Methodology: Ranking, Site Assessments & Volumetrics

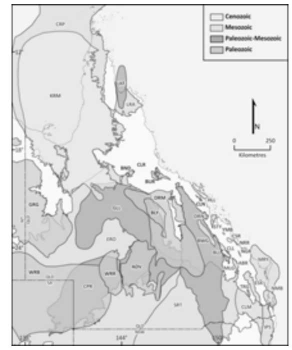
CO_2 Geological Storage Solutions

Queensland Government · CGSS · COAL21 FUND

INTRODUCTION

Queensland CO_2 Storage Atlas

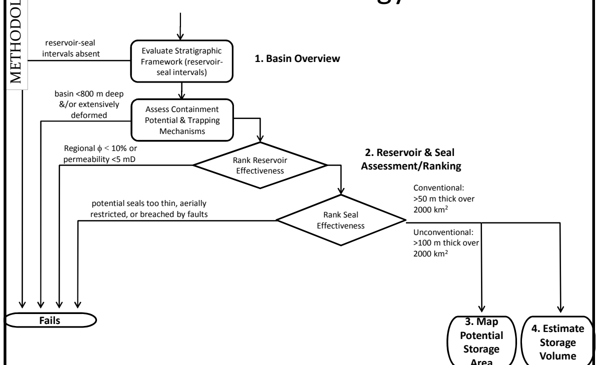
- Aim to identify with highest possible certainty prospective basins for geological storage in onshore Queensland (36 basins).
- Geological assessment – excludes existing resources
- Options assessed include: regional reservoirs (saline reservoirs & aquifers); depleted oil & gas fields; deep unmineable coal seams; and salt caverns.
- Greatest potential in regional reservoirs using migration assisted storage (MAS) – focus of regional assessments and volumetric assessments.



Assessed sedimentary basins classified by age

METHODOLOGY

Assessment Methodology



METHODOLOGY

Common QLD Data Types

Well data (QPED & WCR's), outcrop (GSQ maps)

- Reservoir characteristics
  - Porosity, permeability, production history, lithology, continuity, thickness
- Seal characteristics
  - Capacity, lithology, thickness, continuity

Seismic data (2D)

- Structure, faults, potential traps, migration and leakage paths, reservoir & seal distribution
- Depth-structure maps

Oz SEEBASE™ depth to basement (high level screening tool)

RANKING

Ranking Methodology

- Assessment methodology for storage sites involved three components:
  - seal effectiveness and containment potential
  - reservoir effectiveness, and
  - reservoir depth (does not automatically fail if < 800 m)
- The ability to assess each area is dependent on the quality and spatial distribution of the available datasets
- Does not dismiss a reservoir due to lack of data – allows for uncertainty due to lack of data
- It does not consider factors such as interference with other resources, land usage, distance to CO2 emission nodes or calculated volumetric estimates

Ranking Criteria	
Seal Effectiveness	Conventional Seal
	Unconventional Seal
	Faults through Seal
Reservoir Effectiveness	Porosity
	Permeability
	Depth at Base of Seal Adequate

RANKING

Ranking Methodology

6 factors are ranked based on three defined criteria. A simple colour-coded 'traffic-light' approach is used in the assessment of each criteria:

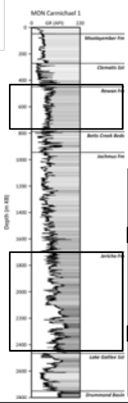
Ranking	Score
Acceptable	3
Uncertain	2
Below Minimum	1

3. Acceptable: definitely above the minimum criteria with information to prove this.
2. Uncertain: unable to make a reasonable assessment one-way or the other on current knowledge-usually due to lack of data.
1. Below Minimum: definitely below the minimum criteria with information to prove this

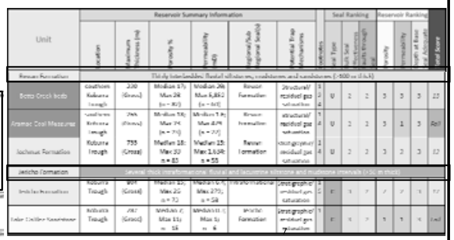
Ranking Criteria		*Ranking Criteria Selection Options*
Seal Effectiveness	Conventional Seal	Adequate regional conventional seal likely.
		Plausible that significant regional/subregional seals present.
		No significant seal.
	Unconventional Seal	Adequate regional unconventional seal likely.
		Plausible 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

Conventional vs Unconventional seals



- 'Conventional' seals act as a physical barrier (trap) to the migration of fluids (e.g. Jericho Formation).
- Unconventional seals potentially include greensands, siltstones and very fine-grained sandstones. The main feature is very low but effective bulk rock permeability. To be considered as an unconventional seal the formation has be > 100 m thick over an area of ~2000 km² (e.g. Rewan Formation – Galilee Basin)



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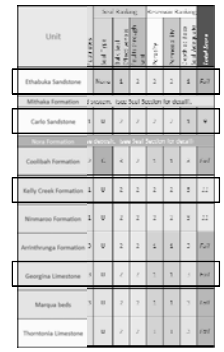
RANKING

Ranking Methodology

- A reservoir that does not have a 'conventional' seal immediately overlying it is set to 'unconventional' and ranked as a 2 (e.g. Kelly Creek Fm).
- The Depth at Base of Seal Adequate is not set as an automatic fail (e.g. Carlo Sandstone)
- Failure occurs if:
  - there is neither 'conventional' nor 'unconventional' seal above the reservoir (e.g. Ethabuka Sandstone);
  - if either the porosity or the permeability of the reservoir is below its respective minimum cut-off (e.g. Georgina Limestone)



Georgina Basin Ranking Chart

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POTENTIAL STORAGE AREAS

Potential Storage Area Mapping

- Maps generated for the maximum known extent of reservoir-seals intervals within a basin that are evaluated as having potential for geological storage of CO_2.
- The maximum potential storage area incorporates
  - A regional seal >800 m deep at its base
  - A seal of suitable thickness to contain CO_2 (>50 m for conventional seal; >100 m for unconventional seal),
  - A suitable quality reservoir for CO_2 (porosity ≥ 10 %; permeability ≥ 5 mD).
- However, the level of detail in mapping maximum potential storage area varies from basin to basin depending on the data availability and geological complexity.

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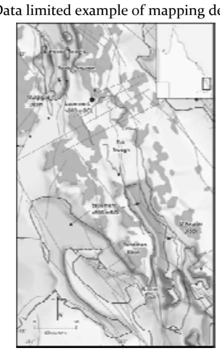
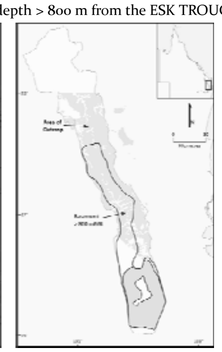
POTENTIAL STORAGE AREAS

Potential Storage Area Mapping

Data limited example of mapping depth > 800 m from the ESK TROUGH



OzSEEBASE™ (2005) depth to basement used to determine where base Esk Trough is > 800 m



Maximum potential storage area (blue shading) where sediments > 800m and units are not outcropping.

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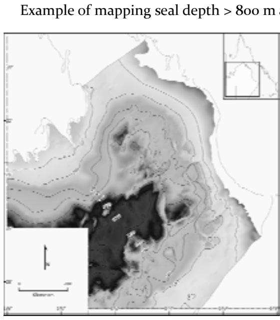
POTENTIAL STORAGE AREAS

Potential Storage Area Mapping

Example of mapping seal depth > 800 m and > 50 m from the EROMANGA BASIN



Depth structure map (mSS) of the C-Horizon (base regional seal). The base regional seal is >800 mBGL (450 mSS) over most of the basin. The regional seal Wallumbilla Fm- Allaru Mudstone is > 50 m across the basin.

Potential Storage area for the Eromanga Basin, defined by depth > 800m and > 50m thickness of regional seal (Allaru Mudstone/Wallumbilla Fm).

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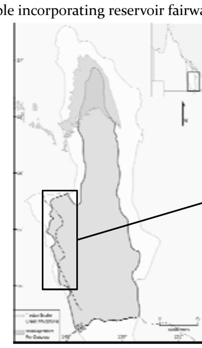
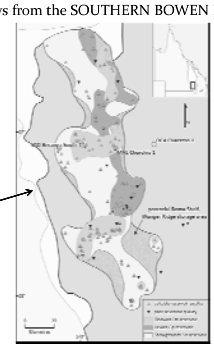
POTENTIAL STORAGE AREAS

Potential Storage Area Mapping

Example incorporating reservoir fairways from the SOUTHERN BOWEN BASIN



Maximum potential storage area in the Southern Bowen Basin where regional seal is > 50 m thick and > 800 m deep.



Mapped reservoir fairways over the Roma Shelf/Wunger Ridge.

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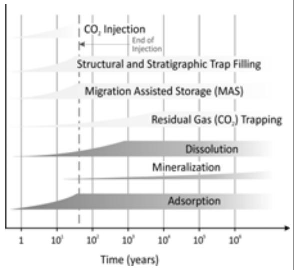
VOLUMETRICS

Volumetric Methodology

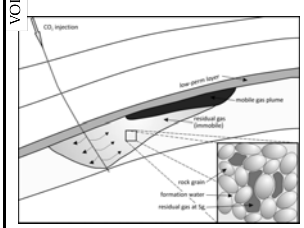
- There are different mechanisms which immobilise (trap) CO_2 in the subsurface, and the timescales over which they operate (Bachu et al. 2007).
- The lower three mechanisms (dissolution, mineralisation and adsorption) are, mostly, very long-term and are not considered here further.
- The volumetric estimations calculated in this atlas are based around free-phase trapping; i.e. top four mechanisms.



Time dependency of processes involved in CO2 geological storage (modified after Bachu et al. 2007). Top four green processes are relevant to the atlas.

VOLUMETRICS

Volumetric Methodology



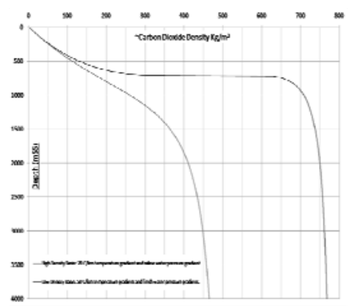
Schematic of trail of residual CO2 that is left behind because of snap-off as the plume migrates upwards during post-injection period (modified from Juanes et al. 2006)

- The migration assisted storage (MAS) process is the main process that can theoretically store enormous quantities of CO_2 in the absence of any subsurface closure.
- The dominant primary trapping mechanism is discontinuous free-phase trapping as *residual gas saturation (RGS)* in the trail of a migration plume.
- Using the porosity cut-offs a residual gas saturation (Sgr) of 0.2-0.6 is likely but this is difficult to calculate without core. Therefore a likely conservative value of Sgr = 0.1 has been used for all volumetric calculations.
- Ultimately the CO_2 trapped by these mechanisms is dissolved into the surrounding formation water

VOLUMETRICS

Volumetric Methodology

- Under the normal range of pressure/ temperature conditions found in sedimentary basins, the density of CO_2 can vary significantly.
- Uses the industry standard method of calculating CO_2 density using pressure & temperature data (Span and Wagner 1996).
- The precision of the CO_2 density estimate depends on the accuracy of pressure and temperature estimates.
- Data obtained from CSIRO Pressureplot database, then cross-checked with well data (ideally 10–20 data points).



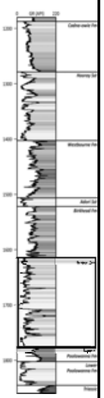
CO_2 density given two end-member basin conditions: a hot fresh-water (red curve) and a cold saline-water basin (blue curve).

VOLUMETRICS

Eromanga Basin – Hutton Sandstone e.g.

- Hutton sandstone = Jurassic fluvial sandstone
- Good-excellent reservoir potential
- Can be cemented at maximum depths in the central depocentre
- Intraformational seal = Birkhead Fm (known to seal hydrocarbons); regional seal = Allaru Mudstone & Wallumbilla Formation

Potential Storage area for the Eromanga Basin, defined by depth > 800m and > 50m thickness of regional seal (Allaru Mudstone/Wallumbilla Fm).



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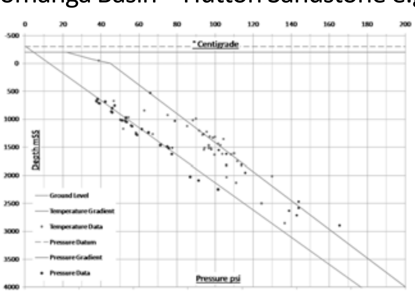
VOLUMETRICS

Eromanga Basin – Hutton Sandstone e.g.

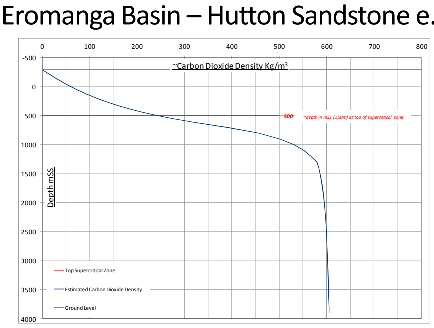


Calculate temperature and pressure gradients from WCR's

- Temperature gradient ~38.8°C/km based on extrapolated BHT data from 12 wells
- Pressure gradient ~1.4353 psia/m combined from groundwater studies and ten selected well DST's and RFT's.

VOLUMETRICS

Eromanga Basin – Hutton Sandstone e.g.

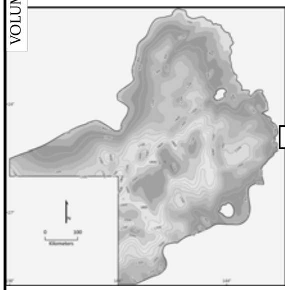


Calculate CO_2 density gradient

- Supercritical below 440 m SS
- The high geothermal gradient means the that there is a relatively lower CO_2 density at any depths compared to other 'colder' basins (e.g. southern Bowen Basin)

VOLUMETRICS

Eromanga Basin – Hutton Sandstone e.g.



Depth-structure map from the top of the Hutton Sandstone.

Isopach map of gross reservoir thickness of the Hutton Sandstone.

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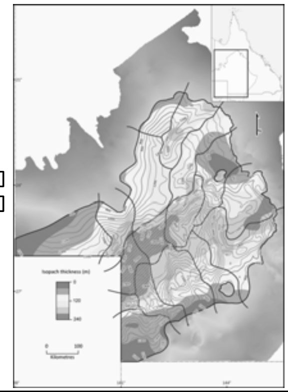
Eromanga Basin – Hutton Sandstone e.g.



Hutton Sandstone top depth-structure contours (mSS), isopach (m) and drainage cell areas. A potential area with < 10 % porosity (from Draper 2002) is shown hatched with a dark orange outline

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VOLUMETRICS

Volumetric Methodology

The equation for volumetric estimation is:

$$MCO_2 = RV * Ø * Sg * \delta_{(CO_2)}$$

- *MCO_2 = mass of CO_2 stored in kilograms*
- *RV = total reservoir rock volume in m^3*
- *Ø = total effective pore space (as a fraction)*
- *Sg = the gas saturation within the above pore space as a fraction of the total pore space (10 %)*
- *$\delta_{(CO_2)}$ = the density of CO_2 at the given reservoir depth (pressure and temperature) in kg/m^3.*

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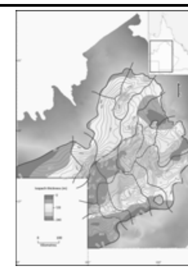
VOLUMETRICS

Hutton Sandstone example

- Porosity vs depth function derived from QPED database
- Depth and thickness from QPED and WCR
- Sum of storage volume in each depth range (accounts for changes in CO_2 density with depth)
- Sgr estimated at 10 % of total calculated storage volume



Median polygon depth (mSS)	Average reservoir thickness (m)	Area (m^2)	Average reservoir depth (mSS)	Temperature °C	Pressure (Mpa)	CO_2 density Kg/m^3	Estimated reservoir porosity %	Estimated percentage of reservoir that fits to meet 1.6 effective at given depth	Net/Gross	Sg	Effective storage volume m^3	Kilograms stored
650	20	47,514,648	660	70.6	9.601	229.6	19.78	17.49	0.80	0.10	13,157,333	3,020,469,395
650	100	[illegible]	700	[illegible]	9.997	241.1	19.78	17.49	0.80	0.10	2,466,895,704	[illegible]
850	20	3,272,659,668	860	78.4	11.581	285.6	18.71	24.98	0.80	0.10	735,139,342	209,927,744,586
1050	20	1,300,147,960	1060	86.1	13.560	334.4	17.47	23.54	0.80	0.10	277,825,785	92,896,047,707

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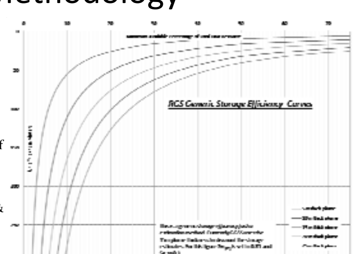
VOLUMETRICS

Volumetric Methodology

- This volumetric estimation calculation overestimates the value: calculating the volume of CO_2 that could be stored over the *entire* reservoir unit.
- As the migrating plume will not access a large proportion of the reservoir this value is unrealistic (assuming homogenous reservoir, injection over entire interval, & formation water displaced uniformly)
- Therefore to limit extreme values developed a very basic RGS storage efficiency factor
- 15m plume estimate used



As the reservoir thickness increases, a smaller proportion of the total reservoir volume can be theoretically considered as potentially available for storage.

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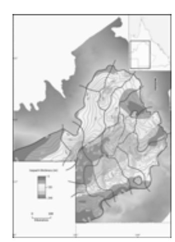
VOLUMETRICS

Hutton Sandstone example

- Storage Efficiency factor determined based on reservoir thickness to be 0.1 for Hutton Sandstone using an average thickness of 124 m.
- Table of regional storage volume estimation input data quality.
- Hutton Sandstone capacity is estimated at 12,262 Mt of CO_2.



Regional Storage Volume Estimation - Data Quality		Comment
Structural Surface Constraints:	Good	Extrapolated from C horizon depth map, using QPED well tops data.
Reservoir Thickness Constraints:	Good	QPED database - numerous wells across the basin.
Reservoir Porosity Constraints:	Fair	Average porosity values estimated from QPED core database. Very scattered data.
Reservoir Sg Constraints:	Poor	Sg 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	Regional spread of extrapolated BHTs.
Pressure Profile Constraints:	Probable Pressure Regime	Formation pressure estimated from DSTs that flowed WTS.
Theoretical Storage Resource		**Comment**
Storage Volume Estimation Method:	Gross Reservoir Isopach	Net to gross ratio estimated at 80% and depth dependant reservoir quality loss estimate included.
Subjective Estimate Accuracy:	Average	Storage efficiency factor is 0.1.
Estimated Potential Storage:	12,262	Megatonnes (theoretical storage resource) — NB: Residual Gas Saturation storage has been approximated using unit specific storage cut-offs (See Volumetric Methodology Section for discussion).

VOLUMETRICS

Volumetric Methodology

- Attempted to be conservative in estimating all the parameters used in the volumetric *estimated potential storage* calculation. It is therefore believed that the estimates given are conceptually close to the boundary between <u>theoretical</u> and <u>effective capacity</u>.

- All estimates have accompanying data quality tables and descriptions of input parameters used (see previous table)

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And the results?

- Next presentation: *Results and conclusions of the Queensland CO2 Geological Storage Atlas*

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