Queensland CO_2 Geological Storage Atlas Workshop

Queensland Government

CGSS

COAL21 FUND

Brisbane October 2009

Workshop Outline

3 presentations

1. Overview of Queensland CO_2 storage Atlas
2. Methodologies used in Atlas
   - Ranking
   - Volumetrics
   - Storage Site identification
3. Atlas results - BB
   - High prospectivity basins
   - Low prospectivity basins
   - Storage in unmineable coal seams and ECBM
   - Storage in depleted fields

"Drive through" interactive GIS session

Outline- Atlas overview

1. Who are CGGS?
2. CO_2 Storage Challenges
3. Methodologies used in Atlas
   - Ranking
   - Volumetrics
4. Atlas results
   - High prospectivity basins
   - Low prospectivity basins
   - Storage in unmineable coal seams and ECBM
   - Storage in depleted fields

Who are we?

- CGSS = CO_2 Geological Storage Solutions
- CO_2 geological storage services firm
- Provide geoscience advice for geological storage of CO_2: Technical, Legal, Regulatory, Strategic
- Assist in deployment of geological storage at industrial scale: Regional Assessment, Prospect Exploration, Site Injection
- Combined 60 years experience in CO_2 storage
- Main Office in Canberra- with Associates and Alliances nationally (Perth, Melbourne, Adelaide, Brisbane) and Internationally

ACKNOWLEDGEMENT

Queensland CO_2 Storage Atlas team

- John Bradshaw
- Barry Bradshaw
- Lynton Spencer
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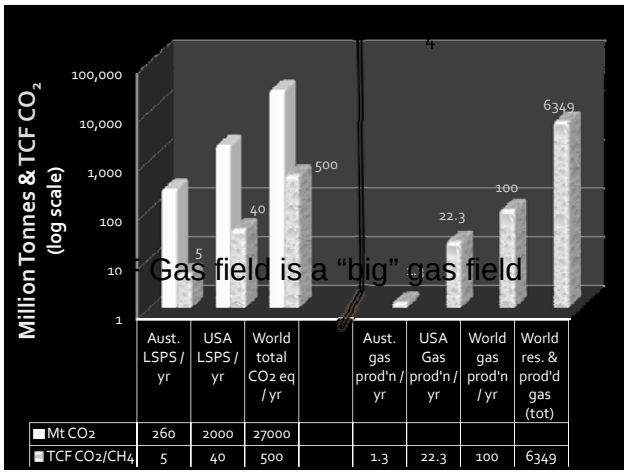
- Wendy Ronda
- Bruce Wyatt
- Greg Tobin
- Karni Sudana
- Helen Wood
- Kat Norman
- James Woodger

Plus QDEEDI team: John Draper, Jonathan Hodgkinson, Mike McKillop, Micaela Preda and Owen Dixon.

Geological storage of CO_2 has the technical potential to provide an opportunity for significant CO_2 emission reductions.

The longer we hesitate, the more the emissions scale up?

What is the scale of emissions?



CHALLENGES

What is prospectivity?

- Prospectivity is a qualitative assessment of the likelihood that a suitable storage location is present in a given area based on the available information
- The ability to assess each area is dependent on the quality and spatial distribution of the available datasets
- Estimates of prospectivity are developed by examining data, examining existing knowledge, applying established conceptual models and, ideally, generating new conceptual models or applying analogues.

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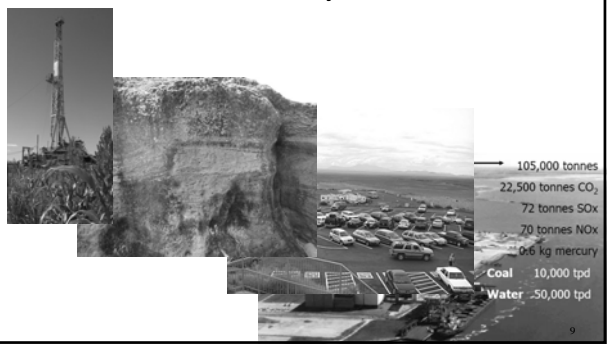
Car Park Mentality



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CHALLENGES

What is Storage Ready?

The processes and outcomes from identifying, proving and securing a geological storage site that is capable of having commercial quantities of CO_2 injected and stored in the deep subsurface on a sustainable basis, whilst maintaining high geological integrity in the geological structures and formations both during and after the injection and storage period.

BUT :

- does not describe the processes involved proving a storage site,
- does not elaborate on levels of proof and certainty that may be required,
- does not express the conceptual nature of the understanding of the geological attributes of the deep subsurface, and
- does not document the actual impacts that the geological characteristics of the deep subsurface may have on a site being proven to be storage ready.

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CHALLENGES

What is the behaviour of CO_2 in the subsurface?

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What are the legal/permitting issues?

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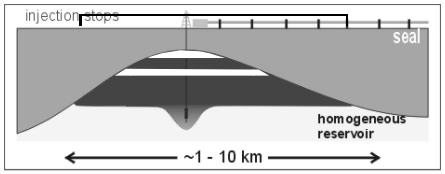
CHALLENGES

Conceptual CO_2 Storage Scenario

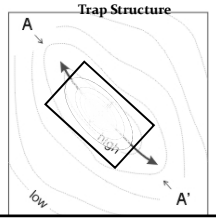
depleted field / structural trap



Assigning permits relatively easy – tightly constrained

But what if hydrocarbon discovery already exists, or believed to exist in structure? EOR - Sequenced development?

Or hydrocarbons found later - Which operator? – Who gets priority?



(template slide courtesy of Robert Root)

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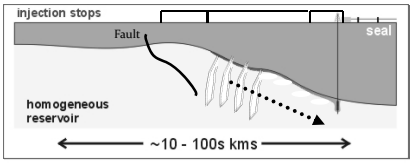
CHALLENGES

Conceptual CO_2 Storage Scenario

hydrodynamic / residual gas / solution trap **(MAS – Migration Assisted Storage)**

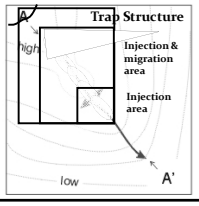


Where do you put permit boundaries ?

How big do you make permits?

What access rights do you employ?

What if there are two storage operators – co-mingling of CO_2?



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CHALLENGES

How do we measure the capacity of a potential storage site?

CHALLENGES

Storage Capacity estimates

- The geological storage of massive volumes of CO_2 is a currently evolving science/technology
- Challenges in nomenclature use for storage processes vs storage trapping mechanisms
- Different ways to estimate storage capacity based on different formulas and parameters
- Question of accuracy of estimates- introduction by Bradshaw 2003 of the storage resource pyramid

CHALLENGES

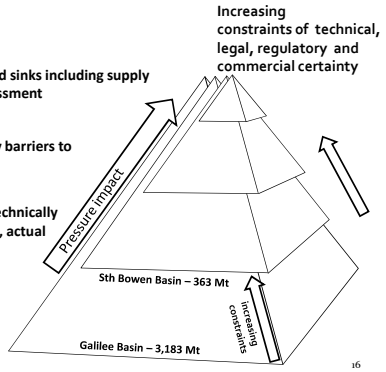
Storage Capacity estimates

Matched capacity:
Detailed matching of sources and sinks including supply and reservoir performance assessment

Practical (Viable) capacity:
Applies economic and regulatory barriers to realistic capacity,

Effective (Realistic) capacity:
Applies technical cut off limits, technically viable estimate, more pragmatic, actual site / basin data

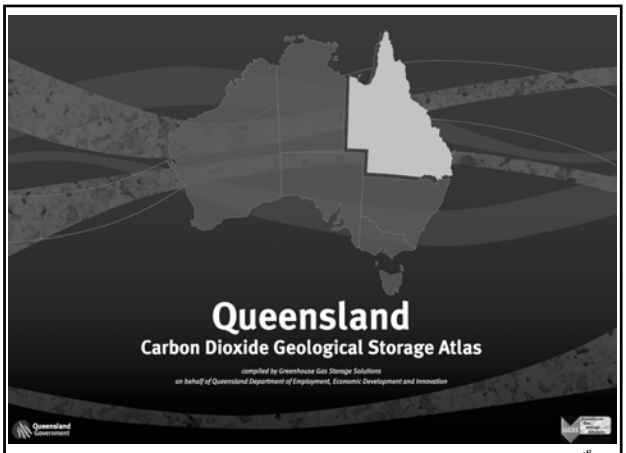
Theoretical capacity:
includes large volumes of "uneconomic" opportunities.
Approaches physical limit of pore rock volume ; unrealistic and impractical estimate



CHALLENGES

Reservoir Pressure Build up: considerations

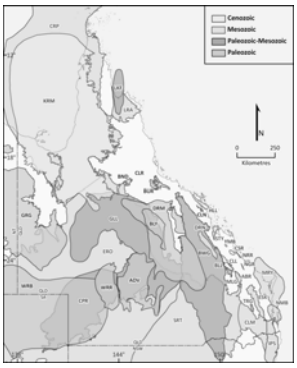
- fracture pressure
  - limitations that may have on storage capacity
  - Impact on injection rate, well numbers & cost
- regulatory regime
  - impact of large scale injection
- entire hydrologic regime
  - will need to be monitored
- Where pressure draw down has occurred due to production of groundwater
  - pressure build-up may be a benefit
  - provided saline water does not mix with the freshwater systems
- consider the use of pressure relief wells
  - Adds to cost



INTRODUCTION

Queensland CO_2 Storage Atlas

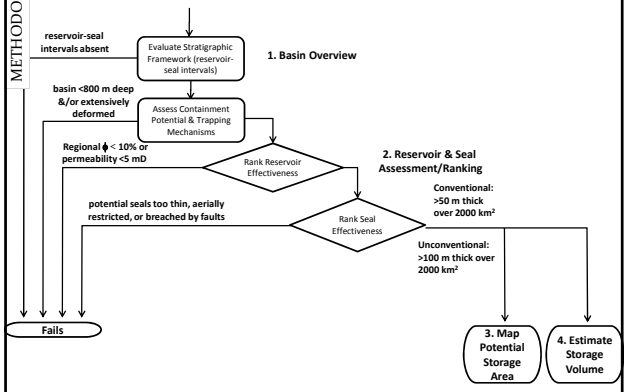
- Stage 1 of QDME Carbon Geostorage Initiative: **768 – 1,296** Mt storage capacity required for major emission nodes
- 36 Queensland basins assessed for geological storage prospectivity
- High-grade basins for more detailed studies & data acquisition to identify storage sites
- Geological assessment – excludes existing resources
- Product includes A3 hardcopy atlas and GIS (ArcGIS and MapInfo formats)



Assessed sedimentary basins classified by age

METHODOLOGY

Assessment Methodology



METHODOLOGY

Ranking Methodology

- Reservoir assessed solely for potential to have a reliably sealed effective storage area with good injectivity
- Each reservoir ranked for its seal effectiveness & reservoir effectiveness
- Does not dismiss a reservoir due to lack of data – allows for uncertainty due to lack of data

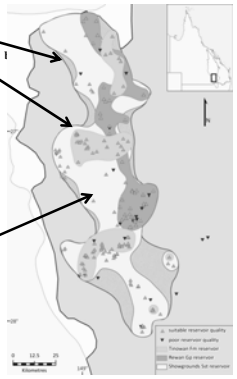
	Ranking Criteria	Ranking Criteria Selection Options
Seal Effectiveness	Conventional Seal	Adequate regional conventional seal likely.
		Plausible that significant regional/subregional seals present.
		No significant seal.
	Unconventional Seal	Adequate regional unconventional seal likely.
		Plausible that unconventional seal is extensive.
		No significant unconventional seal present.
	Faults through Seal	No faults mappable or not pervasive.
		Plausible that no significant faults present.
		Multiple faults and/or displacement ≥ seal thickness.
Reservoir Effectiveness	Porosity	Regionally well defined with ≥10 % porosity.
		Plausible that effective storage pore space present.
		Reservoir facies ineffective <10 % porosity.
	Permeability	Permeability known to be good to adequate.
		Plausible that permeability or injectivity adequate.
		Permeability known to be poor or absent.
	Depth at Base of Seal Adequate	~800 m below hydrostatic head.
		~650-800 m below hydrostatic head.
		~650 m below hydrostatic head.

Ranking	Score
Acceptable	3
Uncertain	2
Below Minimum	1

METHODOLOGY

Volumetrics – Showgrounds Sandstone example

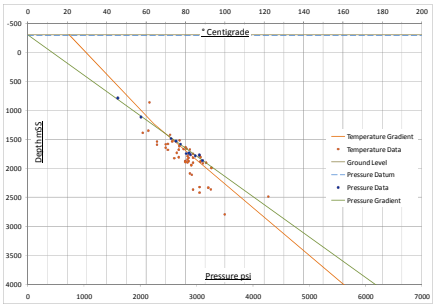
1. Define storage area
- Extent of regional seal (Snake Creek Mudstone/Moolayember Fm) and reservoir fairways used to define probable storage area in Southern Bowen Basin over the Roma Shelf/Wunger Ridge.
- Fairways difficult to map in detail due to association with thin and narrow fluvial channel sandstones, lack of 3-D seismic data, and limited palaeo-geographic maps
- Showgrounds Sandstone most widespread reservoir – contains good quality sandstones to depths of 2,300 m in high energy fluvial channels
- Reservoir quality generally deteriorates towards eastern flank, but difficult to map where reservoirs end in Taroom Trough



Sth Bowen Basin reservoir fairway map

METHODOLOGY

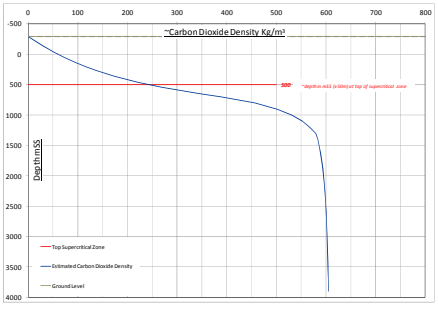
Volumetrics – Showgrounds Sandstone example



2. Calculate temperature and pressure gradients from WCR's
- Temperature gradient ~35°C through southern Bowen Basin
- Pressure gradient ~1.4374 psi/m

METHODOLOGY

Volumetrics – Showgrounds Sandstone example



3. Calculate CO_2 density gradient
- Supercritical below 500 m SS (800 mGL)
- Little increase in density below 1,300 mSS (1,600 mGL)

METHODOLOGY

Volumetrics – Showgrounds Sandstone example

4. Calculate Areas & Reservoir Parameters:

- Area calculated for each depth range over mapped storage area
- Average net pay zone thickness obtained from gas fields over reservoir area
- Average porosity obtained from QPED database
- Drainage cells defined but not used in calculations (beyond regional scope of Atlas)
- Alternatively, can use isopach maps and regional porosity trends if known (e.g. Eromanga Basin)

METHODOLOGY

Volumetrics – Showgrounds Sandstone example

Basin:	Southern Bowen	Ranked Reservoir Unit:	Showgrounds Sandstone	Storage Mechanism:	Residual Gas Saturation

Estimated theoretical carbon dioxide storage resource of the Southern Bowen Basin - Showgrounds Sandstone reservoir is 191 Megatonnes

Regional Storage Volume Estimation - Data Quality		Comment
Structural Surface Constraints:	Good	Regional GA/GSQ interpretation - considered likely to be accurate ± 100 m.
Reservoir Thickness Constraints:	Fair	Braided fluvial channels - generally trending east west - intersected randomly by wells.
Reservoir Porosity Constraints:	Good	Measured porosities from QPED database.
Reservoir Sg. Constraints:	Fair	Average value of 10% of total pore volume used across entire porosity range.

Regional Carbon Dioxide Density Estimation - Data Quality		Comment
Temperature Profile Constraints:	Probable Temperature Profile	Data from CSIRO - selectively edited and final regional temperature profile estimated by GGSS.
Pressure Profile Constraints:	Probable Pressure Regime	Data from CSIRO - selectively edited and final regional pressure profile estimated by GGSS.

Theoretical Storage Resource		Comment
Storage Volume Estimation Method:	Statistical	Net pay zone thicknesses from limited field log analysis. Storage efficiency factor is 1.
Subjective Estimate Accuracy:	Average	

Estimated Potential Storage:	191	Megatonnes (theoretical storage resource)	NB: Residual Gas Saturation storage has been approximated using unit specific storage cut-offs (See Volumetric Methodology Section for discussion).

Statistical Summary Data	Nett Thickness (m)	Porosity %
Data Point Count	21	1634
Average	5.12	12.40
Median	4.60	12.90
Standard Deviation	3.01	4.90
Kurtosis	0.44	0.20
Skewness	0.81	-0.20

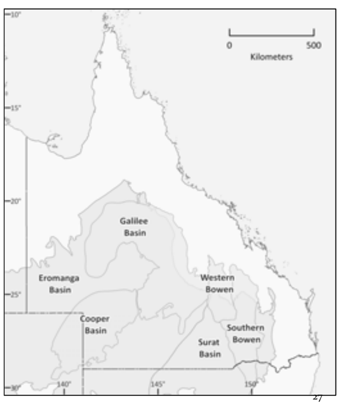
5. Calculate Theoretical CO_2 Storage Capacity

- Sum of storage volume in each depth range (accounts for changes in CO_2 density with depth)
- Gas saturation= 10%
- Storage Efficiency factor determined based on reservoir thickness (high for thin reservoirs, low for thick reservoirs)
- Residual gas saturation storage mechanism volume calculated as 1% of total calculated storage volume
- 191 Mt of theoretical capacity in Showgrounds Sandstone storage area (additional 172 Mt in Tinown and Rewan)

HIGH PROSPECTIVITY

Results: High Prospectivity Basins

- Highly prospective basins contain at least one reservoir-seal interval with demonstrated effectiveness for injection, storage and containment of CO_2
- Most of these high prospectivity reservoirs have either produced hydrocarbons, and/or are major groundwater aquifers.
- Have sufficient data sets to establish their prospectivity.



HIGH PROSPECTIVITY

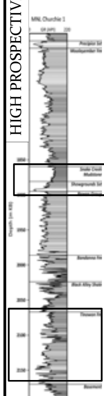
Southern Bowen Basin

Potential geological storage area in the Southern Bowen Basin (blue polygon) & locations of major emissions nodes

- Most basin area >800 mGL and at suitable depth for supercritical CO_2 storage.
- Potential for residual gas saturation trapping on gently dipping western flank. Containment problem where regional seal pinches-out.
- Some large faulted anticlines on eastern flank. Containment issue due to truncated, steeply dipping strata and large thrust faults

HIGH PROSPECTIVITY

Southern Bowen Basin



Unit	Reservoir Summary Information: Location	Maximum Thickness (m)	Porosity %	Permeability (mD)	Regional/Sub Regional Seal(s)	Potential Trap Mechanisms	Footnotes	Seal Ranking: Seal Type	Bulk Seal Effectiveness	Faults through Seal	Reservoir Ranking: Porosity	Permeability	Depth at Base Seal Adequate	Total Score
Moolayember Fm	Intraformational shales and mudstones, generally > 100 m thick, known to seal gas accumulations													
Moolayember Fm	Roma Shelf & Wunger Ridge	Net pay 17 (av = 7; n =5)	Median 14; Max 35; n = 512	Highly variable; Med 2.3; Max 6,200; n = 312	Intraformational	Structural/ residual gas saturation	1	C	2	3	2	2	3	12
Snake Creek Mudstone	Regionally extensive mudstones (lacustrine mfs), < 50 m thick, known to seal gas accumulations													
Showgrounds Sandstone	Roma Shelf & Wunger Ridge	Net pay 13 (av = 5; n = 21)	Median 13; Max 37; n = 1634	Highly variable; Med 14; Max 9,577; n = 1410	Snake Creek Mudstone	Structural/ residual gas saturation	1	C	3	3	2	2	3	13
Rewan Group	Intraformational siltstones and mudstones, > 100 m thick, known to seal gas accumulations													
Rewan Group	Roma Shelf & Wunger Ridge	Net pay 14 (av = 8; n = 11)	Median 11; Max 37; n = 932	Highly variable; Med 0.5; Max 2,245; n = 664	Intraformational	Structural/ residual gas saturation	1	C	2	3	2	2	3	12
Bandanna Formation	Intraformational siltstones, mudstones and tuffs, < 100 m thick													
Bandanna Formation	Roma Shelf & Wunger Ridge	Net pay 8 (av = 6; n = 2)	Median 11; Max 16; n = 17	Low; Median 0.6; Max 24; n = 16	Intraformational	Structural/ residual gas saturation	1	C	2	3	2	1	3	Fail
Black Alley Shale	Regionally extensive shale (marine mfs), < 50 m thick, known to seal gas accumulations													
Tinowan Formation/ Back Creek Group	Roma Shelf & Wunger Ridge	Net pay 38 (av = 17; n = 5)	Median 12; Max 40; n = 684	Highly variable; Med 1.6; Max 9,440; n = 512	Intraformational & Black Alley Shale	Structural/ residual gas saturation	1	C	3	3	2	2	3	13

- 5 reservoir units were ranked – best potential units are the Showgrounds Sandstone sealed by the Snake Creek Mudstone and Tinowon Formation sealed by the Black Alley Shale.
- These reservoirs are well sealed but have highly variable reservoir quality.
- Total theoretical storage volume 363 Mt (Showgrounds Sandstone=191 Mt)

HIGH PROSPECTIVITY

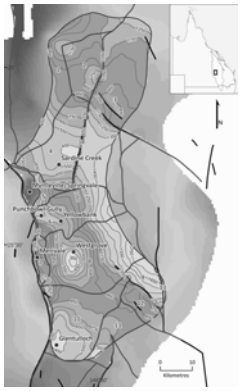
Western Bowen Basin

Potential geological storage areas in the Western Bowen Basin (blue polygons) & locations of major emissions nodes

- Large fault propagation anticlines - provide structural traps for gas fields that filled to spill point defined by bounding faults.
- Potential for residual gas saturation trapping where CO_2 is injected into synclines and migrates updip into anticlines.
- Series of regional seals formed in Late Permian marine shales; seals preserved in southern Denison Trough but often truncated and subaerially exposed in northern trough.
- Gas produced from low permeability reservoirs in Late Permian fluvial-deltaic, coastal and shallow marine sandstones (Aldebaran Sandstone, Freitag Formation, Catherine Sandstone and Mantuan Formation).

HIGH PROSPECTIVITY

Western Bowen Basin



- Volumetric calculations were completed for 4 reservoir units (Aldebaran sandstone – sth Denison Trough; Aldebaran Sandstone nth Denison Trough; Freitag Fm; Catherine Sandstone).
- Total theoretical storage volume 250 Mt. Greatest theoretical capacity in Aldebaran Sandstone over southern Denison Trough (100 Mt).
- Injectivity into low permeability reservoirs main uncertainty.

Aldebaran Sandstone storage area – southern Denison Trough. Gas fields=red circles.

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HIGH PROSPECTIVITY

Cooper Basin

- All at suitable depths for supercritical injection of CO_2, and has trapped hydrocarbons
- Reservoirs tight to moderate quality- best in Toolachee Fm over basinal area sealed by Callamurra Member
- Opportunities if fault seal issues resolved
- Depleted fields are not likely to be available in the near future but Challum field has the largest MTRV

Potential geological storage areas in the Cooper Basin (blue polygons) & locations of major emissions nodes

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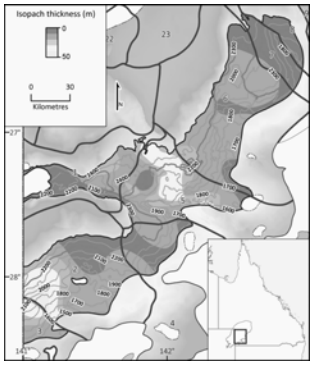
HIGH PROSPECTIVITY

Cooper Basin



- 7 reservoir units were ranked – best potential units are the Toolachee Fm, Patchawarra Fm and Doonmulla Mmb.
- Volumetric calculations were completed for one reservoir unit the Toolachee Formation
- Reservoir thickness was derived from isopach mapping (using Interpretation from Draper et al 2002).
- Calculated theoretical storage volume: 172 Mt.

Toolachee Fm top depth-structure contours (mSS), isopach (m) and drainage cell areas.

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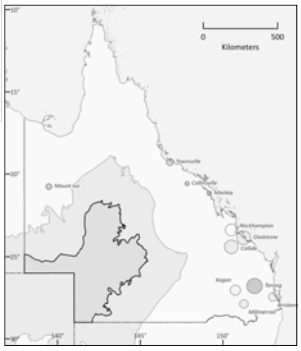
HIGH PROSPECTIVITY

Eromanga Basin



- Regionally extensive, vertically-stacked reservoirs and a thick regional seal succession.
- The presence of large anticlinal structures as well as flat-shallow dipping synclines and monoclines indicate that a range of both structural and residual gas saturation trapping mechanisms could be utilised.
- A large proportion of the basin is suitable for supercritical CO_2 storage.

Potential geological storage area in the Eromanga Basin (blue polygon) & locations of major emissions nodes

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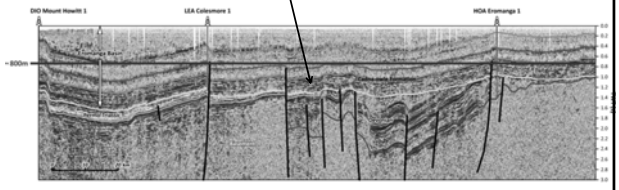
HIGH PROSPECTIVITY

Eromanga Basin

- 7 reservoir units were ranked – 5 of these are targeted for oil exploration
- Those units below the regional seal are generally characterised by moderate-excellent reservoir quality.
- The combined theoretical capacity for these 5 reservoirs is massive (46,499 Mt) – reflects the extensive nature and thickness of reservoir units.
- Hutton Sandstone capacity is estimated at 12,262 Mt of CO_2.



Interpreted seismic line BMR80-23 from the Eromanga Basin

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HIGH PROSPECTIVITY

Galilee Basin

- Triassic & Late Permian strata from relatively continuous reservoir-seal units, and are potentially suitable for geological storage of CO_2 where they are preserved beneath the Eromanga Basin (truncated to the west).
- Main storage mechanism is residual gas migration trapping using low regional dip of strata in Koburra Trough, and southwest plunging faulted ridges in sth Galilee Basin – potential fault seal breaches.
- Permian strata generally >800 mBGL; Triassic Moolayember Formation (regional seal) <800 mBGL over most of Koburra Trough.

Potential geological storage areas in the Galilee Basin (blue polygons) & locations of major emissions nodes

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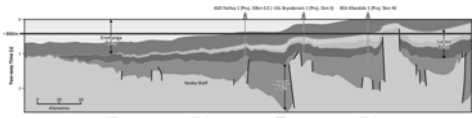
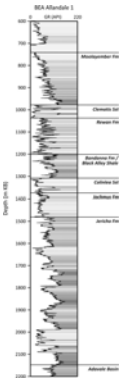
HIGH PROSPECTIVITY

Galilee Basin

- Volumetric calculations were completed for 4 reservoir units.
- Not possible to define reservoir fairways or pay zones therefore large theoretical storage volumes.
- Southern Galilee 2,302 Mt ; Koburra Trough 1128 Mt.
- Seal capacity & faults through seal key uncertainty – needs addressing through fully cored wells & modern seismic.





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HIGH PROSPECTIVITY

Surat Basin

Potential geological storage areas in the Surat Basin (blue polygons) & locations of major emissions nodes

- A large proportion of the basin is suitable for supercritical CO_2 storage.
- The upper Evergreen Formation acts as a regional seal for the underlying Early Jurassic reservoirs (Precipice, Basal Evergreen & Boxvale sandstones).
- A broad structural depression " the Mimosa Syncline" has gently dipping strata to the W & NW providing long-range migration of CO_2, maximising the potential for residual gas saturation trapping

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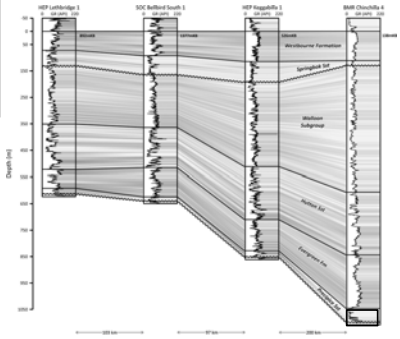
HIGH PROSPECTIVITY

Surat Basin



Well log cross section in the Surat Basin showing regionally extensive sandstone units.

- Volumetric calculations were completed for 4 reservoir units (Precipice, Basal Evergreen, Boxvale, Hutton)
- Theoretical storage capacity using residual gas saturation trapping totals 2,962 Mt (Precipice Sandstone =1,289 Mt).
- Other storage options are limited to depleted oil and gas fields, which only provide ~ 16 Mt of storage capacity.

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HIGH PROSPECTIVITY

Estimated Storage Volumes

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LOW PROSPECTIVITY

Results: Low Prospectivity Basins

13 Low prospectivity basins contain reservoir-seal interval/s with uncertain effectiveness due to either limited data to evaluate their prospectivity, or high variability in the quality of reservoirs and seals.

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UNSUITABLE

Results: Unsuitable Basins

19 unsuitable basins are known to be unprospective as their reservoirs and/or seals are all below the minimum criteria

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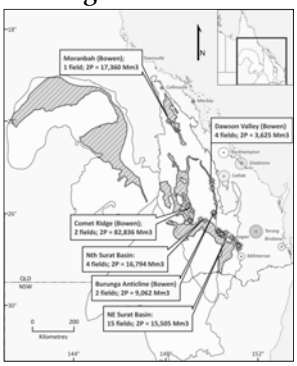
COAL STORAGE

Potential Coal Storage Areas

- Potential storage areas have been defined in major coal basins (Bowen, Surat & Galilee basins)
- Storage volumes have not been calculated – know that these will be unrealistically large – injectivity is real issue
- Results show best potential is in CBM exploration sweet spots – mainly an option for ECBM recovery



Location of thick extensive coal measures at depths >400 and <1000m (grey hatched polygons). Also shown are CSG fields and 2P resources (June 2008).

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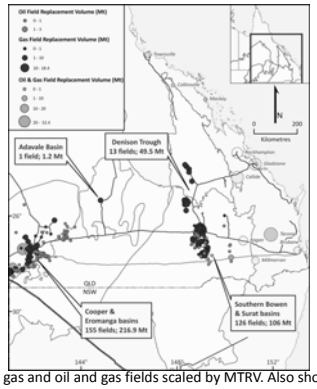
DEPLETED FIELDS

Depleted Fields

- A maximum theoretical replacement volume (MTRV) of 374 Mt CO_2 is estimated for 295 gas and/or oil fields and ~485 reported producing reservoir pools in Queensland
- Most large fields are still producing and are unlikely to be available for CO_2 storage in the near-future.



Location of oil, gas and oil and gas fields scaled by MTRV. Also shown are major emissions nodes and gas (red lines) and oil (green lines) pipelines

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Summary

- This atlas is the first step in targeting basins or parts of basins in onshore Queensland where more detailed studies will help evaluate and characterise future storage sites.
- Good opportunities for geological storage are most evident in the Bowen, Cooper, Eromanga, Galilee and Surat basins
- But further drilling and exploration is required in many parts of these basins to fully document the quality of their storage prospectivity.

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Summary

- The greatest potential for storage is in regionally extensive reservoir-seal intervals rather than depleted fields.
- Queensland Government have legislation (*Greenhouse Gas Storage Act 2009*) that will come into effect Feb 2010
  - Soon to have gazettal rounds in place for permits to:
    - Explore for underground storage reservoirs
    - storage of greenhouse gases to take place

Basin prospectivity based on ranking methodology

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