The CO2CRC Otway Project

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CCOP Workshop
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Key aspects for geological storage of CO_2

- Where can we store? **(Site Selection / Characterisation)**
- How much can we store? **(Storage Capacity)**
- How can we best get it in there? **(Injectivity)**
- How do we know it will stay there? **(Containment)**
- How can we tell? **(Measuring, monitoring, verification)**
- How much will it cost? **(Economics)**
- What is the Risk? **(Risk Assessment / Management)**
- Making it happen **(Regulatory, Liability, Public Perception)**

CO2CRC Storage Program

Conducting leading edge research into Geological Carbon Storage

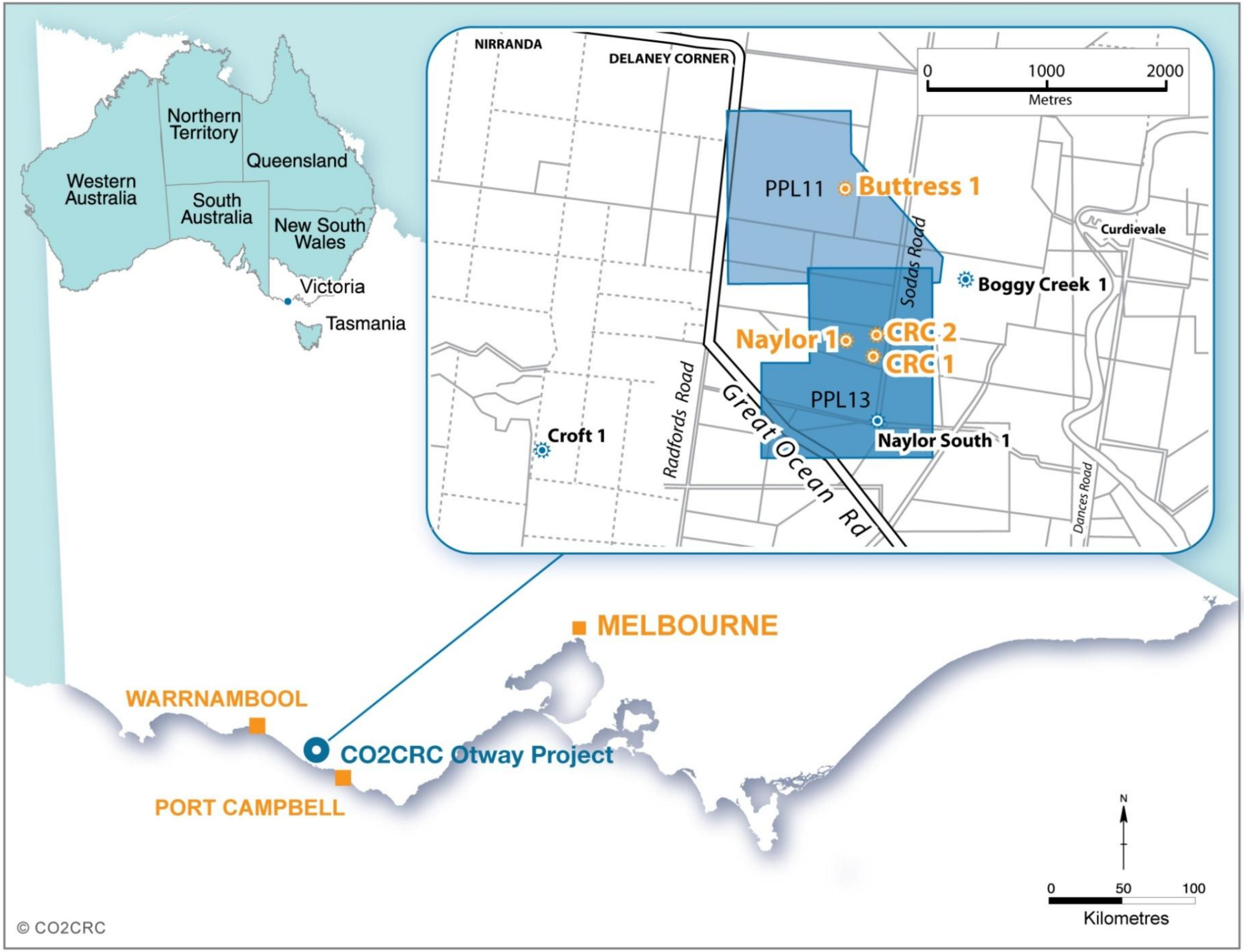
- **Stage 1: 65kt CO_2 injected in depleted Gas Field**
- **Stage 2: Researching CO_2 storage in saline aquifers**
- **15 research projects**
- **Two large field experiments (Otway Stage 2b &2c)**
- **79 researchers across 11 Institutions, 15 current PhD students**
- **2011-12 FY budget of $11,900,000**
- **CO_2 Sequestration facility in SW Victoria (Otway Project)**

Our Field Experiments

The CO2CRC Otway Project

- Australia's only Sequestration Facility
- One of few operational sequestration sites in the world
- Operating since 2008
- Research and injection into depleted hydrocarbon reservoir (Stage 1)
- Research and injection into saline aquifer (Stage 2)
- Unique research facility with global collaboration
- Concept, research and facilities provide blueprints to other CCS projects
- Will remain Australia's only CO2 injection site at least until 2015.

Location of CO2CRC Otway Project



Otway Strategy Map

Stage 1 demonstrated safe storage in a depleted gas reservoir – PNAS Jenkins et al. 2011

Stage 2 to demonstrate safe storage in deep saline formations.

Be one of the world's leading collaborative research organisations focused on CCS.

2005 -2015 Goals
Conduct leading edge storage research that is relevant for practical applications and which reduce commercial and environmental risks.

Demonstrate safe transport and injection of CO_2

- Safely produce CO_2 from Buttress
- Safely produce gas and transport to injection site
- …re formation
- …re site

Demonst… of CO_2 i…

- …in sub surface
- …ace, subsurface)
- Demonstrate ongoing integrity of environment

Stage 1

Measure parameters affecting residual and dissolution trapping in an unco…

- Safely conduct safe Residual gas saturation experiment
- Utilise independent methods to constrain CO_2 S_{gr} given level of uncertainty/variability in formation properties.
- Results to provide input to larger injection experiment
- …d minimise time

Spatially track injected CO_2 plume in an aquifer

- Use 4D seismic to detect injected plume and quantify minimum amount detectable
- Evaluate performance characteristics of different seismic techniques used and their impact on environment, cost and the public.

Stage 2

Maintain effective risk management system

- Risk maintained at ALARP

Communicate with Stakeholders

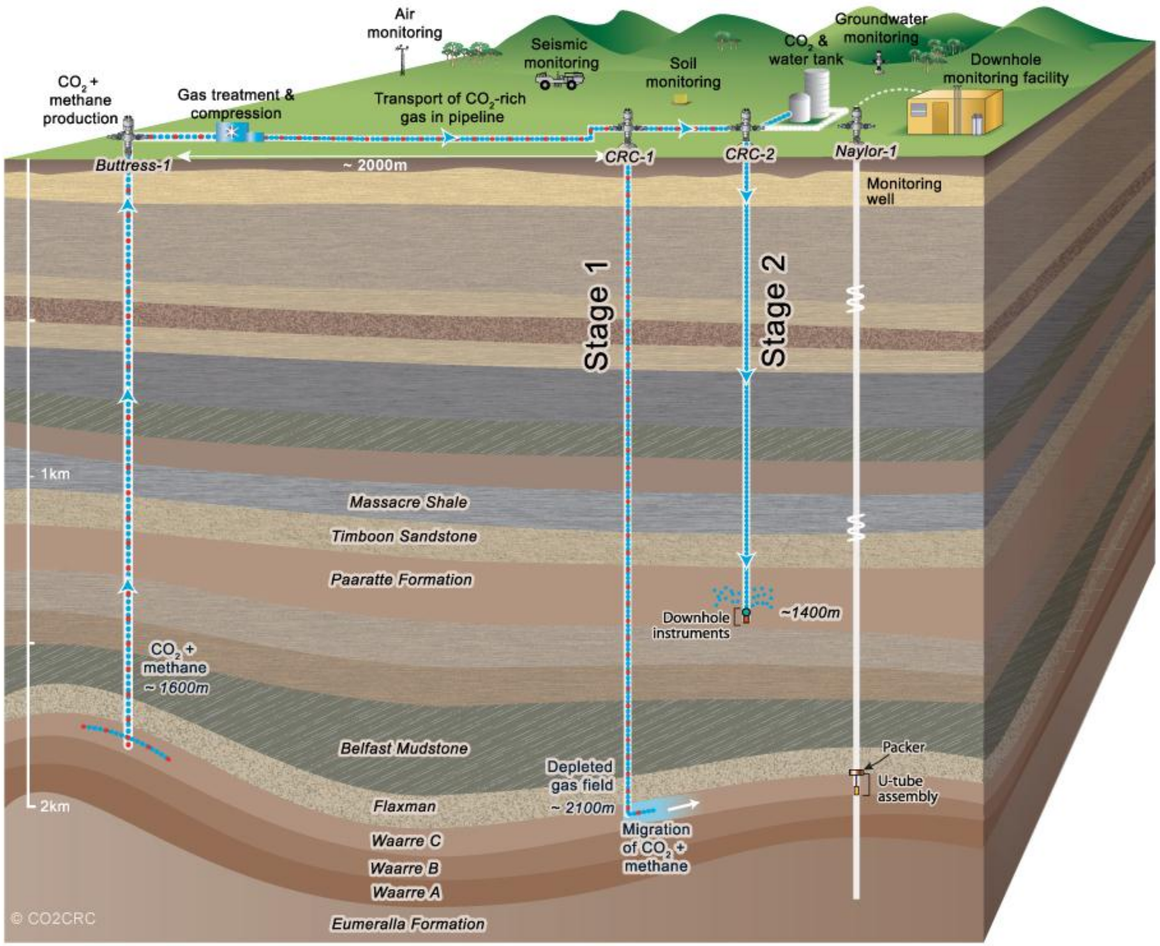
- Maintain community consultation and outreach program
- Publish research outcomes
- Provide data to inform regulatory regime
- Build capacity through targeted training

Vision | Goals | Strategies | Tactics

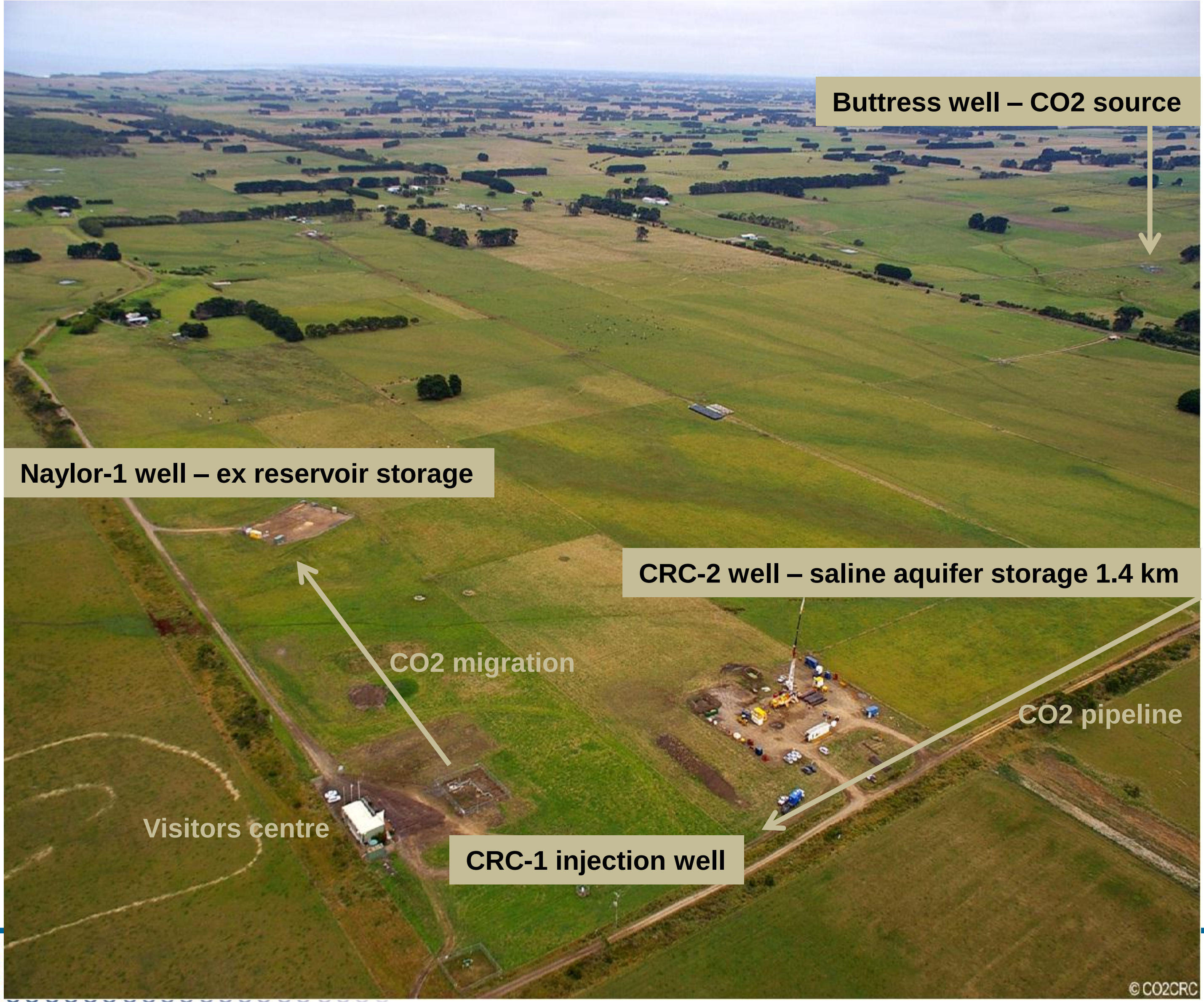
CO2CRC

The CO2CRC Otway Project - Stage 1 & 2

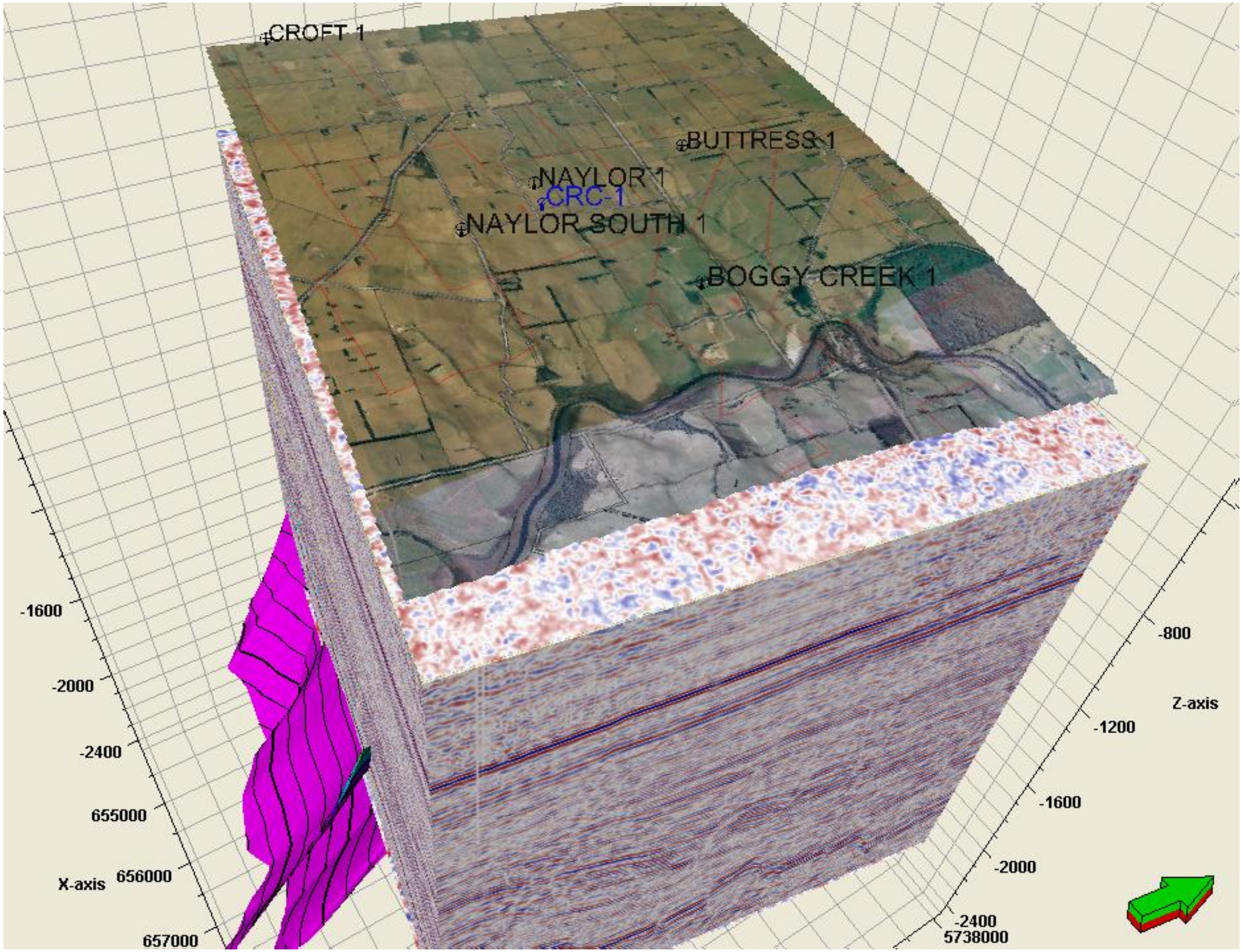
- **Stage 1: 2004 to 2009**
  - Demonstrate safe transport, injection and storage of CO_2 in a structural trap
- **Stage 2: 2009 to 2015**
  - 2a : Drill CRC-2
  - 2b: Measure parameters affecting residual and dissolution trapping in an unconfined aquifer
  - 2c: Spatially track injected CO_2 in an aquifer



CO2CRC Otway Project Aerial View



Otway Project: 3D layered Earth model



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Risk Example – Pre Implementation

Operational Risks											
7	Reservoir Integrity	Reservoir trapping mechanisms adequate to contain injected gas in the absence of regional seal above the injection interval at 1430 m.	Rare	Major	Medium	Reservoir model built. Residual gas saturation test will provide residual gas trapping potential, in addition to dissolution trapping.	Rare	Minor	Low	Technical reports. Peer Review documents	Adapted November 2009
8	Reservoir Integrity	Leakage from reservoir/plugged well, Stage 1 and 2.	Possible	Major	High	Technical risk assessment undertaken by CO2CRC team. Reservoir leakage risk is low. Wells have good cement bond so leakage from behind casing is low. Use abandonment and risk mitigation strategies consist with O&G Industry.	Rare	Moderate	Low	Techncial risk assessment. Bond Logs	Adapted November 2010
9	Plant Operation	Compressor failure/incident impacting timeline of Stage 2B.	Possible	Moderate	Medium	18 months of track record. Knowledge of operations. Appropriate de-mothball and pre-start up procedures. Plant is used only for gaslifting - so relatively modest operation times. For incidents OHS and emergency response plans in place. Wellheads installed with industry standard valves and alarm systems.	Possible	Moderate	Medium	Documentation of pre start audit procdure.	Adapted November 2010
10	Plume Imaging	Compromise scientific objective of Stage 2C. Inability to effectively detect the CO2 plume in the Paaratte fm because of challenging subsurface conditions, malfunction of seismic equipment.	Possible	Moderate	Medium	Seismic forward modeling predicts good results to image injection amounts between 5 and 7 k tons of CO2 injection. Land seismic survey methods tested during Stage 1, robust image processing developed.	Rare	Moderate	Low	Technical reports and publications	Adapted November 2011
Regulatory Risks											
11	EPA regulation	Unable to fulfill EPA regulatory conditions.	Rare	Moderate	Medium	Technical risk analysis on possible leakage paths considered when formulating KPI's. Monitoring to be performed as per plan. EPA to be briefed on research findings on a regular basis and potential ability to review KPI's based on new findings if justifiable. Received exemption from Vic CCS legislation.	Rare	Minor	Low	Regular EPA reporting	Adapted November 2010
12	Landowner agreement	Break down of relationship and failure to adhere of agreements with all landowners.	Possible	Major	High	Agreements inplace and landowner regular engagements.	Rare	Minor	Low	Landowner Agreements and DOI license	Adapted November 2010
13	Tenement Relinquishment	Reliquishment budget inadequte.	Possible	Minor	Low	Cost of rehabiliiation and relinquishment allowed for in project budget following standard gas oil well abandonment process and reviewed in 2007. Review every two years and seek additional funds from Board if necessary.	Possible	Minor	Low	Tenements, legal advice	Adapted November 2010

Core Enabling Legislation

Impact Assessment and Planning Approvals

- *Environment Protection and Biodiversity Act 1999* - not a controlled action
- *Environmental Effects Act 1978* - no environment effects statement
- *Planning and Environment Act 1987* - planning scheme amended

Environmental Portfolio Approvals

- *Environment Protection Act 1970 -* ***R****esearch* ***D****emonstration* ***& D****evelopment*

Petroleum Portfolio Approvals

- *Petroleum Act 1998 - various petroleum related activities approved*

Water Portfolio Approvals

- *Water Act 1989 - various drilling and injection activities approved*

Land Access

- *Planning and Environment Act 1987*
- *Land Acquisition and Compensation Act 1986*

Regulatory Approvals

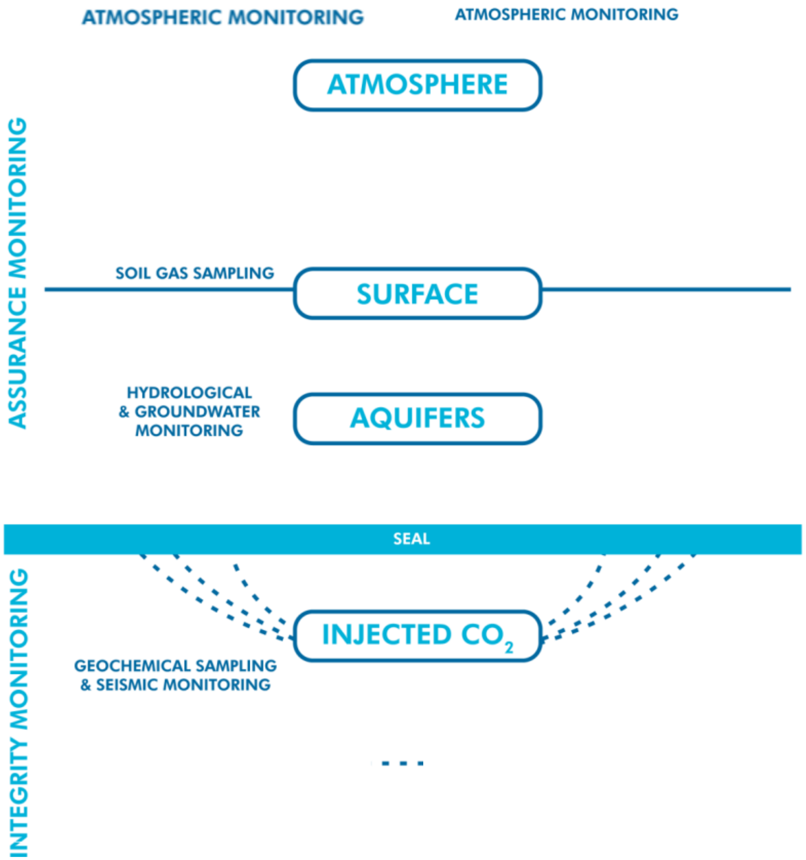
Activity	Approvals/Permits	Regulator	Application Process
Production of CO_2	Production Plan	DPI	- Petroleum Act 2000 (DPI).
Compression & Transport of CO_2: 1) Plant (compressor) 2) Gathering line 3) Other facilities (centre, etc…)	Planning Approval, Gathering Line Approval	DSE, DPI, Moyne Shire, DOI	- Petroleum Act 2000 (DPI) - Ministerial Amendment request of the Planning & Environment Act 1987 (Moyne Shire/DSE) - Exemption of Pipeline Act 2005 (DPI) - Cultural Heritage Act (DPI) - Compensation agreement: consent to land access - Project of Significance and Compulsory Acquisition (DOI) - Exemption of Rural Fire Service (CFA)
Drilling of New well	Drilling License	SRW, DPI	- Submit EMP, SPM and Drilling plan. Well drilled under water license.
Injection of CO_2 (CRC-2)	Disposal Approval	SRW, EPA	- Water Act 1989 Section 76 & 67: Application for approval to dispose of matter by means of a bore - Compensation agreement: consent to land access
Storage of CO_2	Storage Approvals	EPA	- Environment Protection Act 1970: Research Development and Demonstration (RDD) Approval (EPA)
Monitoring & Verification 1) Atmospheric 2) SOBN Water wells 3) Down-hole (Naylor-1) Monitoring	Planning Approval, Compensation Agreement, DSE access rights	EPA,DSE, Moyne Shire	- Ministerial Amendment request of the Planning & Environment Act 1987 (Moyne Shire/DSE) - Consent to use (SOBN) bores (DSE) - Compensation agreement: consent to land access

Community & Assurance

Questions raised about CCS

- Is it safe?
- Will it affect groundwater?
- What will happen if there is a leak?
- Will my land/crops/livestock/house be affected?
- Will I get compensation?
- Will my electricity bill go up?
- Will jobs be created?
- Will I get royalty payments?

Assuring the community – a monitoring plan



- **Measuring the atmospheric concentration of CO_2**
- **Measuring the concentration of CO_2 in the soil**
- **Analysing the groundwater**
- **Measuring the temperature and pressure, recording sound waves and detecting chemical changes**

Atmospheric monitoring

Atmospheric monitoring equipment

Existing CO_2 sources characterised before injection

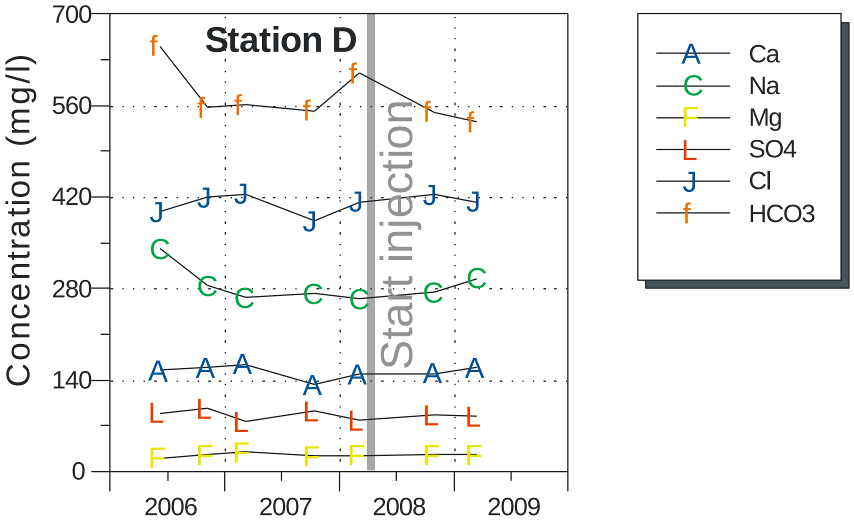
Look for evidence of emissions from CO_2 storage – distinguish **from** large scale diurnal and seasonal fluctuations.

D. Etheridge et al., CSIRO

Soil gas monitoring

- **Baseline surveys of soil gas before injection**
- **Determine likely source of CO_2 in soil gas by isotopic composition, presence of other gases and tracers**
- **Repeat surveys and look for anomalies**

Groundwater Monitoring



- **Establish baseline** groundwater levels and chemistry **of** freshwater aquifers
- **Sample before injection and regularly during and after injection**
- **Samples analysed for pH, redox, electrical conductivity, temperature, alkalinity, Ca^{2+}, Mg^{2+}, isotopes (δ^2H, $\delta^{13}C$, $\delta^{18}O$, $\delta^{34}S$), etc.**

Downhole fluid sampling

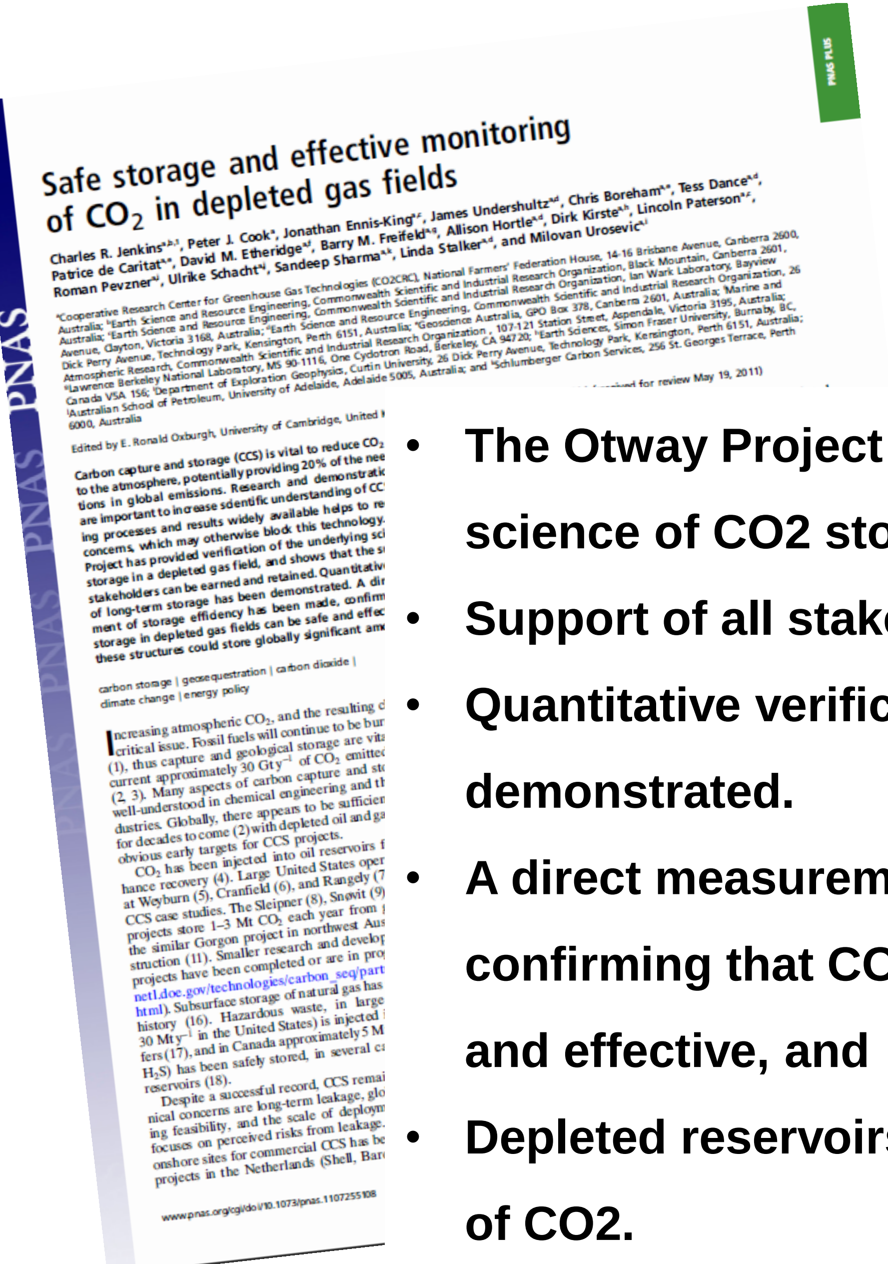
CO2CRC

Seismic monitoring

- **Range of seismic techniques**
- **Vertical Seismic Profiling (VSP) (source surface, receiver downhole)**
- **High Resolution 3D surveys**
- **Microseismic surveys (measures creaks in the subsurface)**

Proceedings National Academy of Science

Jenkins et al Dec 2011



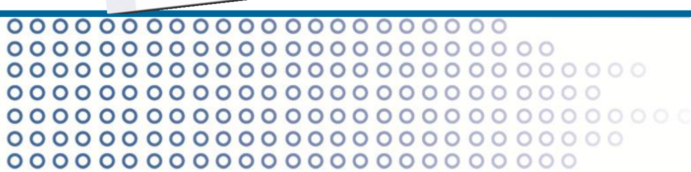
Safe storage and effective monitoring of CO_2 in depleted gas fields

Charles R. Jenkins, Peter J. Cook, Jonathan Ennis-King, James Undershultz, Chris Boreham, Tess Dance, Patrice de Caritat, David M. Etheridge, Barry M. Freifeld, Allison Hortle, Dirk Kirste, Lincoln Paterson, Roman Pevzner, Ulrike Schacht, Sandeep Sharma, Linda Stalker, and Milovan Urosevic

carbon storage | geosequestration | carbon dioxide | climate change | energy policy

www.pnas.org/cgi/doi/10.1073/pnas.1107255108

- **The Otway Project provided verification of the underlying science of CO2 storage in a depleted gas field.**
- **Support of all stakeholders can be earned and retained.**
- **Quantitative verification of long-term storage has been demonstrated.**
- **A direct measurement of storage efficiency has been made, confirming that CO2 storage in depleted gas fields can be safe and effective, and**
- **Depleted reservoirs could store globally significant amounts of CO2.**

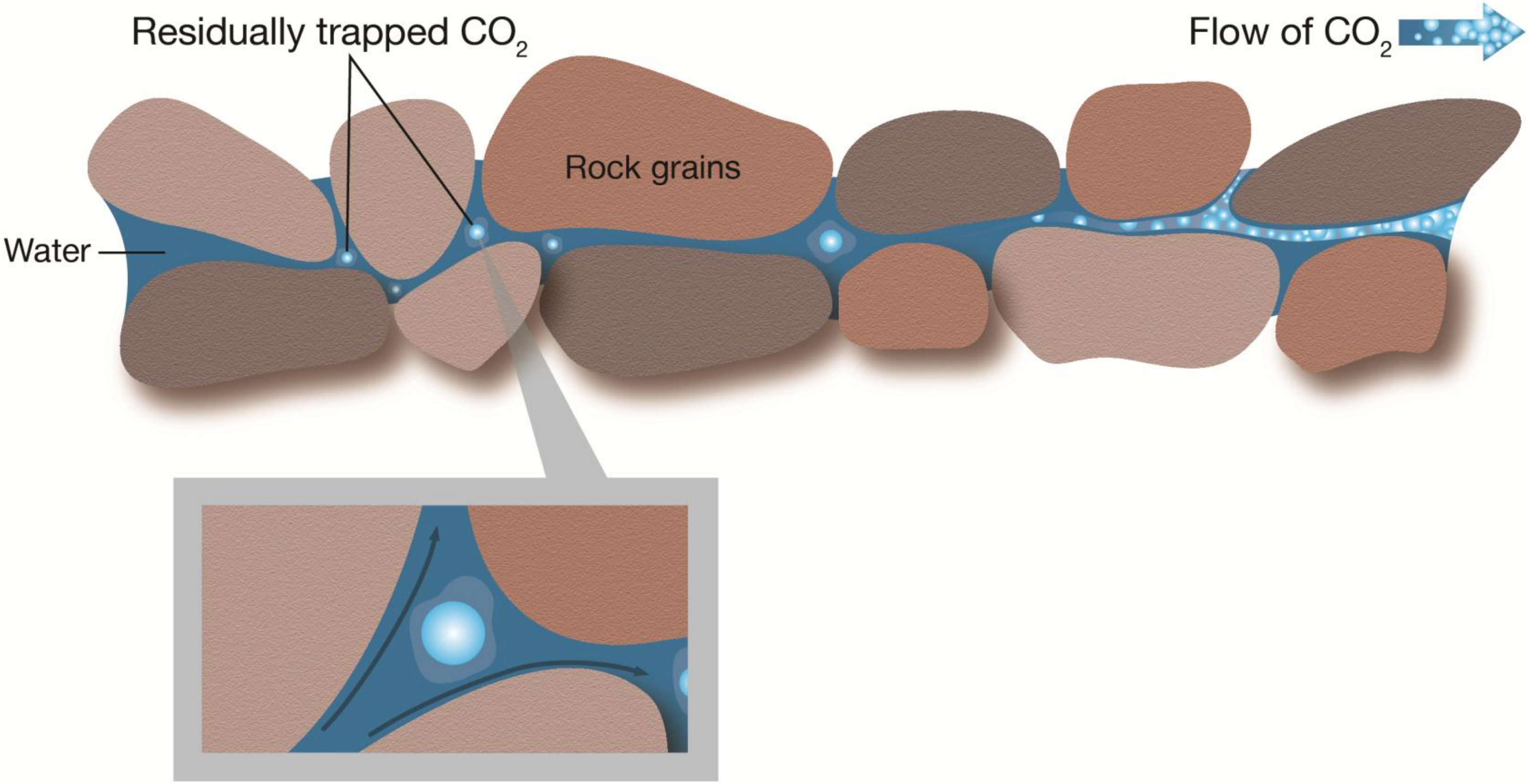


- ABC Ballarat
- ABC Science Online
- ABC Radio National AM
- ABC Radio News
- The Weekly Times
- Radio NZ Wellington
- Nelson Mail
- Sunday Star Times
- Marlborough Express
- Timaru Herald
- Manawatu Standard
- WA Business News
- Electric Light and Power
- Industry Search
- Utility Products
- Scinexx (Germany)
- Sina English (China)
- PhysOrg.com (Canada)
- E! Science news (Canada)
- Australasian Science
- Eco-business.comDalje.com (Croatia)
- Financial Post (Canada)
- Edmonton Journal (Canada)
- Canada.com (Canada)
- UPI.com (USA)
- Energetic City (Canada)
- Calgary Herald (Canada)
- Ottawa Citizen (Canada)
- MENA FN (Middle East North Africa)
- Energy Daily (USA)
- Capture Ready (China)
- Liberal Victoria
- Clear The Air News Blog
- R&D Magazine

Otway Stage 2 – storage in saline aquifers

Trapping in a saline formation

Residual trapping is where small amounts of CO_2 are disconnected from each other, trapped in the pore space.



Capillary Trapping

Volumetric equation for capacity calculation

$$G_{CO_2} = A\, h_g\, \phi\, \rho\, E$$

G_{CO_2} = Volumetric storage capacity

A = Area (Basin, Region, Site) being assessed

h_g = Gross thickness of target saline formation defined by A

ϕ = Avg. porosity over thickness h_g in area A

ρ = Density of CO_2 at Pressure & Temperature of target saline formation

E = Storage "efficiency factor" (fraction of total pore volume filled by CO_2)

The $15M question: how to determine Sgr?

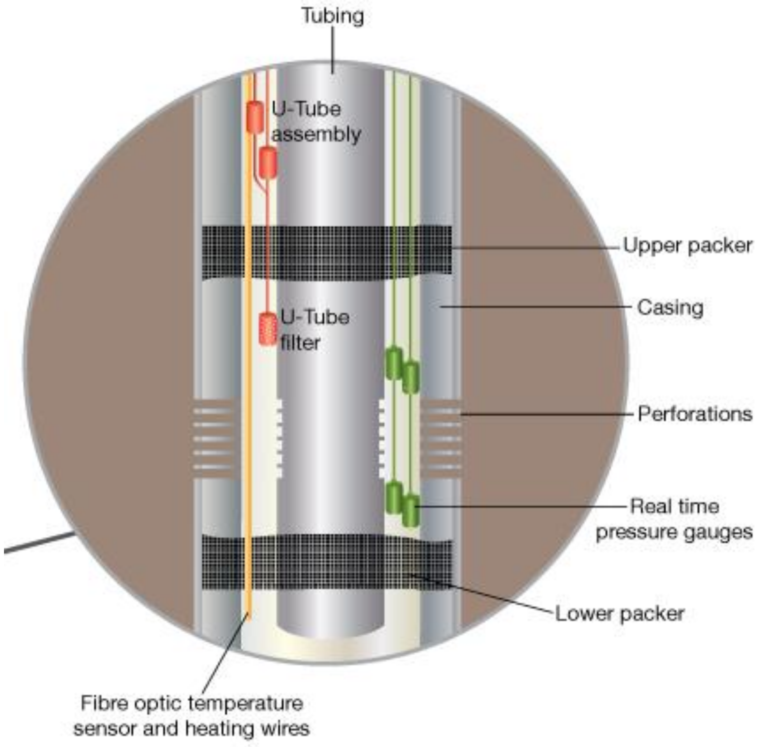
NETL DOE, 2006

Stage 2b – Residual Saturation Tests

- **Objective: Determine the residual CO_2 saturation, S_{gr}**
- **Five (5) independent measurement approaches to determining residual trapping:**
  - Saturation logging using Residual Saturation Tool **< 1 m**
  - Thermal test **~1-2 m**
  - Tracer tests **~4-10 m**
  - Pressure test **< 20 m**
  - Dissolution Test **< 1 m**

Hydraulic pressure test

- **Pressure data are sensitive to residual gas saturation**
- **Pressure sensors are installed above and below the perforation**
- **Pressure transients are recorded to infer the amount of gas trapped in the formation**



→Pressure change depends on relative permeability

→Relative permeability depends on residual gas saturation


LEANNE
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X-TREME

Noble Gas Tracer Test (Kr-Xe)

- **Tracers are injected into the formation with water and then back produced (U-Tube sampling)**
- **Noble Gas Tracers partition between aqueous and CO2-rich phase**
- **Portions will partition into the gas and become immobile (hence not produced back)**
- **Tracers in water remain mobile and are being back produced**

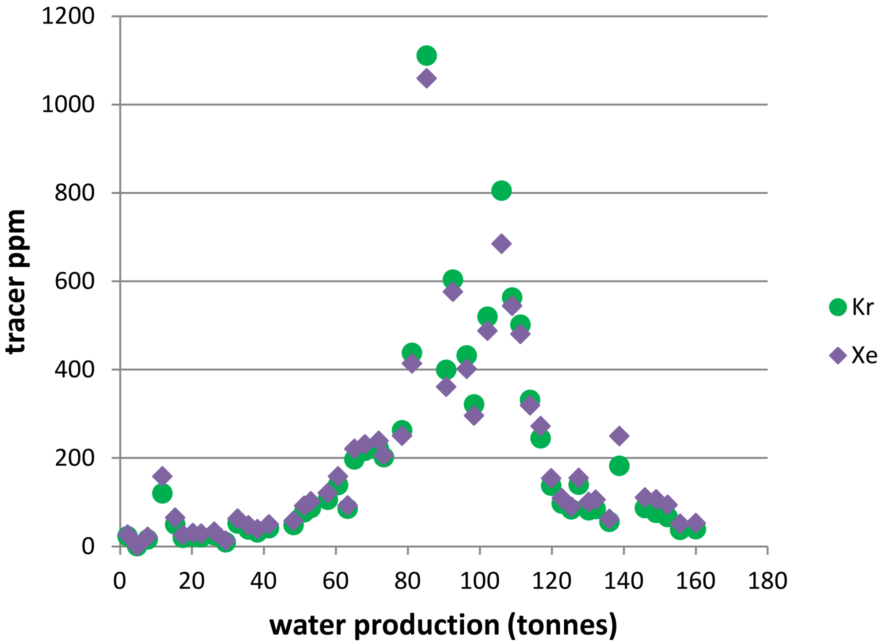
→***Measured with GC's and MS's in Mobile Geochem Lab***

→***Residual saturation can be inferred by comparing Break Through curves***

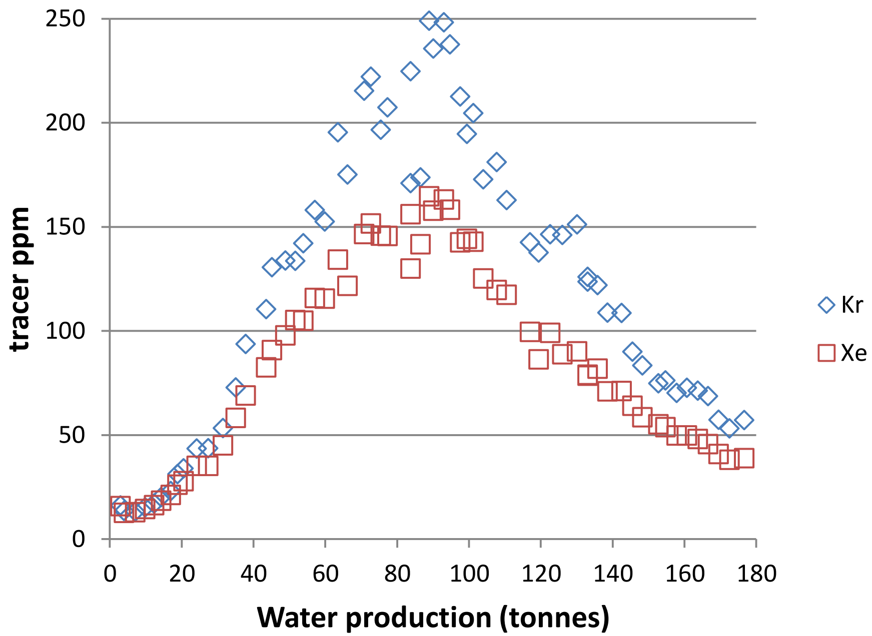
Tracer Injection

Kr-Xe Partitioning

Baseline Test (100% Pore Water)



Residual CO2 Saturated



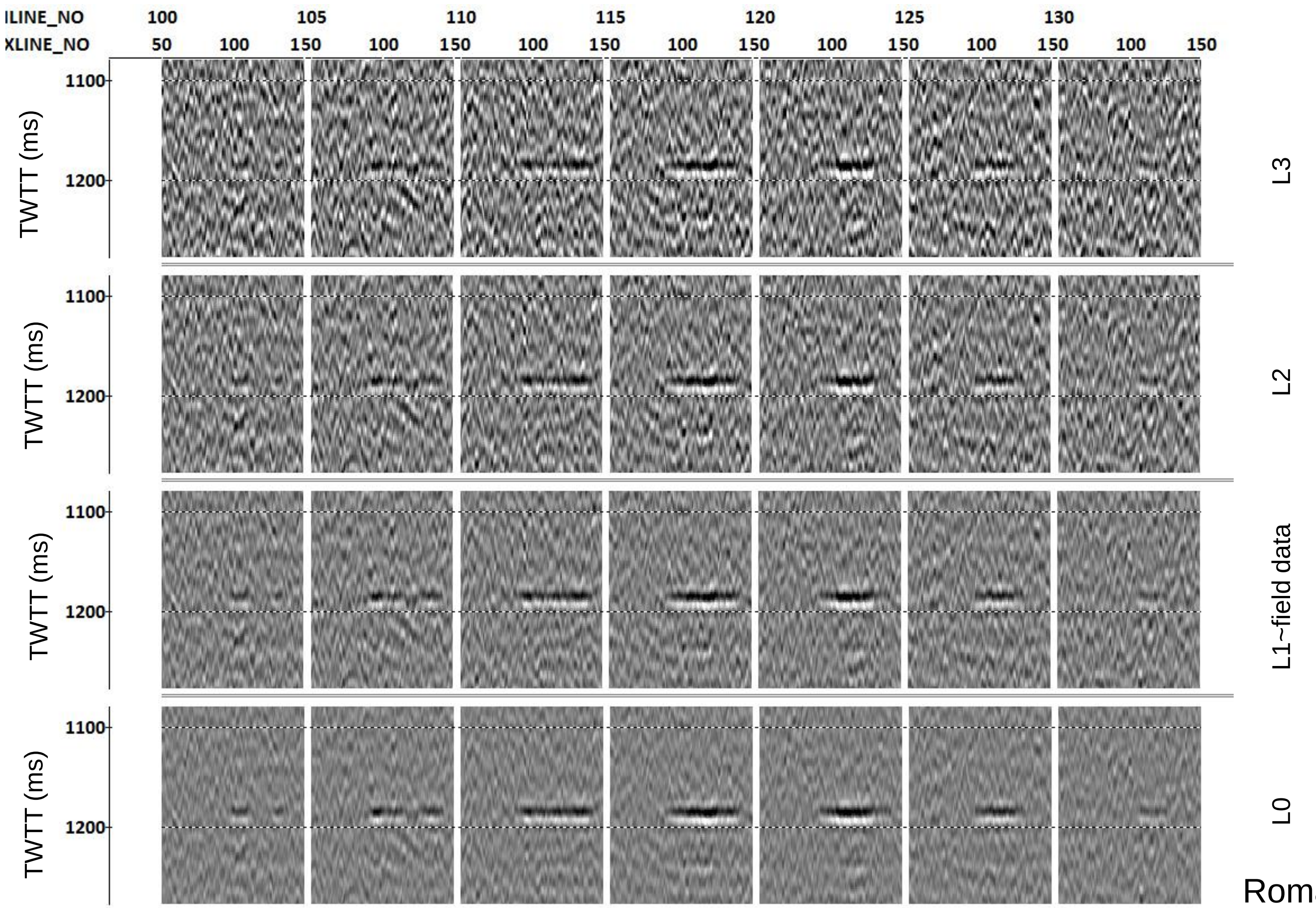
The impact of Otway Stage 2B
(Residual Gas Saturation & Dissolution Test)

1. Developing a **single-well test** for reservoir characterisation (porosity, permeability, capillary pressure, and heterogeneity).
2. Determination of Sgr through different techniques.
3. Different techniques provide different depth of investigation into the reservoir, from cm to several 100m (time dependent).
4. Sgr is required for calculation of CO_2 quantity stored in the pore space by residual trapping.
5. CO_2 residually trapped (permanently stored) is key for immediate safe and long-term storage.

Next research phase: Otway Stage 2C

Research Aim	Goals	Success Criterion
Safely demonstrate stabilisation of CO_2 in a deep unconfined aquifer:	1. Demonstrate the detection of gas using 4D seismic monitoring.	A gas plume with sufficiently high column and areal extent developed for the 4D signal to exceed the noise level using at least one of the monitoring technologies (see section x).
	2. Monitor plume evolution and match refine plume migration forecast via iterative dynamic modelling.	Deviations from modelled injection performance and plume distribution detected through monitoring. Match achieved between monitoring findings and predictive model.
	3. Evaluate characteristics of different seismic techniques to optimally monitor CO_2.	Several different seismic monitoring techniques applied (see section x) and quantitatively compared (i.e. sensitivity, S/N Resolution, Coverage), relative to environment, ease of acquisition and cost.
	4. Confirm ‘point of stabilisation’ through monitoring validation of dynamic model predictions.	The plume stabilisation, predicted by dynamic modelling, validated by direct verification of seismic-scale plume immobilisation between time-lapse observations.

Seismic modelling for 30kt injection of CO2



Roman Pevzner

Thank you

CO2CRC Participants

Australian Government Geoscience Australia | CSIRO | Curtin University | MONASH University | The University of Adelaide Australia

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BG Group | bhpbilliton | Brown Coal Innovation Australia | bp | Chevron

ministry of science + innovation Te Pūnaha Hiringa Whakaea | GNS Science Te Pū Ao | INPEX | KIGAM Korea Institute of Geoscience and Mineral Resources | NSW Government Trade & Investment

QER | RioTinto | Queensland Government | sasol reaching new frontiers | Shell

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