CAGS Technical Workshop
Canberra 18th – 22nd January 2010

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QUEENSLAND CO_2 GEOLOGICAL STORAGE ATLAS – RESULTS

Queensland Government

Outline

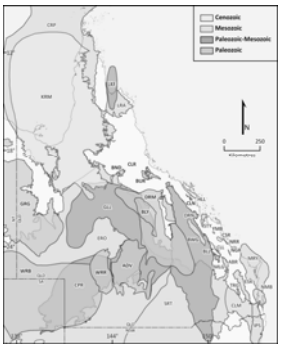
1. Atlas Scope
2. Assessment results from 5 High Prospectivity basins
3. Summary of low prospectivity basins
4. Summary of unsuitable basins
5. Discussion of storage in depleted oil & gas fields
6. Discussion of potential for storage in unmineable coals and ECBM

Basin prospectivity based on ranking methodology

ATLAS SCOPE

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 or site economics
- 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 presentation.



Assessed sedimentary basins classified by age

HIGH PROSPECTIVITY

High Prospectivity Areas – Summary

- Contain at least one reservoir-seal interval with demonstrated effectiveness for injection, storage and containment of CO_2 (i.e. have a total ranking score ≥ 13).
- Twenty reservoirs from five basin areas (Bowen, Cooper, Eromanga, Galilee and Surat basins).
- Most reservoirs have either produced hydrocarbons, and/or are major groundwater aquifers.
- Have sufficient data sets to establish their prospectivity.

HIGH PROSPECTIVITY

Southern Bowen Basin

- Large north-south trending foredeep located close to major emission hubs.
- Mature hydrocarbon province in Queensland: ~94 conventional fields (OIP resources ~ 400 Bcf gas & 10 MMbbl oil) – most near depleted; 5 commercial CSG fields (~450 Bcf)
- Maximum potential storage area defined over western flank (Roma Shelf/Wunger Ridge area) where most conventional hydrocarbons are trapped.

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

HIGH PROSPECTIVITY

Southern Bowen Basin

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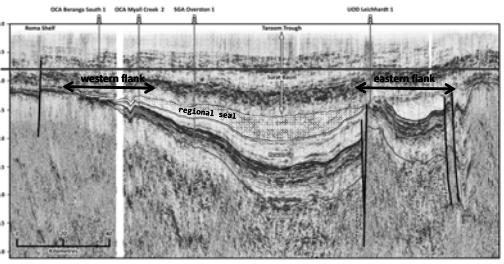
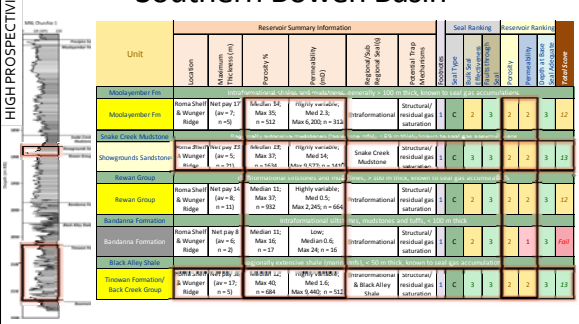


- Lacustrine mudstones from Moolayember Formation (Snake Creek Mudstone) form regional seal for the underlying Triassic fluvial sandstones (Showgrounds Sandstone & Rewan Group).
- Potential for residual gas saturation trapping on gently dipping western flank – best quality reservoirs sourced from western cratonic province. 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. Poor reservoir quality due to proximity to eastern volcanic arc.

HIGH PROSPECTIVITY

Southern Bowen Basin



- 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.

HIGH PROSPECTIVITY

Southern Bowen Basin

- Volumetric calculations were completed for 3 reservoir units (Showgrounds Sandstone, Rewan Formation and Tinowan Formation).
- Reservoir net pay zone thicknesses from WCR's and average porosity from QPED database used in calculations.
- Total maximum theoretical storage volume 363 Mt - greatest theoretical capacity in Showgrounds Sandstone (191 Mt).

Showgrounds Sandstone storage. Also shown are drainage cell interpretations and hydrocarbon fields (red circles).

HIGH PROSPECTIVITY

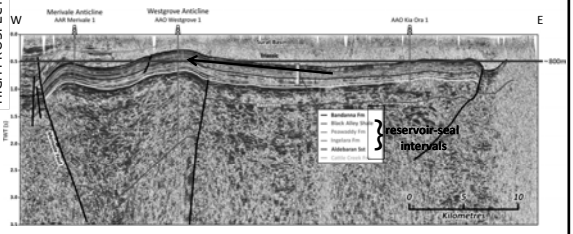
Western Bowen Basin

- Inverted extensional basin located close to major emission hubs.
- Mature hydrocarbon province in Queensland: 13conventional gas fields (OIP resources 374 Bcf) – tight gas fields with recent reserves growth; 2 world-class CSG fields (2925 Bcf)
- Maximum potential storage areas defined over northern and southern parts of Denison Trough where conventional hydrocarbons are trapped.

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

HIGH PROSPECTIVITY

Western Bowen Basin



- Potential for residual gas saturation trapping where CO_2 is injected into saddles and migrates updip into fault propagation anticlines.
- Series of thick 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).

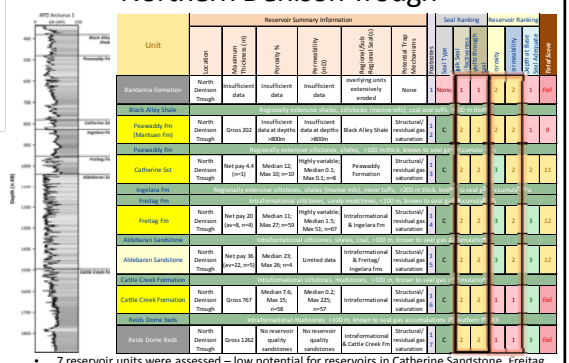
HIGH PROSPECTIVITY

Southern Denison Trough

- 9 reservoir units were assessed – only high prospectivity unit is the Aldebaran Sandstone.
- Reservoir well sealed but highly variable, generally low permeability sandstones.

HIGH PROSPECTIVITY

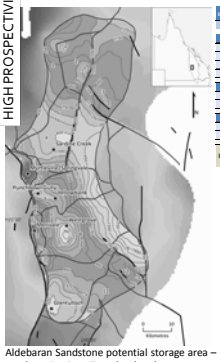
Northern Denison Trough



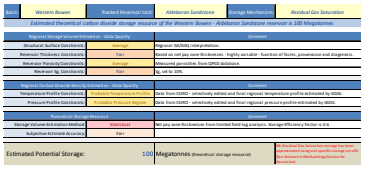
- 7 reservoir units were assessed – low potential for reservoirs in Catherine Sandstone, Freitag Formation and Aldebaran Sandstone (generally low permeability reservoirs).
- Structural traps present but seals often truncated and subaerially exposed.

HIGH PROSPECTIVITY

Western Bowen Basin



Aldebaran Sandstone potential storage area – southern Denison Trough. Also shown are drainage cell interpretations and hydrocarbon fields (red circles).

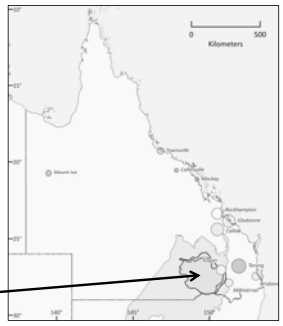


- Volumetric calculations were completed for 4 reservoir units (Aldebaran sandstone – sth Denison Trough; Aldebaran Sandstone nth Denison Trough; Freitag Fm; Catherine Sandstone).
- Reservoir net pay zone thicknesses from WCRs & average porosity from QPED database used in calculations.
- Total theoretical storage volume 250 Mt.
- Greatest theoretical capacity in Aldebaran Sandstone over southern Denison Trough (100 Mt).
- Injectivity into low permeability reservoirs main uncertainty.

HIGH PROSPECTIVITY

Surat Basin

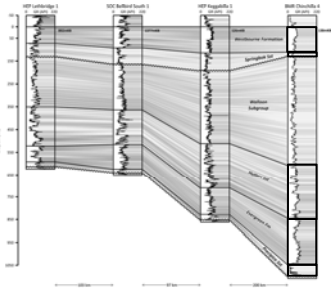
- Large intracratonic basin (overlies Bowen Basin) located close to major emission hubs.
- Mature hydrocarbon province in Queensland: ~45 fields (OIP resources ~500 Bcf gas & 50 MMbbl oil) – most near depleted; 19 commercial CSG fields (~1140 Bcf)
- Groundwater heavily utilised in populated areas.
- Large maximum potential storage area defined over much of basin area (regionally extensive reservoirs and seals extend over broad structural depression – ideal for RGS trapping).



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

HIGH PROSPECTIVITY

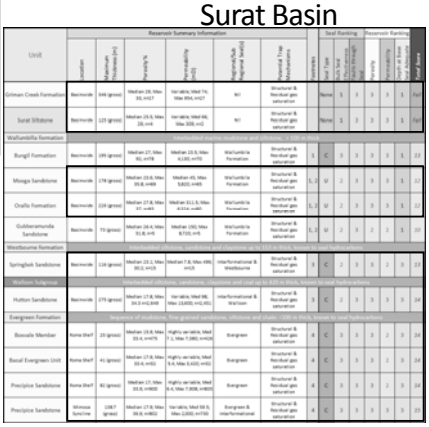
Surat Basin



- Shallow marine to lacustrine shales and siltstones from the Early Jurassic upper Evergreen Formation and the Late Jurassic Westbourne Formation provide regional conventional seals for CO_2 + several intraformational seals present).
- Regionally-extensive fluvial sandstone units provide potential reservoirs throughout the basin.

HIGH PROSPECTIVITY

Surat Basin



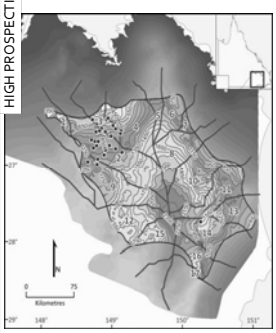
•The Precipice, Basal Evergreen, Boxvale , Hutton and Springbok (ranked 13-15) are the most important reservoir units in the basin. Four of these are the 'traditional' reservoirs targeted for oil exploration and are below the regional seal units

•Reservoirs that ranked 12 have good reservoir quality but they are < 800 m deep.

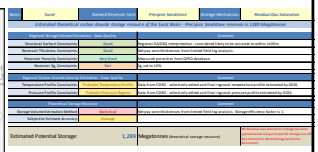
•2 units failed due to lack of regional seal.

HIGH PROSPECTIVITY

Surat Basin



Precipice Sandstone reservoir map showing depth (mSS) structure surface. Also shown are drainage cell interpretations and hydrocarbon fields (red circles).



- Volumetric calculations were completed for 4 reservoir units (Precipice, Basal Evergreen, Boxvale, Hutton)
- Reservoir net pay zone thicknesses from WCR's and average porosity from QPED database used in calculations.
- Theoretical storage capacity using residual gas saturation trapping totals 2,962 Mt in the evaluated reservoirs – greatest capacity in Precipice Sandstone (1,289 Mt).

HIGH PROSPECTIVITY

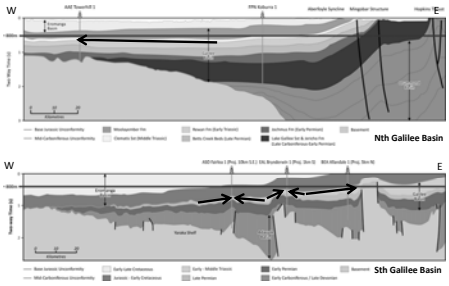
Galilee Basin

- Large and relatively shallow basin remotely located from major emission hubs.
- No commercial hydrocarbons discovered despite ~50 years exploration – current focus on CSG resources.
- Contains good quality groundwater resources.
- Several potential storage areas mapped over the northern and southern basin areas.
- Only regional well and seismic data available to evaluate storage potential.

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

HIGH PROSPECTIVITY

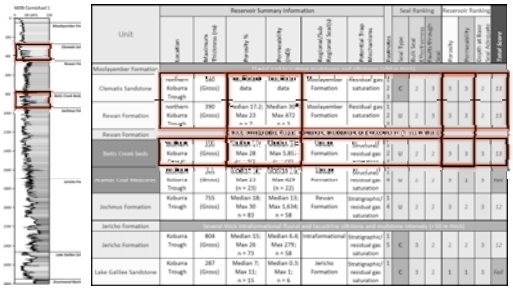
Galilee Basin



- Main storage mechanism is residual gas migration trapping using low regional dip of strata in nth Galilee, and southwest plunging faulted ridges in sth Galilee Basin (potential fault seal breaches).
- Triassic & Late Permian strata from relatively continuous fluvial-lacustrine 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).

HIGH PROSPECTIVITY

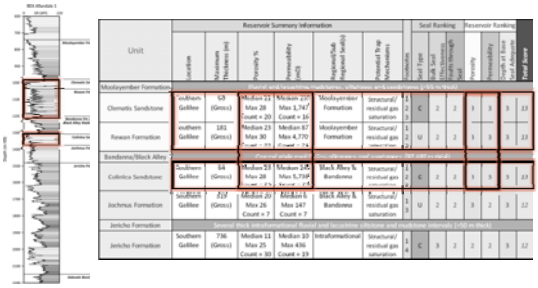
Northern Galilee Basin



- 7 reservoir units were ranked – best potential units are the Clematis Sst/Rewan Fm sealed by Moolayember Formation; Betts Creek beds with unconventional Rewan Formation seal.
- These reservoirs have good-excellent & moderate-good measured porosity & permeability based on limited well data.

HIGH PROSPECTIVITY

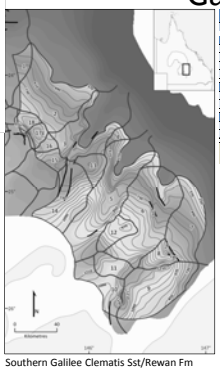
Southern Galilee Basin



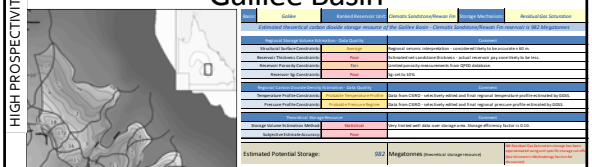
- 6 reservoir units were ranked – best potential units are the Clematis/Rewan sealed by Moolayember Formation; Colinlea Sandstone sealed by Black Alley/Bandanna Fm.
- These reservoirs have good-excellent measured porosity & permeability based on limited well data.

HIGH PROSPECTIVITY

Galilee Basin



Southern Galilee Clematis Sst/Rewan Fm depth (mSS) structure surface with drainage cells.



- Volumetric calculations were completed for 4 reservoir units (Clematis Sst, Rewan Fm, Betts Creek beds and Colinlea Sst).
- Not possible to define reservoir fairways or pay zones with regional well data coverage – reservoir data is largely unconstrained, storage volumes should therefore be used with caution.
- Large theoretical storage volumes: Southern Galilee 2,302 Mt ; Northern Galilee Basin 1,128 Mt.
- Clematis Sandstone/Rewan Formation in Southern Galilee has estimated capacity of 982 Mt.
- Seal capacity & faults through seal key uncertainty – needs addressing through fully cored wells & modern seismic.

HIGH PROSPECTIVITY

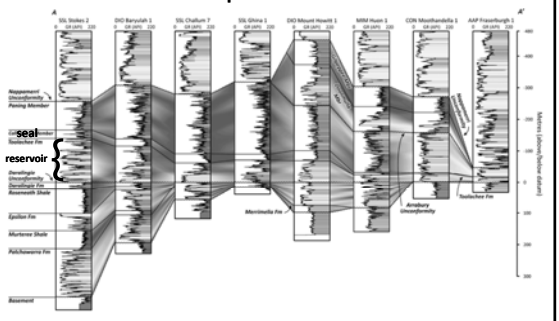
Cooper Basin

- Large intracratonic depocentre located very remotely from major emission hubs.
- Mature hydrocarbon province in Queensland: 81 conventional fields (OIP resources: ~1500 Bcf gas, 30 MMbbls oil) – most near-depleted
- Maximum potential storage area defined over southeastern basin area where most hydrocarbons are trapped.

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

HIGH PROSPECTIVITY

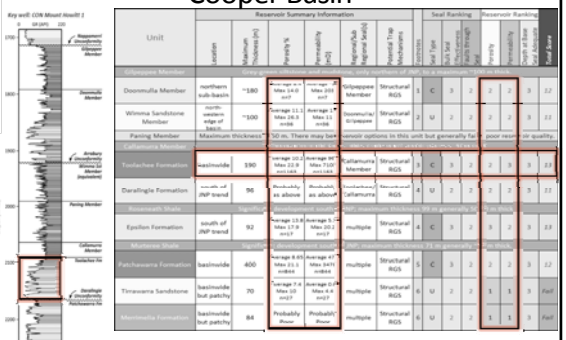
Cooper Basin



- Gentle dip of structure towards basin flanks provides suitable conditions for RGS trapping of CO_2.
- Reservoirs generally tight (80% failure at depths >2400 mSS) - best in regional fluvial sandstones from Toolachee sealed by fluvio-lacustrine Callamurra Member.

HIGH PROSPECTIVITY

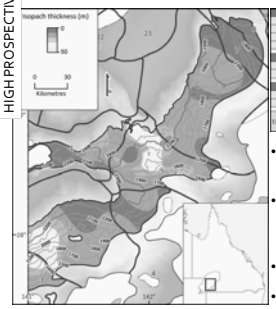
Cooper Basin



- 7 reservoir units were ranked – best potential units are the Toolachee Fm and Epsilon Fm (latter not regionally extensive).
- Variable reservoir quality main issue.

HIGH PROSPECTIVITY

Cooper Basin



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

- 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
- No estimate is made for the Patchawarra Fm but it is likely to be similar to the Toolachee Formation

HIGH PROSPECTIVITY

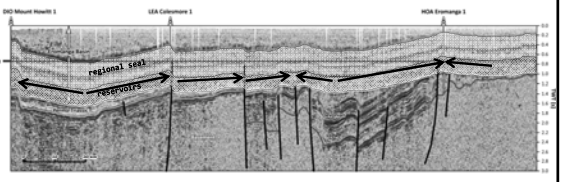
Eromanga Basin

- Large intracratonic basin remotely located from major emission hubs.
- Sub-mature oil province in Queensland: ~80 fields (OIP resource ~300 MMbbl oil) – several sub-economic pools also discovered.
- Groundwater heavily utilised in populated areas.
- Very large maximum potential storage area defined over much of basin area (regionally extensive reservoirs and seals at depths >800 m BGL).

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

HIGH PROSPECTIVITY

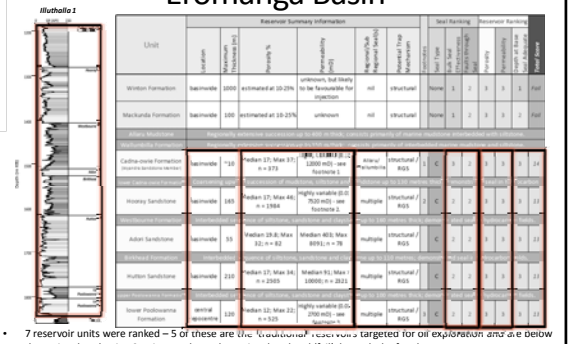
Eromanga Basin



- Ideal components for geological storage provided by thick regionally extensive regional seal interval comprising marine shales interbedded with varying amounts of sandstone, limestone and siltstone overlying vertically stacked fluvio-lacustrine to shallow marine reservoirs and intraformational seals.
- 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.

HIGH PROSPECTIVITY

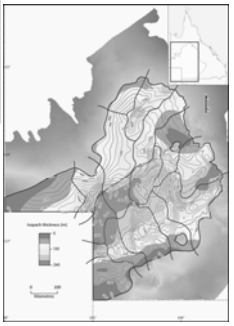
Eromanga Basin



- 7 reservoir units were ranked – 5 of these are the traditional reservoirs targeted for oil exploration and are below the regional seal units; 2 units are above the regional seal and 'fail' due to lack of seal.
- Those units below the regional seal are generally characterised by moderate-excellent reservoir quality.
- Bulk seal effectiveness of the intraformational seals (Birkhead, Westbourne etc) may be limited on a regional scale is effective locally as demonstrated by the occurrence of hydrocarbon accumulations.

HIGH PROSPECTIVITY

Eromanga Basin



Hutton Sandstone top depth-structure contours (mSS), isopach (m) and drainage cell areas

- Volumetric calculations were completed for 5 reservoir units (Poolowanna Fm, Hutton Sst, Adori Sst, Hooray Sst & Wyandra Sst).
- Reservoir thickness was derived from isopach mapping (using QPED formation top data).
- Porosity vs depth function incorporated into calculations.
- The combined theoretical capacity for these 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.

LOW PROSPECTIVITY

Results: Low Prospectivity Basins

- 13 basins evaluated as having low prospectivity.
- 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.

UNSUITABLE

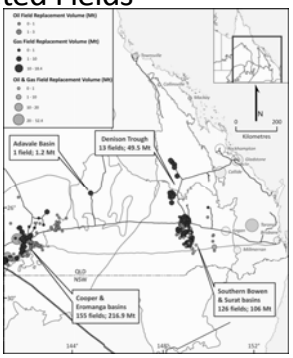
Results: Unsuitable Basins

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

DEPLETED FIELDS

Depleted Fields

- A maximum theoretical replacement volume (MTRV) calculated on original in place resources as reported by QDEEDDI 2008
- A MTRV of 374 Mt CO_2 is estimated for 295 gas and/or oil fields and ~485 reported producing reservoir pools in Queensland
- However, most large fields are still producing and are unlikely to be available for CO_2 storage in the near-future. Only 99 fields are either depleted or near-depleted (<5 % original 2P reserves remaining), which have a combined MTRV of 64.6 Mt CO_2

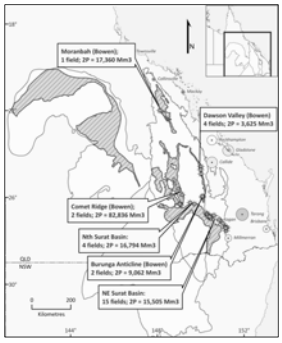


Location of oil, gas and oil and gas fields scaled by MTRV. Also shown are major emissions nodes and gas (red lines) and oil (green lines) pipelines

COAL STORAGE

Potential Coal Storage Areas

- Potential storage areas defined in major coal basins (Bowen, Surat & Galilee basins) using depth cut-offs of >400 m (sub-economic depth for mining) and <1,000 m (permeability).
- 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 over the Comet Ridge & Dawson Valley



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

Summary

- The greatest potential for storage is using RGS trapping in regionally extensive reservoir-seal intervals rather than depleted fields or coal seams
  - 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
- 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

ACKNOWLEDGEMENT

Queensland CO_2 Storage Atlas team

- John Bradshaw
- Barry Bradshaw
- Lynton Spencer
- Anna-Liisa Lahtinen
- Kamal Khider
- Damien Ryan
- Jim Colwell
- Alfredo Chirinos
- Phillippa Cooke
- Mark Woodger
- 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.

CGSS

Queensland Government