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Adelaide, Australia
30 May 2005



EVALUATING SITES FOR SUBSURFACE CO₂
INJECTION/SEQUESTRATION: TANGGUH,
BINTUNI BASIN, PAPUA, INDONESIA

(VOLUME 1: Text)

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ABSTRACT

The venting of anthropogenic CO₂ 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 CO₂, which might be vented into the atmosphere. The LNG process will necessitate the separation of CO₂, 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 CO₂ injection and sequestration/storage in saline aquifers. The study identifies specific subsurface locations for several Environmentally-Sustainable Sites for CO₂ Injection (ESSCI) in Bintuni Basin, where the Tangguh production fields are located.

Alternatives to atmospheric venting of the estimated CO₂ 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 CO₂ is injection into the downdip aquifer leg of the Roabiba Sandstone Formation hydrocarbon reservoir. Injected CO₂, 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) CO₂ 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 CO₂ 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 CO₂ 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 CO₂ 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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AGU	: American Geophysical Union	CMR	: magnetic resonance tool (Schlumberger trade-name)
ANGP	: Australian-New Guinea plate	CNL	: compensated neutron porosity log tool (Schlumberger trade-name)
ARCO	: Atlantic Richfield Inc.	CSAT	: wireline seismic geophone tool (Schlumberger trade-name)
ASP	: Australian School of Petroleum	DLL	: dual laterolog tool (Schlumberger trade-name)
bar	: equivalent to Atmospheres	DSI	: dipole sonic induction tool (Schlumberger trade-name)
BBQE	: billion barrels of oil equivalent	DT	: delta T (sonic transit time)
BCPD	: barrels of condensate per day	eLOT	: extended leak-off test
BG	: British Gas Ltd. Inc.	LOT	: leak-off test
BHMC	: Bird's Head micro-continent	FDL	: formation density log tool (Schlumberger trade-name)
BO	: barrels of oil	FMI	: 64-button borehole resistivity imaging tool (Schlumberger trade-name)
BOE	: barrels of oil equivalent	FMS	: 32-button borehole resistivity imaging tool (Schlumberger trade-name)
BP	: British Petroleum Ltd. Inc.	GR	: gamma-ray
C	: Celsius	ILD	: induction conductivity tool (Schlumberger trade-name)
CCC	: complete carbon cycle	LWD	: logging while drilling
CCV	: CO2 sequestration in cavity or void	MDT	: formation fluid sampling and pressure testing tool (Schlumberger trade-name)
CDOGR	: CO2 sequestration in depleted oil/gas reservoir	MRIL	: magnetic resonance tool (Western-Atlas and NUMAR trade-name)
CECMP	: CO2 for enhanced coal bed/seam methane production	MSCT	: mechanical sidewall rotary coring tool (Schlumberger trade-name)
CEGR	: CO2 sequestration with enhanced gas recovery	MSFL	: micro-spherically focussed laterolog tool (Schlumberger trade-name)
CEOR	: CO2 sequestration with enhanced oil recovery	MWD	: measurement while drilling
CO2	: carbon dioxide	OBM	: oil-based mud (drilling fluid)
CSA	: CO2 sequestration in saline aquifer	RHOB	: density log (Schlumberger trade-name)
CUCS	: CO2 sequestration in unmineable coal seams/beds	RKB	: rotary kelly bushing (drill floor datum)
DITF	: drilling induced tensile fractures	SHmax	: stress horizontal (maximum)
DOE	: Department of Energy (USA)	SHmin	: stress horizontal (minimum)
DST	: drill-stem test	SV	: stress vertical
EEA	: European Environmental Agency (EU)	SGR	: spectral gamm-ray (Schlumberger trade-name)
EO	: Earth Observatory (US Agency of NASA)	SOBM	: synthetic oil-based mud (drilling fluid)
EOR	: enhanced oil recovery	SP	: spontaneous potential tool and log
ERT	: Electrical Resistance Tomography	Sw	: water saturation
ESSCI	: Environmentally Sustainable Site for Carbon Dioxide Injection	Swir	: irreducible water saturation
F	: Fahrenheit	VSP	: vertical seismic profile log (Schlumberger trade-name)
FAPS	: Fault Analysis Projection System (software program)	WBM	: water-based mud (drilling fluid)
FAST	: Fault Analysis Seal Technology (software program)	WD-1	: Wiriagar Deep #1
GeoCARD	: GeoCARD 3D geo-cellular model (software program)	WD-2	: Wiriagar Deep #2
GEODISC	: Geological Disposal of CO2	WD-3	: Wiriagar Deep #3
GHG	: greenhouse gases	WD-4	: Wiriagar Deep #4
HST	: highstand systems tract	WD-5	: Wiriagar Deep #5
IPCC	: Inter-governmental Panel on Climate Change	WD-6	: Wiriagar Deep #6
Ka	: Thousands of years before present	WD-7	: Wiriagar Deep #7
KOM	: Kumawa-Onin-Misool Ridge (also known as MOK)	WD-8	: Wiriagar Deep #8
LNG	: liquefied natural gas	V-1	: Vorwata #1
LTFB	: Lengguri Thrust/Fold Belt	V-2	: Vorwata #2
Ma	: Millions of years before present	V-3	: Vorwata #3
MFS	: maximum flooding surface	V-4	: Vorwata #4
MICP	: mercury injection capillary pressure	V-5	: Vorwata #5
MMBO	: million of barrels of oil	V-6	: Vorwata #6
MMscf/d	: million standard cubic feet per day (gas flowrate)	V-7	: Vorwata #7
MPa	: megapascals	V-8	: Vorwata #8
MSL	: mean sea level	V-9	: Vorwata #9
NASA	: National Aeronautical and Space Administration (USA)	V-10	: Vorwata #10
NGLG	: New Guinea Limestone Group	V-11	: Vorwata #11
NIST	: National Institute of Standards & Technology	N-1	: Nambumbi #1
NINGPM	: Nederland Nieuw-Guineese Petroleum Maatschappij	R-1	: Roabiba #1
NOAA	: National Oceanic and Atmospheric Administration	O-1	: Ofaweri #1
NTFA	: National Tidal Facility of Australia	W-1	: Wos #1
PMEL	: Pacific Marine Environmental Laboratory	EO-1	: East Onin #1
PSC	: Production Sharing Contract		
PSI	: pounds per square inch		
PSIA	: pounds per square inch absolute		
RS	: Royal Society		
RST	: regressive systems tract		
SB	: sequence boundary		
SFZ	: Sorong Fault-Shear Zone		
TCF	: trillions of cubic feet (gas)		
TST	: transgressive systems tract		
TVDss	: True Vertical Depth subsea		
Unc	: unconformity		
UND	: University of North Dakota		
UNFCCC	: United Nations Framework Convention on Climate Change		
WIMC	: West Irian micro-continent		
XRD	: x-ray diffraction		
YBP	: years before present		

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