Project Order, Variations and Research Progress

Project Title: Understanding and quantifying the geochemical response to re-injection of CSG water permeates, brines and blends

This document contains three sections. Click on the relevant section for more information.

Section 1:	Research Project Order as approved by the GISERA Research Advisory Committee and GISERA Management Committee before project commencement
Section 2:	Variations to Project Order
Section 3:	Progress against project milestones

GISERA, GPO Box 2583, Brisbane QLD 4001, Australia

1 Original Project Order

Project Order

Proforma 2011

1. Short Project Title (less than 15 words)

Project 1 – Geochemical response to re-injection

Long Project Title	Understanding and quantifying the geochemical response to re-injection of CSG water permeates, brines and blends
GISERA Project Number	W1 1114
Proposed Start Date	July 2011
Proposed End Date	June 2014
Project Leader	Henning Prommer

2. GISERA Research Program

☐ Biodiversity Research ☐ Marine Research ☐ Land Research

☒ Water Research ☐ Social & Economic Research

3. Research Leader, Title and Organisation

Henning Prommer
Principal Researcher
CSIRO Land & Water
0,68 FTE

4. Summary (less than 300 words)

Injection of reverse osmosis treated production water from coal seams into surrounding aquifers may provide the most viable measure to dispose of production water. The geochemical dis-equilibrium between the injectant water composition and the prevailing mineral inventory will drive a range of mineral reactions that must be clearly understood and quantified in order to anticipate and manage future water quality changes at both the local and the regional scale. This project is aimed at (i) data analysis and experimental work that provides an advanced characterisation of the reactivity of the sediment material of aquifers targeted for re-injection (ii) the development of a reactive transport modelling framework that will allow the analysis and prediction of water quality changes resulting from reinjection of treated CGS waters and (iii) the evaluation and improvement of the reactive transport modelling framework during analysis of laboratory and field-trial data from selected target aquifers.

5. Budget Summary (From Excel Budget Pack worksheet "Project Plan Summary")

Expenditure	2011/12 Year 1	2012/13 Year 2	2013/14 Year 3	2014/15 Year 4	2015/16 Year 5	Total
Labour	79,788	262,111	254,016		-	595,915
Operating	70,542	120,000	94,785		-	285,327
Total Costs	**150,330**	**382,111**	**348,801**		**-**	**881,242**
CSIRO	150,330	382,111	348,801		-	881,242
Total Expenditure	**150,330**	**382,111**	**348,801**		**-**	**881,242**

Expenditure per Task	2011/12 Year 1	2012/13 Year 2	2013/14 Year 3	2014/15 Year 4	2015/16 Year 5	Total
Task 1	57,998				-	57,998
Task 2		42,457				42,457
Task 3	92,332					92,332
Task 4		169,827				169,827
Task 5			155,023			155,023
Task 6		127,370				127,370
Task 7			155,023			155,023
Task 8		42,457				42,457
Task 9			38,755			38,755
Total Expenditure	**150,330**	**382,111**	**348,801**		**-**	**881,242**

Cash Funds to Project Partners	2011/12 Year 1	2012/13 Year 2	2013/14 Year 3	2014/15 Year 4	2015/16 Year 5	Total
CSIRO	120,264	305,689	279,041			704,994
Sub Total	120,264	305,689	279,041			704,994
Total Cash to Partners	**120,264**	**305,689**	**279,041**			**704,994**

Source of Cash	2011/12	2012/13	2013/14	2014/15	2015/16	Total

Contributions	Year 1	Year 2	Year 3	Year 4	Year 5	
Australia Pacific LNG	**120,264**	**305,689**	**279,041**			**704,994**
Total Cash Contributions	120,264	305,689	279,041			704,994

In-Kind Contribution from Partners	2011/12 Year 1	2012/13 Year 2	2013/14 Year 3	2014/15 Year 4	2015/16 Year 5	Total
CSIRO	30,066	76,422	69,760			176,248
Total In-Kind Contribution from Partners	**11,600**	**18,466**	**76,422**	**69,760**		**176,248**

	Total funding over all years	Percentage of Total Budget
Australia Pacific LNG Investment	704,994	80%
Total Partner Investment	176,248	20%
Total Other Investment		
TOTAL	**881,242**	**100%**

Task	Mile-stone Number	Milestone Description	Funded by	Participant Recipient	Start Date (mm-yy)	Delivery Date (mm-yy)	Fiscal Year	Fiscal Quarter	Payment $
Task 1	1.1	Project established and reference panel set up	GISERA	CSIRO	15.11.2011	1.2.2012	2011/12	3	57,998
Task 2	2.1	Assessment of mineralogical and other geochemical characterization and analytical data collected by APLNG from core samples	GISERA	CSIRO	15.11.2011	1.12.2012	2012/13	2	42456.78
Task 3	3.1	Construction and initial setup of laboratory columns for cores collected from representative target aquifers	GISERA	CSIRO	15.11.2011	1.4.2012	2011/12	4	92,332
Task 4	4.1	Operation of column experiments to experimentally investigate geochemical reactions for selected aquifer types	GISERA	CSIRO	1.4.2012	1.3.2013	2012/13	3	169827.1
Task 5	5.1	Model-based analysis of geochemical data collected during the laboratory-scale column experiments	GISERA	CSIRO	1.9.2012	1.8.2013	2013/14	1	155022.7
Task 6	6.1	Preliminary, pre-trial modelling studies to support the design and monitoring strategy of selected field-scale injection experiments	GISERA	CSIRO	1.12.2011	1.8.2012	2012/13	1	127370.3
Task 7	7.1	Model-based analysis (reactive transport modelling) of hydrochemical data collected during injection trials at representative target aquifers	GISERA	CSIRO	1.7.2012	1.9.2013	2013/14	1	155022.7
Task 8	8.1	Workshops with CSIRO-APLNG for interim reporting and quality assurance	GISERA	CSIRO	1.12.2011	1.6.2013	2012/13	4	42456.78
Task 9	9.1	Shortcourse on modelling geochemical changes	GISERA	CSIRO	1.3.2013	1.12.2013	2013/14	2	38755.67

6. Other Researchers (include organisations)

Researcher	Time Commitment (project as a whole)	Principle area of expertise	Years of experience	Organisation
Henning Prommer	0.68 FTE	Analysis and quantification of geochemical changes during aquifer recharge	>20	CSIRO/UWA
Evelien Martens	1.00 FTE	Reactive transport modelling	5	CSIRO
Dr Bradley Patterson	0.32 FTE	Design, operation and analysis of laboratory and field experiments	>20	CSIRO
Dr Leif Wolf	0.20 FTE	Reinjection research integration, risk assessment	>12	CSIRO
Andrew Furness	0.80 FTE	Construction of experimental facilities and operation of experiments	5	CSIRO

7. GISERA Objectives Addressed

Research that improves and extends knowledge of environmental impacts and opportunities of CSG-LNG projects, enabling the CSG-LNG industry to better meet the expectations of relevant communities and the broader public

Informing government, regulators and policy-makers on key issues regarding policy and legislative framework for the CSG-LNG industry

8. Program Outcomes Achieved

Details are provided in *Section 13. Project Objectives and Outputs*

9. Program Outputs Achieved

Details are provided in *Section 13. Project Objectives and Outputs*

10. What is the knowledge gap that these research outputs will address?

The research outputs derived from this project will (i) characterise base-level ambient geochemical conditions for the key aquifer types targeted for re-injection and (ii) improve the capacity to understand, quantify and predict future water quality changes that will be induced by the re-injection of CSG-waters. The research outputs will provide key knowledge and tools to identify and manage potential negative impacts.

11. How will these Research outputs and outcomes be used by State Government and other water managers to achieve Adaptive Management of Water Resources?

The research outputs and outcomes will help to inform government, regulators and policy-makers on key issues regarding policy and legislative framework for the CSG-LNG industry, particularly in the area of water quality changes resulting from the re-injection of treated CSG waters. The project will develop and illustrate methodologies on how the geochemical impacts of re-injection can be assessed and predicted.

12. Project Development (1 page max.)

The project was developed in consultation between Australia Pacific LNG (Andrew Moser, Ryan Morris, and Rebecca Pickering) and CSIRO. Current activities of the Queensland Water Commission and DERM were considered and discussed with Randall Cox and Sanjeev Pandey (QWC), who confirmed the need for the proposed activities.

Recent public discussion centres on the remaining uncertainty in groundwater impact predictions, which result from the current lack of robust geochemical data. In addition, there is incomplete understanding on whether re-injection could lead to a serious deterioration of the prevailing water quality, which could, for example, be created by an undesired mobilisation of trace metals.

The aquifer characterization and experimental work carried out in this study will greatly minimise these existing uncertainties. Laboratory-scale studies are proposed in order to create well-controlled experimental conditions that exclude the impact of hydrogeological and geochemical heterogeneity. The field-scale component of the proposed work is needed to test the acquired understanding and quantification framework and to assess upscaling effects between laboratory and field-scale behaviour. Based on this knowledge, adaptive management strategies can be developed.

The work builds strongly on past and ongoing research activities of the project team that address related issues arising from the injection of reverse osmosis treated waters during the ongoing groundwater replenishment trial in Perth Leederville aquifer. It also builds on the past experience of the project team in developing conceptual and numerical models on geochemical processes (such as arsenic mobilisation) that are triggered in aquifers used for aquifer storage and recovery.

13. Project Objectives and Outputs

The key objective of this project is to develop methodologies that allow the assessment and quantification of the extent of the geochemical changes that may be triggered by the reinjection of treated CSG waters. Another key objective is to illustrate the use of these techniques such that in the future they can be used on a routine basis for assessments under varying hydrogeological and hydrogeochemical conditions. The project will develop both process understanding and quantification capabilities that will feed into the larger-scale impact assessments addressed by *Project 3*. Outputs include:

- Comprehensive conservative/reactive transport modelling of the pre-trial geochemical conditions of the key aquifers targeted for re-injection. This step closes important data gaps with respect to thoroughly assessing the potential for undesired geochemical changes and to manage those, should they occur.
- Experimental assessment of water rock/sediment interactions triggered by the injection of different types of CSG waters. This step will provide qualitative and quantitative information that can be used to develop conceptual models of geochemical changes.
- Development of a modelling framework for a model-based quantification of key geochemical changes triggered by the re-injection of treated CSG waters, based on the results of the geochemical characterisation and on laboratory-scale experimental results.
- In close collaboration with investigators of *Project 3*, develop modelling strategies and techniques to compliment the value of the planned field-scale injection trials carried out by Australia Pacific LNG. To achieve this, pre-trial modelling studies will be carried out that are aimed at assisting the experimental design and the corresponding monitoring plan. The novel techniques developed in this step will be applicable in the future to asses additional hydrogeological and geochemical settings (target aquifers).
- After completion of the field trials, evaluate the reactive transport modelling framework developed for the column experiments for the model-based interpretation of the data collected in the field trial. Identify and investigate upscaling issues that are most likely to arise when moving from lab- to field-scale. This step will also provide important information for further upscaling to regional-scale impact assessments as addressed by *Project 3*.

14. Project Plan

14.1 Project Schedule

ID	Task Title	Task Leader	Scheduled Start	Scheduled Finish	Predecessor
Task 1	Report on project establishment and set up of reference panel.	Leif Wolf	15.11.2011	1.2.2012	
Task 2	Compilation and assessment of mineralogical and other geochemical data collected by APLNG from core samples	Henning Prommer or Bradley Patterson (to be decided)	15.11.2011	1.12.2012	Task 1
Task 3	Construction and initial setup of laboratory columns for cores collected from representative target aquifers	Bradley Patterson	15.11.2011	1.4.2012	Task 1
Task 4	Operation of column experiments	Bradley Patterson	1.4.2012	1.3.2013	Task 3
Task 5	Model-based analysis of geochemical data collected during the laboratory-scale column experiments	Henning Prommer	1.9.2012	1.8.2013	Task 2, Task 4
Task 6	Preliminary, pre-trial modelling studies to support the design and monitoring strategy of selected field-scale injection experiments	Henning Prommer	1.12.2011	1.8.2012	Task 1
Task 7	Model-based analysis (reactive transport modelling) of hydrochemical data collected during injection trials at representative target aquifers	Henning Prommer	1.7.2012	1.9.2013	Task 2, Field trials operated by APLNG
Task 8	Workshops with CSIRO-APLNG for interim reporting and quality assurance	Leif Wolf	1.12.2011	1.6.2013	

Task 9	Shortcourse on geochemical transport modelling to assess and quantify re-injection impacts	Henning Prommer	1.3.2013	1.12.2013	Task 3, Task 7

Task 1.

TASK NAME: Project set up & management

TASK LEADER: Leif Wolf

OVERALL TIMEFRAME: 2011/12

- Establish a project reference panel
- Provide and control linkages with related projects
- Refine work plan according to bi-annual Australia Pacific LNG-CSIRO discussions

Task 2.

TASK NAME: Geochemical characterisation of selected target aquifers

TASK LEADER: Henning Prommer or Bradley Patterson (to be discussed/decided)

OVERALL TIMEFRAME: 2011/12

BACKGROUND: The evolution of water quality changes in aquifers targeted for re-injection depends on the hydrogeological properties that control the pathways, the degree of physical mixing of injected and ambient water, and the inventory and reactivity of the minerals that constitute the aquifer matrix. To date only insufficient knowledge and data exist, in particular for the latter. To close this gap CSIRO and Australia Pacific LNG have selected a suite of analytical methods that will be used for a detailed geochemical characterisation of sediment/rock samples collected during the ongoing and future core recovery activities. Sample collection and chemical/mineralogical analysis is coordinated with Australia Pacific LNG. Within Task 2 the collected data will be compiled and assessed. The mineralogical characterisation includes XRD/XRF analysis of multiple samples per injection interval. Furthermore, samples will be analysed for chrome reducible S (SCr), total C (TC), total organic C (TOC), total inorganic C (TIC). ICP-AES for extractable Fe, Al and Mn and for 18 transition elements (Ag, As, B, Ba, Be, Cd, Co, Cr, Cu, Mn, Mo, Ni, Pb, Sb, Se, Sn, V, Zn).

TASK OBJECTIVE: Gain a comprehensive understanding of the mineralogical/elemental composition and potential reactivity of the aquifer material that constitutes selected aquifers targeted for re-injection.

TASK OUTPUTS: Geochemical characterisation of selected target aquifers

SPECIFIC DELIVERABLE: Report

Task 3.

TASK NAME: Construction and initial setup of laboratory columns

TASK LEADER: Bradley Patterson

OVERALL TIMEFRAME: 2011/12

BACKGROUND: Depending on the size, type and condition of the core samples collected from selected target aquifers the experimental setup required for the flow through column experiments needs to be designed and tested. Given that the recovered core material is anticipated to consist mostly of consolidated material, cores will potentially need to be embedded in resin and a suitable construction of sampling ports need to be designed and tested.

TASK OBJECTIVE: Design and test suitable experimental setup for controlled flow through experiments.

TASK OUTPUTS: Final experimental setup and monitoring plan for the column experiments.

Task 4.

TASK NAME: Operation of column experiments

TASK LEADER: Bradley Patterson

OVERALL TIMEFRAME: 2012/13

BACKGROUND: The columns will presumably be operated in a saturated up flow mode at a flow rate of 50 mL/day, which corresponds to a Darcy velocity of 5 cm/day (assuming a porosity of 0.3). This will lead to a column residence time of ~ 6 days. Groundwater, from the location at which the core was collected, will initially be passed through the column for a period of ~30 days to stabilize groundwater/aquifer chemistry prior to the introduction of reverse osmosis (RO) water. Once groundwater effluent concentrations and physical parameters (pH, Eh, EC and DO) have stabilized, RO water will be passed through the column at a flow rate of 50 mL/day, and changes in water chemistry monitored. To identify the level of RO water processing on geochemical changes different RO waters will be sequentially introduced (~ every 3 months) into the columns. The RO waters used will be (i) deoxygenated RO water mixed with higher EC water, (ii), deoxygenated RO water and (iii) oxygenated RO water.

TASK OBJECTIVE: Determine experimentally the geochemical reactions that occur during passage of different types of treated CSG waters

TASK OUTPUTS & SPECIFIC DELIVERABLES: Experimental data and initial conceptual models of water-sediment/rock interactions.

Task 5.

TASK NAME: Model-based analysis of experimental data collected during the laboratory-scale column experiments

TASK LEADER: Henning Prommer

OVERALL TIMEFRAME: 2012/13

TASK OBJECTIVE: Development and testing of conceptual models and translation into reactive transport models that can simulate the water quality evolution observed during the laboratory-scale column experiments.

TASK OUTPUTS: Capabilities/tools to quantitatively describe major geochemical processes.

SPECIFIC DELIVERABLES: Aquifer-specific PHT3D reaction modules for key target aquifers, calibrated models.

Task 6.

TASK NAME: Pre-trial modelling studies

TASK LEADER: Henning Prommer

OVERALL TIMEFRAME: 2011/12

BACKGROUND: The experimental setup/design, the type of collected data and the timing of sampling events all have a significant impact on how strongly they are able to constrain the development and calibration of the numerical models that are aimed at providing process-based quantitative descriptions of the coupled flow, transport and reactive processes. The value of the data collected during a laboratory and/or field experiment is therefore greatly enhanced through pre-trial modelling studies in which experimental designs are evaluated and rigorously compared and improved through "Data worth" analysis.

TASK OBJECTIVE: Optimise value of field-scale injection trials.

TASK OUTPUTS: Optimised experimental design in terms of (i) numbers and types conservative/reactive tracers to be used (ii) tracer amendment duration and (iii) proposed monitoring frequencies

SPECIFIC DELIVERABLES: Preliminary models, monitoring plans, manuscript on using data worth analysis to optimise tracer injection experiments

Task 7.

TASK NAME: Model-based analysis of field-scale injection trials

TASK LEADER: Henning Prommer

OVERALL TIMEFRAME: 2012/13

BACKGROUND: The field-scale re-injection trials will provide the opportunity to evaluate and further improve the conceptual and numerical models that will be developed during the analysis of the column experiments. In contrast to the column experiments, in which the flow field is well-controlled, flow and transport in the field will be affected by hydrogeological heterogeneity. In the initial phase the break through behaviour of conservative tracers will be analysed and the model(s) parameterised accordingly. The reaction model(s) developed for the column experiments will provide the starting point for the development and calibration of the field-scale models. Scaling-effects are anticipated as, for example, field-scale reaction rates are found typically to be slower.

TASK OBJECTIVE: Evaluate and further develop aquifer-specific reactive transport models that provide a process-based description of coupled flow, transport and reactive processes.

TASK OUTPUTS & SPECIFIC DELIVERABLES: Final, aquifer-specific conceptual and numerical models for the geochemical responses to treated CSG water re-injection, report/manuscript(s).

Task 8.

TASK NAME: CSIRO-Australia Pacific LNG workshops

TASK LEADER: Leif Wolf

OVERALL TIMEFRAME: 2011/13

TASK DESCRIPTION: Twice a year, CSIRO-Australia Pacific LNG workshops will be held with the project reference panel.

TASK OBJECTIVE: Review project progress, identification of necessary adjustments to the workplan. The workshops will be used to summarize knowledge for the GISERA reporting duties.

TASK OUTPUTS & SPECIFIC DELIVERABLES: Workshop results documented and distributed to project partners.

Task 9.

TASK NAME: Modelling short course

TASK LEADER: Henning Prommer

OVERALL TIMEFRAME: 2013/14

BACKGROUND: The modelling approaches developed within this project on the basis of specific sites will be applicable to hydrogeological and hydrogeochemical settings. A short course will be developed and delivered to inform and educate professionals, regulators and other researchers.

TASK OBJECTIVE: Illustrate and transfer the knowledge and tools developed within this project.

TASK OUTPUTS & SPECIFIC DELIVERABLES: Short course material and (modelling) short course

15. Budget Justification

The budget for this project has been approved by GISERA's Research Advisory Committee and Management Committee.

16. Project Governance

Project management tasks and disseminations activities are specified in item 14.

17. Communications Plan

General communication will be managed by GISERA.

The pathway to impact for this project includes:

- The research in this project is being carried out in cooperation with Australian Pacific LNG experts who currently conduct injection trials, and the project has already led to improvements in the design of Australia Pacific LNG's injection trial program. By this means the work is directly informing existing industry trials and is building industry science capacity.
- Other industry experts (Santos, Arrow, QGC) need to conduct similar injection trials and have indicated their interest in participating in this work in future. These avenues for collaboration will continue to be pursued. By this means, the work is poised to extend its impact to the CSG-LNG industry as a whole, across a broader commercial and geographic base.
- The large data sets derived from the injection trials will provide for state of the art estimates of long-term geochemical responses to reinjection, that frequently occur on long time spans, e.g. decades to millennia. Clearly, the work addresses both the immediate and long-term research goals of GISERA.
- The modelling undertaken in this project will enable results from trials of limited duration to be extended to longer time frames. This provides a key public good benefit in that it will enable robust estimations of potential impacts to be made well before they have become apparent. Consequently, the project will be informing environmental risk management decisions well ahead of long term monitoring programs.
- This work will inform updates and application of regulations like the CSG Water Management – Injection Guidelines which was recently drafted by the Queensland Department of Environment and Resource Management (DERM). The openly published project reports will provide empirical information on the spatial and temporal extent to which geochemical reactions in the subsurface will have a measurable impact on water quality. This will supplement the modelled estimates that have been used to derive existing guidelines. Existing relationships with the regulator ensures that they are kept informed of project results as the project progresses.
- The work will also inform optimisation of the pre-treatment of the injectant (e.g. is deoxygenation necessary?) and possibly reduce the energy demands of pre-treatment. Information enabling this to occur will be provided by the direct participation of

industry stakeholders in the project and, of course, the public access to research results.

- Direct technical cooperation with the industry experts in the planning of the trials, the collection of samples and the analysis of the results ensures effective knowledge transfer.
- For broader public benefit, stakeholder workshops with government agencies, interested communities and GISERA representatives will be organised.
- The results will be disseminated at national and international conferences as well as a number of peer reviewed journal papers.
- PhD students will be integrated into the work program to allow for direct capacity building. The lead researcher in the project, Prof. Dr. Henning Prommer lectures at the University of Western Australia and is an active participant in the National Centre for Groundwater Research and Training (NCGRT). Upon commencement of the GISERA project, he will start joint research with an already identified University PhD candidate on the modelling of the injection trials.

18. Risks

At this stage no major risks particular to this project are foreseen.

Capacity to deliver: Henning Prommer and Bradley Patterson have both individually sufficient experiences to lead and supervise the various activities and ascertain the research outcomes. Therefore the impact of key staff departure is low and could be mitigated.

19. Intellectual Property and Confidentiality

Background IP (clause 10.1, 10.2)	**Party**	**Description of Background IP**	**Restrictions on use (if any)**	**Value**
	CSIRO	Reactive transport modelling, hydrogeological expertise and know how, experience with geochemical characterisation of (injection) target zones + predictions and analysis of geochemical changes, column	None	

2 Variations to Project Order

Changes to research Project Orders are approved by the GISERA Director, acting with authority provided by the GISERA National Research Management Committee, in accordance with the National GISERA Alliance Agreement.

The table below details variations to research Project Order.

Register of changes to Research Project Order

Date	Issue	Action	Authorisation
19/04/13	Research project start date delayed; milestone dates require rescheduling	All milestone dates rescheduled to reflect later project start date; timing of milestones relative to start date not altered.	Peter Stone
20/03/14	The results from the field experiments appear not to be compatible with the reaction network that was hypothesised to explain the column results. The column modelling will be restarted once the first results from Tasks 10 and 11 are available.	Milestone 5 will be pushed back to May 2014.	[signature]
20/03/14	Task yet to commence. A preliminary date has been set for October 2014.	Milestone 9 will be pushed back to October 2014.	[signature]

24/04/14	In order to predict the occurrence of metal/metalloid mobilisation during the full-scale reinjection scheme and also to explore means for minimising the mobilization, it is important to clearly identify the geochemical mechanisms that cause the release. Therefore, a series of additional sorption and respirometry test experiments, accompanied by the development of geochemical models that describe these data, will be conducted.	Milestone 10 and 11 have been created.	
23/06/14	Start of activity delayed due to completion of Task 11 being delayed. Preliminary results from Tasks 10 and 11 indicate that the originally assumed conceptual models do not hold in the light of the new data.	Milestone 5 will be pushed back to August 2014.	
23/06/14	Start of activity delayed due to completion of Task 11 being delayed.	Milestone 7 will be pushed back to August 2014.	
23/06/14	Interpretation of analytical results was delayed.	Milestone 10 will be pushed back to July 2014.	
23/06/14	Initially used core material turned out to be unsuitable (not representative) and some experiments had to be repeated.	Milestone 11 will be pushed back to July 2014.	
05/03/15	The model is being revised in order to consider what was learned from performing extra two tasks (10 and 11)	Milestone 5 will be pushed back to April 2015.	
05/03/15	Continuing to work on the field-scale model with the aim to complete the work at a robust level that will allow submission of a manuscript.	Milestone 7 will be pushed back to April 2015.	

17/06/15	An additional deliverable will be a calibrated conservative/reactive transport model and report with recommendations regarding the necessity of acid amendment and/or deoxygenation.	Milestone 12 has been created	

3 Progress against project milestones

Progress against milestones are approved by the GISERA Director, acting with authority provided by the GISERA National Research Management Committee, in accordance with the National GISERA Alliance Agreement.

Progress against project milestones/tasks is indicated by two methods: Traffic Light Reports and descriptive Project Schedule Reports.

1. Traffic light reports in the Project Schedule Table below show progress using a simple colour code:
   - Green:
     - Milestone fully met according to schedule.
     - Project is expected to continue to deliver according to plan.
     - Milestone payment is approved.
   - Amber:
     - Milestone largely met according to schedule.
     - Project has experienced delays or difficulties that will be overcome by next milestone, enabling project to return to delivery according to plan by next milestone.
     - Milestone payment approved for one amber light.
     - Milestone payment withheld for second of two successive amber lights; project review initiated and undertaken by GISERA Director.
   - Red:
     - Milestone not met according to schedule.
     - Problems in meeting milestone are likely to impact subsequent project delivery, such that revisions to project timing, scope or budget must be considered.
     - Milestone payment is withheld.
     - Project review initiated and undertaken by GISERA Research Advisory Committee.

2. Progress Schedule Reports outline task objectives and outputs and describe, in the ‘progress report’ section, the means and extent to which progress towards tasks has been made.

Project Schedule Table

ID	Task Title	Task Leader	Scheduled Start	Scheduled Finish	Predecessor
Task 1	Report on project establishment and set up of reference panel.	Leif Wolf	Jul-12	Sept-12	
Task 2	Compilation and assessment of mineralogical and other geochemical data collected by APLNG from core samples	Henning Prommer or Bradley Patterson (to be decided)	Jun-12	Jul-13	Task 1
Task 3	Construction and initial setup of laboratory columns for cores collected from representative target aquifers	Bradley Patterson	Jun-12	Nov-12	Task 1
Task 4	Operation of column experiments	Bradley Patterson	Nov-12	Oct-13	Task 3
Task 5	Model-based analysis of geochemical data collected during the laboratory-scale column experiments	Henning Prommer	Apr-13	Apr-15	Task 2, Task 4
Task 6	Preliminary, pre-trial modelling studies to support the design and monitoring strategy of selected field-scale injection experiments	Henning Prommer	Jul-12	Mar-14	Task 1
Task 7	Model-based analysis (reactive transport modelling) of hydrochemical data collected during injection trials at representative target aquifers	Henning Prommer	Feb-13	Apr-15	Task 2, Field trials operated by APLNG
Task 8	Workshops with CSIRO-APLNG for interim reporting and quality assurance	Leif Wolf	Jul-12	Jan-14	
Task 9	Shortcourse on geochemical transport modelling to assess and quantify re-injection impacts	Henning Prommer	Oct-13	Oct-14	Task 3, Task 7

Task 10	Undertake Respirometry experiments and analysis	Henning Prommer	Feb-14	Jul-14	
Task 11	Undertake Sorption experiments and analysis	Henning Prommer	Feb-14	Jul-14	
Task 12	Optimising reinjection operations	Henning Prommer	Jul-15	Oct-15	

Project Schedule Report

Task 1.

TASK NAME: Project set up & management

TASK LEADER: Leif Wolf

OVERALL TIMEFRAME: 2012/13

- Establish a project reference panel.
- Provide and control linkages with related projects.
- Refine work plan according to bi-annual Australia Pacific LNG-CSIRO discussions.

PROGRESS REPORT:

The project was established and key tasks and milestones were discussed with representatives from Origin. In February 2013 a 3-day workshop was held between CSIRO team members and Origin representative to evaluate the progress of the work, coordinate interaction between Projects 1 and 3, and discuss ongoing and future work. Regular phone hook-ups were initiated between CSIRO researchers and Origin to discuss field-data gathering, to coordinate sample collection, to provide input to and discuss the experimental design of field trials. A field visit involving CSIRO team members from all projects to Reedy Creek will take place on the 27 and 28 May 2013. The site visit will allow further discussions to coordinate the project. No formal project reference panel was established.

Task 2.

TASK NAME: Geochemical characterisation of selected target aquifers

TASK LEADER: Henning Prommer or Bradley Patterson (to be discussed/decided)

OVERALL TIMEFRAME: 2012/13

BACKGROUND: The evolution of water quality changes in aquifers targeted for re-injection depends on the hydrogeological properties that control the pathways, the degree of physical mixing of injected and ambient water, and the inventory and reactivity of the minerals that constitute the aquifer matrix. To date only insufficient knowledge and data exist, in particular for the latter. To close this gap CSIRO and Australia Pacific LNG have selected a suite of analytical methods that will be used for a detailed geochemical characterisation of sediment/rock samples collected during the ongoing and future core recovery activities. Sample collection and chemical/mineralogical analysis is coordinated with Australia Pacific LNG. Within Task 2 the collected data will be compiled and assessed. The mineralogical characterisation includes XRD/XRF analysis of multiple samples per injection interval. Furthermore, samples will be analysed for chrome reducible S (SCr), total C (TC), total organic C (TOC), total inorganic C (TIC). ICP-AES for extractable Fe, Al and Mn and for 18 transition elements (Ag, As, B, Ba, Be, Cd, Co, Cr, Cu, Mn, Mo, Ni, Pb, Sb, Se, Sn, V, Zn).

TASK OBJECTIVE: Gain a comprehensive understanding of the mineralogical/elemental composition and potential reactivity of the aquifer material that constitutes selected aquifers targeted for re-injection.

TASK OUTPUTS: Geochemical characterisation of selected target aquifers.

SPECIFIC DELIVERABLE: Report.

PROGRESS REPORT:

Task completed (report completed, it is currently in CSIRO's peer-review process). Core samples were collected and analysis results were supplied. Processing of results and data interpretation were carried out for a range of sites targeted for injection.

Task 3.

TASK NAME: Construction and initial setup of laboratory columns

TASK LEADER: Bradley Patterson

OVERALL TIMEFRAME: 2012/13

BACKGROUND: Depending on the size, type and condition of the core samples collected from selected target aquifers the experimental setup required for the flow through column experiments needs to be designed and tested. Given that the recovered core material is anticipated to consist mostly of consolidated material, cores will potentially need to be embedded in resin and a suitable construction of sampling ports need to be designed and tested.

TASK OBJECTIVE: Design and test suitable experimental setup for controlled flow through experiments.

TASK OUTPUTS: Final experimental setup and monitoring plan for the column experiments.

PROGRESS REPORT:

Selected cores were shipped from field sites to the CSIRO Land and Water laboratory in Floreat. Initial efforts were dedicated to develop suitable experimental setups for flow-through column experiments. Initial testing indicated that most cores show a very low permeability. A first flow-through experiment was started for an intact core sample from Talinga. To maximise water-sediment contact and thus reaction-time, column flow-through is regularly interrupted. In the meantime three additional flow-through experiments are underway with core material from Reedy Creek. Core material was crushed to increase reactivity and to study the impact of surface area. A report describing the initial column setup was compiled.

Task 4.

TASK NAME: Operation of column experiments

TASK LEADER: Bradley Patterson

OVERALL TIMEFRAME: 2012/13

BACKGROUND: The columns will presumably be operated in a saturated up flow mode at a flow rate of 50 mL/day, which corresponds to a Darcy velocity of 5 cm/day (assuming a porosity of 0.3). This will lead to a column residence time of ~ 6 days. Groundwater, from the location at which the core was collected, will initially be passed through the column for a period of ~30 days to stabilize groundwater/aquifer chemistry prior to the introduction of reverse osmosis (RO) water. Once groundwater effluent concentrations and physical parameters (pH, Eh, EC and DO) have stabilized, RO water will be passed through the column at a flow rate of 50 mL/day, and changes in water chemistry monitored. To identify the level of RO water processing on geochemical changes different RO waters will be sequentially introduced (~ every 3 months) into the columns. The RO waters used will be (i) deoxygenated RO water mixed with higher EC water, (ii), deoxygenated RO water and (iii) oxygenated RO water.

TASK OBJECTIVE: Determine experimentally the geochemical reactions that occur during passage of different types of treated CSG waters

TASK OUTPUTS & SPECIFIC DELIVERABLES: Experimental data and initial conceptual models of water-sediment/rock interactions.

PROGRESS REPORT:

The originally scoped work and the data collection that was envisaged for task 4 have now been concluded.

Task 5.

TASK NAME: **Model-based analysis of experimental data collected during the laboratory-scale column experiments**

TASK LEADER: Henning Prommer

OVERALL TIMEFRAME: 2012/13

TASK OBJECTIVE: Development and testing of conceptual models and translation into reactive transport models that can simulate the water quality evolution observed during the laboratory-scale column experiments.

TASK OUTPUTS: Capabilities/tools to quantitatively describe major geochemical processes.

SPECIFIC DELIVERABLES: Aquifer-specific PHT3D reaction modules for key target aquifers, calibrated models.

PROGRESS REPORT:

Completed. A first numerical model was constructed for the Talinga core column experiment. A reaction network was defined on the basis of the geochemical characterisation (Task 2) and on the basis of the chemical analysis for the ambient groundwater and the injectant (RO water). However, the results from the Reedy Creek field injection trial and also the preliminary results from Tasks 10 and 11 appeared not to be compatible with the reaction network that was hypothesised to explain the column results and the model had to be revised. The revised model has now been completed.

Task 6.

TASK NAME: Pre-trial modelling studies

TASK LEADER: Henning Prommer

OVERALL TIMEFRAME: 2011/12

BACKGROUND: The experimental setup/design, the type of collected data and the timing of sampling events all have a significant impact on how strongly they are able to constrain the development and calibration of the numerical models that are aimed at providing process-based quantitative descriptions of the coupled flow, transport and reactive processes. The value of the data collected during a laboratory and/or field experiment is therefore greatly enhanced through pre-trial modelling studies in which experimental designs are evaluated and rigorously compared and improved through "Data worth" analysis.

TASK OBJECTIVE: Optimise value of field-scale injection trials.

TASK OUTPUTS: Optimised experimental design in terms of (i) numbers and types conservative/reactive tracers to be used (ii) tracer amendment duration and (iii) proposed monitoring frequencies

SPECIFIC DELIVERABLES: Preliminary models, monitoring plans, manuscript on using data worth analysis to optimise tracer injection experiments

PROGRESS REPORT:

Completed. Pre-trial modelling was carried out for the Spring Gully injection experiment and results were discussed with Origin. A sampling plan was proposed on the basis of the modelling. In the meantime additional pre-trail modelling has been carried out for the Reedy Creek injection Trial, with the specific goal on optimising the timing of the tracer amendment during the push-pull (injection-storage-recovery) experiment. The modelling for the manuscript on data worth analysis has been prepared. The manuscript has been peer-reviewed and is now published in *Journal of Hydrology.*

Task 7.

TASK NAME: **Model-based analysis of field-scale injection trials**

TASK LEADER: Henning Prommer

OVERALL TIMEFRAME: 2012/13

BACKGROUND: The field-scale re-injection trials will provide the opportunity to evaluate and further improve the conceptual and numerical models that will be developed during the analysis of the column experiments. In contrast to the column experiments, in which the flow field is well-controlled, flow and transport in the field will be affected by hydrogeological heterogeneity. In the initial phase the break through behaviour of conservative tracers will be analysed and the model(s) parameterised accordingly. The reaction model(s) developed for the column experiments will provide the starting point for the development and calibration of the field-scale models. Scaling-effects are anticipated as, for example, field-scale reaction rates are found typically to be slower.

TASK OBJECTIVE: Evaluate and further develop aquifer-specific reactive transport models that provide a process-based description of coupled flow, transport and reactive processes.

TASK OUTPUTS & SPECIFIC DELIVERABLES: Final, aquifer-specific conceptual and numerical models for the geochemical responses to treated CSG water re-injection, report/manuscript(s).

PROGRESS REPORT:

Completed. A field-scale flow, heat and reactive transport model has been constructed and calibrated using the data from the Reedy Creek field injection trial. The model has been used to predict the geochemical changes under varying injection treatment scenarios. The modelling results have been presented to the regulators and permission for re-injection at Reedy Creek has been granted.

Task 8.

TASK NAME: CSIRO-Australia Pacific LNG workshops

TASK LEADER: Leif Wolf

OVERALL TIMEFRAME: 2011/13

TASK DESCRIPTION: Twice a year, CSIRO-Australia Pacific LNG workshops will be held with the project reference panel.

TASK OBJECTIVE: Review project progress, identification of necessary adjustments to the workplan. The workshops will be used to summarize knowledge for the GISERA reporting duties.

TASK OUTPUTS & SPECIFIC DELIVERABLES: Workshop results documented and distributed to project partners.

PROGRESS REPORT:

A 3-day workshop was held in February 2013 and a second workshop was held during the field site visit (27/28th May). In February 2014 a third workshop was held from 5-9 February between CSIRO Team members and Origin.

Task 9.

TASK NAME: **Modelling shortcourse**

TASK LEADER: Henning Prommer

OVERALL TIMEFRAME: 2013/14

BACKGROUND: The modelling approaches developed within this project on the basis of specific sites will be applicable to hydrogeological and hydrogeochemical settings. A short course will be developed and delivered to inform and educate professionals, regulators and other researchers.

TASK OBJECTIVE: Illustrate and transfer the knowledge and tools developed within this project.

TASK OUTPUTS & SPECIFIC DELIVERABLES: Short course material and (modelling) short course

PROGRESS REPORT:

A 2-day reinjection shortcourse, which included several lectures on modelling was presented as a NCGRT shortcourse in Brisbane (23-24 October). The course was well attended (>30 participants) by regulators, researchers and consultants.

Task 10.

TASK NAME: **Undertake Respirometry experiments and analysis**

TASK LEADER: Henning Prommer

OVERALL TIMEFRAME: 2013/14

BACKGROUND: Respirometry experiments and analysis

- Undertake respirometry experiments using an Oxymax Respirometer on 100g sub-samples of rock material collected from the Reedy Creek site – 10 Precipice Sandstone samples (to investigate chemical evolution and metal release in response to controlled oxygenation

- Model-based data-interpretation to determine the rate of pyrite oxidation and to evaluate to relate oxygen consumption to geochemical changes and trace metal release

TASK OBJECTIVE: Evaluate the influence of aquifer sediment oxygenation on metal release.

TASK OUTPUTS & SPECIFIC DELIVERABLES: Model of geochemical response to induced redox changes with a particular focus on the potential for metal/metalloid mobilisation by aerobic injection water

PROGRESS REPORT:

Completed. Respirometer tests with core material from the Reedy Creek site were performed and the experiments and their interpretation was completed. The results were influencing the development of the conceptual and numerical models that formed the basis for the model-based interpretation of the injection trial data.

Task 11.

TASK NAME: **Undertake Sorption experiments and analysis**

TASK LEADER: Henning Prommer

OVERALL TIMEFRAME: 2013/14

BACKGROUND: Sorption experiments and analysis

- Batch sorption experiments with rock material collected from the Reedy Creek site (Precipice Sandstone)
- Development of surface complexation model for arsenic sorption under variable geochemical conditions. The adsorption model will consider the dependence of sorption on pH and the concentrations of competing ions

TASK OBJECTIVE: Develop understanding of surface complexation reactions under variable geochemical conditions

TASK OUTPUTS & SPECIFIC DELIVERABLES: Development of a surface complexation model for the aquifer sediments at the Reedy Creek injection trial site with particular focus on site-specific geochemical factors controlling metal/metalloid sorption and desorption.

PROGRESS REPORT:

Completed. A detailed experimental plan has been prepared to characterise the sorption behaviour of the Precipice Sandstone. Initial sorption experiments were performed with the Precipice core material from the Reedy Creek site. However, the experiments indicated a strong influence of calcite dissolution on pH buffering. It was concluded that the core material was not sufficiently suitable as it did not represent the permeable sections of the target aquifer. Therefore the experiments were restarted with alternative core material from the Reedy Creek site. The experiments investigated sorption isotherms at two different pHs, sorption under variable pH conditions and competitive sorption effects. A surface complexation model that explains the experimentally measured data was constructed and applied in Task 7.

Task 12.

TASK NAME: **Optimising reinjection operations**

TASK LEADER: Henning Prommer

OVERALL TIMEFRAME: July 2015-October 2015

BACKGROUND: The reinjection of CSG production waters has been trialled at the Reedy Creek site. From an operational and geochemical point of view the trial was largely successful leading to the construction of an operational injection scheme. However, two specific issues have been identified that require further critical evaluation. First, the results from the Reedy Creek trial suggested that the pH of the injectant should possibly be modified in order to minimise the risk of metal mobilisation. This can be achieved by amending acid (such as hydrochloric acid) prior to injection. Secondly, the interpretation of the geochemical data suggest that there is no evidence that (i) oxidation of metal-sulfides has occurred and that deoxygenation of the injectant, as it is currently applied, might not be necessary and considerable savings in operational costs are feasible. If feasible, an application could be made to the regulator to remove this component of the treatment process at the operational injection schemes at Reedy Creek and Spring Gully, and potentially other future operational injection schemes.

Based on these insights three new push-pull tests are currently being undertaken to (i) test the impact of acid amendment to the injectant and (ii) to test the geochemical response to the injection of oxygenated water. This part of the project will focus on the interpretation of the field data that were collected in these new field experiments at the Condabri site. Major steps of the task include

- Workshop to review/discuss operational and geochemical requirements and risks (CSIRO, Origin)
- Construction of a flow and bromide transport model for the Condabri injection trial site
- Simulation of flow and conservative transport for the push-pull experiments and calibration of hydrogeological parameters using the bromide tracer tests
- Construction of a Condabri reactive transport model on the base of the Condabri bromide transport model and the previously developed Reedy Creek reactive transport model
- Constrained by the field data successive improvement and calibration of the reactive transport model
- Model-based assessment of the impact of pH amendment and deoxygenation of the injectant for potential operational scenarios at both Condabri and Reedy Creek.

TASK OBJECTIVE: Optimise operational cost and minimise geochemical and operational risks.

TASK OUTPUTS & SPECIFIC DELIVERABLES: Calibrated conservative/reactive transport model and report with recommendations regarding the necessity of acid amendment and/or deoxygenation

PROGRESS REPORT:

Completed. A flow and conservative transport model for the three successive injections trials at Condabri was constructed and calibrated against the measured bromide and chloride data. Subsequently the model was further developed into a reactive transport model and the model calibration that used the measured hydrochemical data as constraints was completed. The results were used to investigate the geochemical response to a long-term injection at Condabri for various injectant treatment scenarios. In the final step a predictive model was constructed for the Reedy Creek site. The results are presented in the final report.