection pressure and improving the lateral sweep of the injected fluid (CO_2 or water).
- **Objective**: Appraise the PIP technique at the OITC to serve two purposes:
  1. Testing PIP as a remediation technique and preparing the PS-2 for MB injection
  2. To assess potential for enhancing CO_2 injection
- **Intent**: Utilising Otway infrastructure and GFV monitoring plan, undertake an analysis of the sweep performance using water PIP, measuring downhole pressure, seismic response, saturation & dissolution, around both CRC-3 & -8.



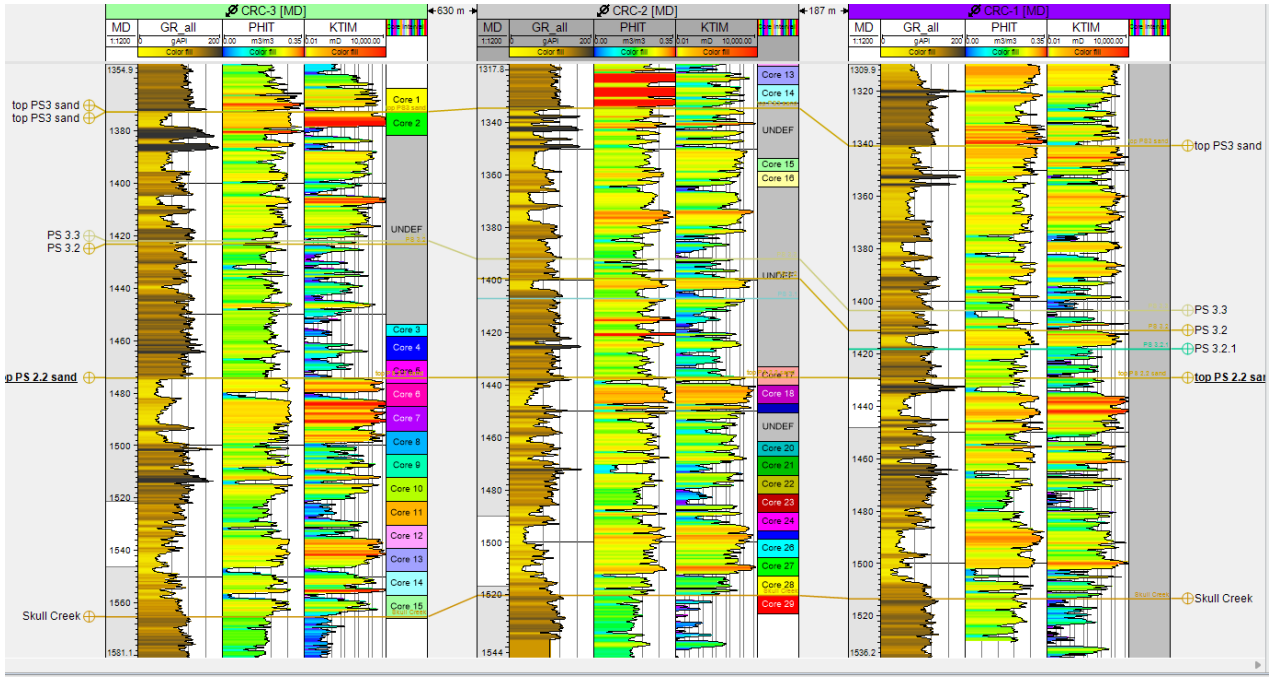
Flow through poorly connected and well-connected pores (Kahler & Kabala 2016)



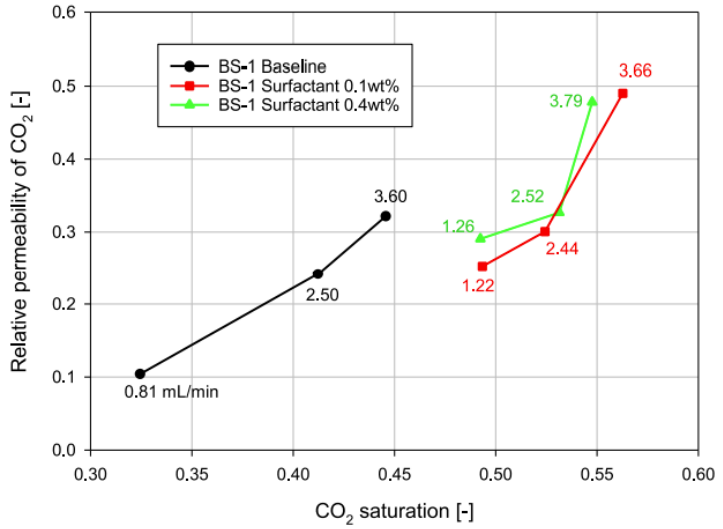
Simulated contaminant removed with pulsing (Kahler & Kabala 2016)

Surfactant R&D Project

- **Background**: Surfactants, investigated by KIGAM, can increase usable storage capacity by changing CO_2 plume properties and enhancing two-phase fluid interactions through interfacial tension (IFT) reduction and wettability alteration.
- **Objective**: To develop surfactant technology and understand it's effectiveness as a CO_2 storage optimisation technique (bench).
- **Intent**:
  - CO2CRC to support the use of OITC 'data' for continued KIGAM-led bench scale development of surfactant. This will include existing and new core from PS-1 and PS-2 of the Paaratte Formation.
  - KIGAM will develop the application of surfactant from low to mid TRL, with a view for a future 'huff-n-puff' field trial utilising the CRC-2 well.



OITC well and cored intervals



Rel Perm curves (BS-1) for baseline and surfactant cases (Seok et al 2023)

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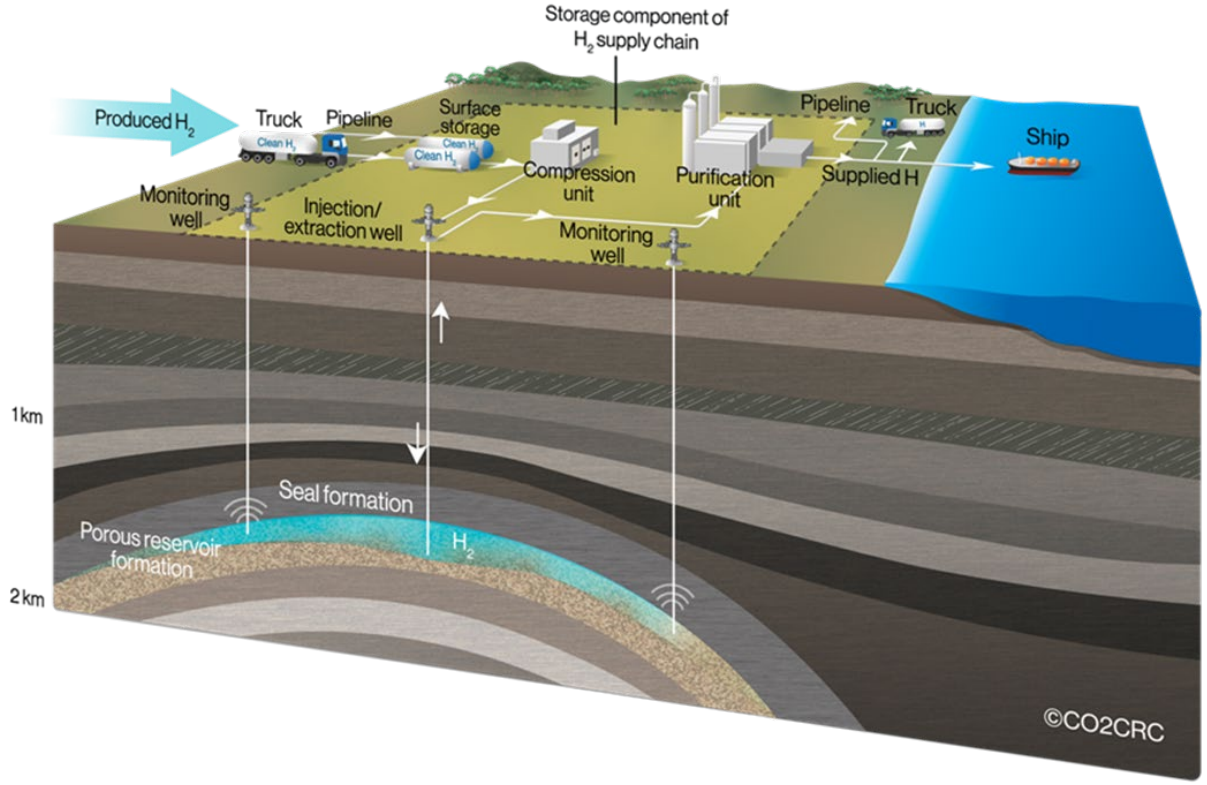
KIGAM Korea Institute of Geoscience and Mineral Resources

Otway Stage 4 Acknowledgements

- CO2CRC wish to acknowledge the Otway Stage 4 support provided by:
  - Australian Federal Government
  - BHP
  - BP
  - Chevron Australia Pty Ltd
  - ExxonMobil
  - Research Institute of Innovative Technology for the Earth (RITE), (Japan)
  - The Korean CCUS Association (K-CCUS)
- CO2CRC also acknowledges the technical support, to date, from our Otway Stage 4 science partners at Curtin University, Geoscience Australia, KIGAM, Lawrence Berkeley National Laboratory, RITE, Sapienza University of Rome, Stanford University, Strathclyde University, and The University of Melbourne

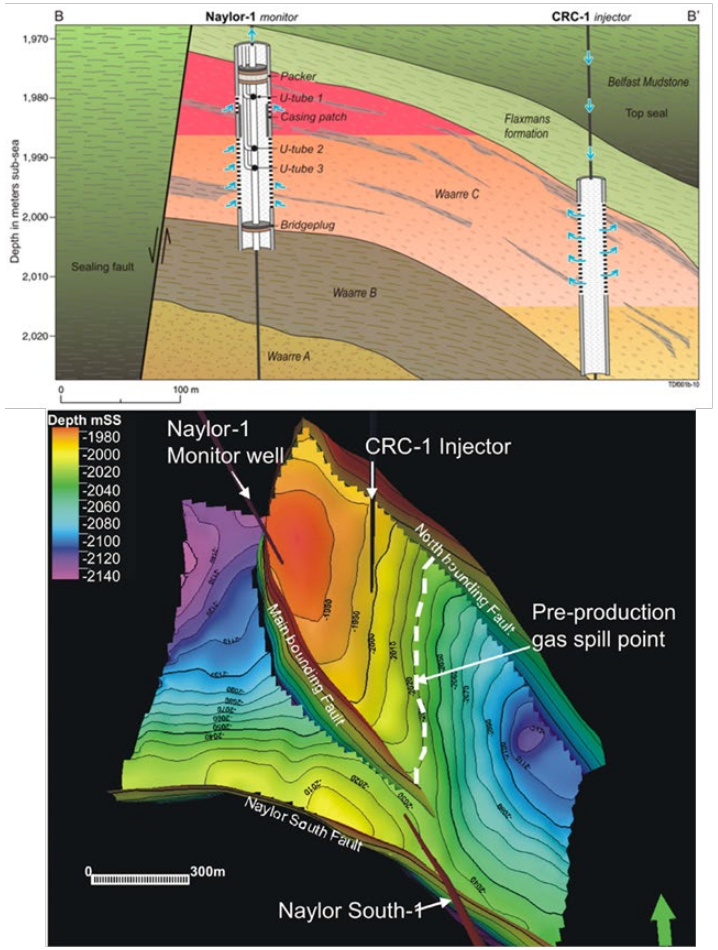
UHS Demonstration Objectives

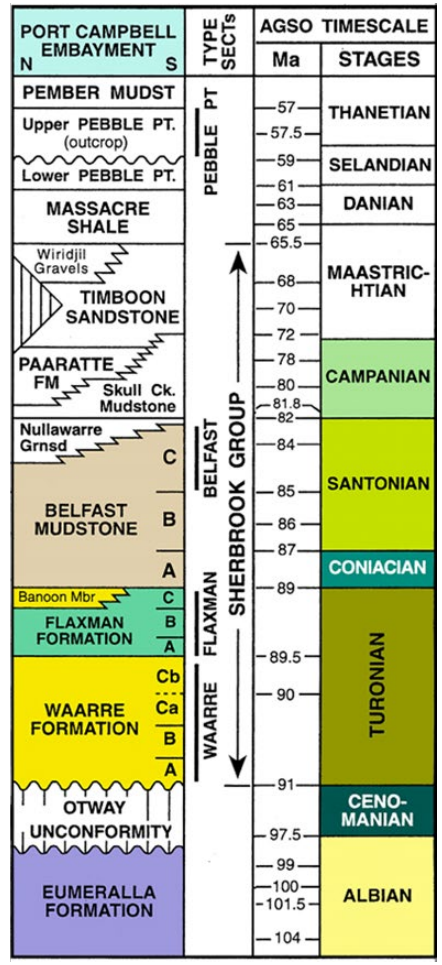
- Show that UHS is a safe large-scale storage solution and a vital element of effective hydrogen supply chains.
- Accelerate UHS technology development to ensure commercial readiness before 2030.
- Provide a foundation for detailed techno-economic analysis of geological storage options for hydrogen.
- Inform and frame policies, regulations and standards that ensure safe UHS operations and support community confidence.



UHS Demonstration Planning

- Depleted gas reservoir injection target at ca. 2km depth.
- Acceptance and injection of commercially significant H_2 volume.
- Confirm injection performance and assess of subsurface processes.
- Withdrawal of H_2, assessment of recovery; purification + offtake.
- Assess evolution of reservoired gases over multiple storage cycles





CO2CRC acknowledges and appreciates the strong relationships it has with industry, community, government, research organisations, and agencies in Australia and around the world