DECLARATION

The work contained in this thesis is original, except as acknowledged in the customary manner, and has not been submitted previously for a degree at any university. To the best of my knowledge and belief, this thesis contains no material previously published or written by another person, except where due reference is made.

The author consents to the thesis being made available for photocopying and loan if accepted for the award of the degree.

________________________________________

Jonathan Peter Salo
Adelaide, Australia
30 May 2005
EVALUATING SITES FOR SUBSURFACE CO₂ INJECTION/SEQUESTRATION: TANGGUH, BINTUNI BASIN, PAPUA, INDONESIA

(VOLUME 1: Text)

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The venting of anthropogenic CO$_2$ emissions into the atmosphere at increasing rates is probably influencing global warming and climate change. The Tangguh LNG development project in Papua, Indonesia will produce significant volumes of CO$_2$, which might be vented into the atmosphere. The LNG process will necessitate the separation of CO$_2$, estimated at 2.4 trillion cubic feet (TCF sc), from the natural gas reserves prior to liquefaction and shipping. This study screens and assesses the possible alternatives to atmospheric venting, and recommends subsurface CO$_2$ injection and sequestration/storage in saline aquifers. The study identifies specific subsurface locations for several Environmentally-Sustainable Sites for CO$_2$ Injection (ESSCI) in Bintuni Basin, where the Tangguh production fields are located.

Alternatives to atmospheric venting of the estimated CO$_2$ volume at Tangguh include both non-geologic and geologic disposal options. Non-geologic options such as biosphere sinks (enhanced forest or agricultural growth), deep-ocean sinks (subsea dispersal), and direct commercial usage (e.g. use in beverage or fertilizer production, fire-retardant manufacturing) are impractical and of questionable impact in remote Papua, Indonesia.

Several subsurface geological disposal options were investigated, but the most viable geologic disposal option for Tangguh CO$_2$ is injection into the downdip aquifer leg of the Roabiba Sandstone Formation hydrocarbon reservoir. Injected CO$_2$, at supercritical phase, is expected to migrate updip into the sealed structural traps at Vorwata or Wiriagar Deep, as the natural gas reserves are produced.

A probabilistic ranking of data quality and quantity for five potential ESSCI reservoirs determined that the Middle Jurassic Roabiba Sandstone Formation has the highest likelihood of viable ESSCI sequestration/storage.

A probabilistic ranking of data quality and quantity for eight ESSCI structural traps within the western flank of Bintuni Basin, determined that Vorwata, followed by Wiriagar Deep, are the most viable ESSCI structural traps at the Middle Jurassic reservoir level.

Five potential ESSCI seals were evaluated and it was determined the best seal potential occurs in the Pre-Ayot Shales, directly overlying the Middle Jurassic reservoir at Vorwata. This unit is capable of holding a 3300 to 4660 foot (1006 to
1420 meter) CO\textsubscript{2} column. Seal integrity of the Pre-Ayot is very good because it is a relatively homogeneous deep-water shale that is composed primarily of ductile illite and kaolinite clays with a minor quartz and feldspar content. Sequence stratigraphy analysis suggests that the zone extends over the entire Vorwata three-way dip closure, with thickness between 17 feet (5 m) and 233 (71 m) feet.

The maximum effective storage capacity of the Middle Jurassic reservoirs for each structure was calculated, taking into account irreducible water, trapped water, and trapped residual gas pore volumes. The Vorwata structure is capable of storing 19.3 TCFsc supercritical CO\textsubscript{2} at reservoir temperature and pressure. The Wiriagar Deep structure has potential storage capacity of 3.5 TCFsc, and Ubadari 2.8 TCFsc, at their respective reservoir temperatures and pressures.

A ‘Rating Product Ranking’ was developed to quantify the results of the quality and quantity of four factors: Reservoir Data, Structure Data, Seal Data, and Storage Ratio. Each structure, and the respective top and lateral seal overlying the Middle Jurassic reservoirs, was evaluated. The net result was that Vorwata rated a 0.88 on a scale of zero to one, where 1.0 represents 100% confidence in ESSCI potential. Ubadari and Wiriagar Deep scored, respectively, 0.52 and a 0.45.

Finally, the structures were evaluated for relative proximity to the proposed CO\textsubscript{2} source (i.e. the LNG plant location). With a weighted distance factor calculated with the Rating product for each potential injection site, Vorwata rated 0.88 on a scale of zero to one, Wiriagar scored 0.24, and Ubadari scored only 0.09.

The Middle Jurassic ‘Roabiba Sandstone Formation reservoir’ at the Vorwata structure has the greatest potential as an ESSCI storage site. The Middle Jurassic ‘Aalenian Sandstone Formation reservoir’ at the Wiriagar Deep is the second-best potential ESSCI storage site. The subsurface ESSCI injection location proposed for the ‘Roabiba Sandstone Formation’ aquifer, 10 km southeast and down-dip from the known gas-water contact (GWC), is on the southeast Vorwata plunging anticlinal nose. An alternate potential ESSCI injection location proposed for the ‘Roabiba Sandstone Formation’ aquifer is 6 km south of and down-dip from the known gas-water contact (GWC) on Vorwata structure southern flank.

A key issue was to determine the possible risk of fault re-activation from CO\textsubscript{2} injection. NE-SW striking vertical faults have the highest risk of re-activation requiring an increase of over ~1460 psi (103 kg/cc) over hydrostatic at 14,000 ft TVDss (4267 m), for slippage to occur. The closest fault with a high risk of re-
activation is 5 km northwest of the recommended ESSCI site location. Supercritical CO₂ pressure is not expected to exceed the estimated pressure determined to cause fault re-activation.

A 3D geological model of the Mesozoic interval was constructed over a large area of western Bintuni Basin. The model was constructed so as to preserve as much geological heterogeneity as possible yet still have a manageable number of active cells. Faults were incorporated into the model as strike-slip vertical fault surfaces (or indexed fault polygons) as a separate attribute.

The geo-cellular model was built suitable for importation into a reservoir simulator (VIP), and a 25-year simulation run for natural gas production from the Vorwata Middle Jurassic reservoir, with concurrent CO₂ injection downdip into the Vorwata Middle Jurassic aquifer at the primary recommended ESSCI site location. The simulation verified the recommended location with the CO₂ slowly migrating into the Vorwata structural trap within the Middle Jurassic reservoir, and not compromising the hydrocarbon reserves or production.

It is recommended that additional data be acquired such as conventional core, formation water samples, and specific logs such as dipole-sonic, multi-chambered dynamic formation testers (MDT), and mechanical rotary sidewall coring tools (MSCT).

Lastly, several CO₂ monitoring methods and techniques are recommended for Tangguh to monitor CO₂ migration, pressures, and potential leakages. One such method is a vertical monitoring well at the recommended injection site. Other monitoring techniques include smart well completions, detection monitors at production wells with tracers injected prior to CO₂ injection. In addition, crosswell seismic surveys, electromagnetic methods, and electrical-resistance tomography techniques are suggested during the injection phase.
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