GISERA
Gas Industry Social and Environmental Research Alliance

Project Order, Variations and Research Progress

Project Title: Mitigating Fugitive Gas Emissions from Well Casings

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

1 Original Project Order

Project Order

Proforma 2019

1. Short Project Title

Mitigating Fugitive Gas Emissions from Well Casings

Long Project Title	Advancing New Materials to Assist Mitigating Fugitive Gas Emissions from Well Casings
GISERA Project Number	G.6
Proposed Start Date	01/09/2019
Proposed End Date	31/12/2020
Project Leader	Bailin Wu

2. GISERA Region

☐ Queensland	☐ New South Wales	☒ **Northern Territory**
☐ South Australia	☐ Western Australia	☐ Victoria

3. GISERA Research Program

☐ Water Research	☒ **GHG Research**	☐ Social & Economic Research
☐ Biodiversity Research	☐ Agricultural Land Management Research	☐ Health Research

4. Project Summary

Objective

The main objective of this project is to evaluate the suitability of novel materials developed by material scientists at CSIRO to help mitigate methane gas migration and emission along the microfractures/microannuli behind external well casings. This type of compromised well integrity is the most common well integrity risk (APPEA, 2017). Fugitive gas emission from gas wells is a significant public concern associated with unconventional gas development in the Northern Territory. This project will identify which novel material types are potentially suitable to permanently seal microfractures/microannuli.

Description

CSIRO has been developing novel materials for civil and oil and gas applications for many years. The project will leverage this expertise and IP in material science to address a persistent industry problem of gas migration and emission along microfractures/microannuli behind well casings.

The project is divided into three phases as follows,

- Phase 1 Material selection and performance criteria

A comprehensive literature review will be conducted to gain a better understanding on materials and technologies in sealing microfractures and/or microannuli from leaking wells and the conditions that they need to operate downhole. This is followed by a brainstorm session for all the project team members to identify and short list a set of candidate materials for experimental evaluation and to develop a set of material performance criteria. The technical experts and government representatives from the Technical Reference Group will be invited to the brainstorm session and to review and endorse the performance criteria.

- Phase 2 Bench top screening & evaluation

Screening experiments are conducted using bench top setup to evaluate and select the most promising materials for further evaluation under downhole condition. Synthetic planar fractures are created by shimming up two plates with a variety of apertures. Effectiveness of sealing is assessed based on hydraulic conductivity and strengths of sealed fractures.

- Phase 3 Performance evaluation under downhole condition

The most promising materials are evaluated based on their capability to seal planar microfractures and curved microannuli under downhole condition. Effects of cyclic wellbore pressure on sealed fractures will be simulated. Effectiveness of sealing is assessed based on hydraulic conductivity and strengths of sealed fractures.

Need & Scope

Australia has abundant unconventional gas resources with estimates of over 200 trillion cubic feet (TCF) of all identified coal seam gas (CSG) resources and more than 1000 TCF of recoverable shale gas across the country (Cook et al, 2013). The impact of developing the unconventional resources on the environment remains a significant concern in Australia.

Wells play a central role in unconventional gas development and ensuring well integrity during their entire life and beyond is a significant challenge. Leaking wells or loss of well integrity is an ongoing risk for the oil and gas industry resulting in loss of production, safety concerns and environmental damage. A substantial amount of work has been conducted to identify well failure mechanisms and failure rates (King & King 2013; King 2014; Davies et al. 2014; Wu et al. 2016; Huddlestone-Holmes et al. 2017). For example, a literature review on well integrity submitted to the NT Hydraulic Fracturing Inquiry showed that the rate of total well integrity failures that have the potential to cause environment contamination is about one in 1000 wells. However, the rate for single-well barrier failures which may not lead to environment contamination is higher, about 1-10 in 100 wells (Huddlestone-Holmes, et al 2017). Well failure rate due to gas migration outside well casing has been reported to be 0.73% of all the wells in Alberta, Canada from a large well database (over 400,000 wells) (Bachu 2017). Recent direct measurements of methane emission from 138 abandoned oil and gas wells in the US demonstrated that about 6.5% of the wells had measurable CH_4 emissions, that was estimated to contribute less than 1% of the regional CH_4 emission in the study area (Townsend-Small, et al. 2016). A similar study on 102 abandoned oil and gas wells (properly plugged and abandoned) in the UK revealed that 30% of the wells had a positive CH_4 flux at the soil surface (Boothroyd et al., 2016). However, the CH_4 flux from the properly plugged and abandoned wells is low relative to the activity commonly used on decommissioned well sites, for example, sheep grazing (Boothroyd et al. 2016). While the potential to leak from plugged and abandoned well exists, environmental regulation, monitoring and mitigation activities will further limit the potential for actual leakage.

There are many different types and severity of well leaks. The causes of well leaks are often related to aging equipment in the well and operation errors during well construction, completion and stimulation (Normann 2018). These types of leaks can be relatively easy to mitigate once identified. The other causes for leakage is related to well cementing or well operations after the cement is set. These can be due to insufficient cement height, poorly placed cement, bad hole cleaning and mud cake removal, poorly executed cement job, slurry losses during cementing, bad centralization of casing or liner, excessive borehole breakout/washout, wrong cement slurry design, cement shrinkage, variation of temperatures and pressure in the well inducing cement de-bonding (Normann 2018). Figure 1 shows potential fluid movement pathways for a decommissioned oil and gas well. Gas migration can take place along microfractures and microannuli in the cement sheath behind the casing and/or on the interfaces with the casing or formation rock. This type of compromised well integrity is recognized as the most common well integrity risk in the APPEA's recent submission to the NT Hydraulic Fracturing Inquiry (APPEA, 2017) and CSIRO report (Huddlestone-Holmes et al., 2017).

Once identified, the conventional approach to mitigating cementing related well leakage is to conduct cement slurry squeezing where the cement slurry is forced through perforations or cut slots into the casing/wellbore annular space (Nelson & Dowell 1990). When the slurry is forced against a permeable formation, the solid particles filter out on the formation face as the aqueous phase (cement filtrate) enters the formation matrix. A properly designed squeeze job causes the resulting cement filter cake to fill the openings between the formation and the casing. Upon curing, the cake forms a nearly impenetrable solid (Suman and Ellis, 1977). While squeeze cementing has been applied to repair failed primary cement jobs successfully (due to mud channelling or insufficient cement height in the annulus), it has also proved ineffective in sealing microfractures/microannuli which often has an aperture much less than 150 um (Normann 2018). This is because conventional Portland cement has a particle size that is similar to or larger than the aperture of microfractures/microannuli, and the cement slurry cannot penetrate deep enough into these micro features.

CSIRO has been developing novel materials for civil and oil and gas applications for many years. These include hybrid inorganic polymer systems and related formulations deployed in the building and construction sectors (Sagoe-Crentsil et al 2010), an organic polymer system for water shutoff in oil and gas producing wells (CSIRO, 2017) and polymer composite application for oil and gas infrastructure rehabilitation in the oil and gas industry. Furthermore, CSIRO has significant experience working on oil and gas well related integrity issues.

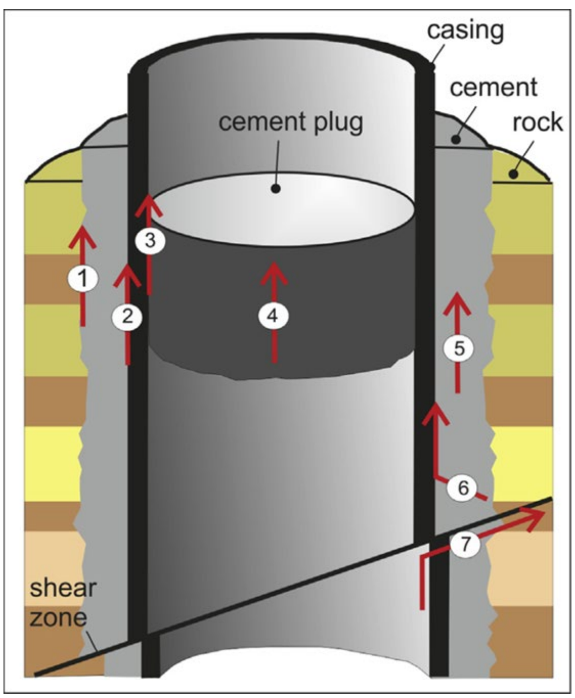

Figure 1 Pathways for fluid movement in decommissioned production wellbore. 1 – microannuli between cement and surrounding rock formations, 2 – microannuli between casing and surrounding cement, 3 – microannuli between cement plug and casing or production tubing, 4 – microfractures or mud channels through cement plug, 5 – microfractures or mud channels through the cement sheath between casing and rock formation, 6 – microannuli or mud channels across the cement outside the casing and then between this cement and the casing, 7 – fractures along a sheared wellbore (after Davies et al. 2014).

The project will leverage CSIRO expertise in developing novel material solutions to address a persistent industry problem related to unconventional gas development and create added value for the CSIRO in-house IP by identifying new area of applications. Furthermore, the identified new materials may be applied to other well related problems such as drilling fluid loss in oil and gas well drilling, decommissioning oil and gas wells and remediating leaking wells for CO_2 geological storage.

NT Hydraulic Fracturing Inquiry Recommendations

The project will address part of the NT HF Inquiry Recommendations 5.1 (Page 55), which states

"*That prior to the grant of any further exploration approvals, the Government mandates an enforceable code of practice setting out minimum requirements for the decommissioning of any onshore shale gas wells in the NT. The development of this code must draw on world-leading practice. It must be sufficiently flexible to accommodate improved decommissioning technologies.*

The code must include a requirement that:

- *wells undergo pressure and cement integrity tests as part of the decommissioning process, with any identified defects to be repaired prior to abandoning the well; and*
- *cement plugs be placed to isolate critical formations and that testing must be conducted to confirm that the plugs have been properly set in the well".*

and recommendation 5.3, which states

"That prior to the grant of any further exploration approvals, in consultation with industry and other stakeholders, the Government develops an enforceable code of practice setting out the minimum requirements that must be met to ensure the integrity of onshore shale gas wells in the NT."

The defects described in Recommendation 5.1 include microfractures/microannuli outside the well external casing that can result in fugitive gas migration and emission to the atmosphere and/or shallow aquifers. These defects also represent compromised well integrity (Recommendation 5.3). Despite unconventional gas wells being constructed using modern well technology and best industry practices, the above defects persist due to geological uncertainties and operational and human competencies (Dusseault et al. 2016). This project will explore new technologies that can be applied to remediate these issues and maintain well integrity.

Methodology

The methodologies to be applied in each project phase are as follows:

- Phase 1 - The project will start by conducting a comprehensive state-of-the-art literature review. There are two objectives for this review; a) determine existing sealing materials/technologies for leaking wells with microfractures/microannuli, and b) establish performance criteria for sealing materials. This is followed by a brainstorm session for all the project team members to identify and short list a set of candidate materials (or their formulation) for experimental evaluation. The technical experts and government representatives from the Technical Reference Group will be invited to participate in the brainstorm session and to review/endorse the material performance criteria.
- Phase 2 - The selected candidate materials will be evaluated and screened for their performance in sealing planar microfractures in bench top set up experiments. The micro fractures with a range of apertures are formed by shimming up two flat surface plates (rock, cement, steel or perspex). The slurry of sealing material will be injected into the planar microfractures using a syringe pump. Once cured, a set of measurements will be conducted to assess the sealing effect, such as ultrasonic velocities and hydraulic conductivity. The tested samples are then cut up for visual observation under microscope and/or SEM and for measurements on the strengths of the sealed microfractures. The performance of the CSIRO materials will be compared with the baseline performance of Portland cement.
- Phase 3 - The most promising sealing materials are further evaluated by conducting sealing experiments under downhole condition (elevated pressure and temperature) using a Hoek cell. Planar micro fractures will be created by shimming up the two halves of a cylindrical sample (the two halves can be different materials). The slurry of sealing materials will then be injected into the fracture under pressure and temperature. The suitability of the materials will be evaluated based on their injection pressure, hydraulic conductivity of the sealed fracture, and the maximum differential pressure that can be sustained by the sealed fractures and the mechanical strengths of the sealed fractures. The effect of cyclic downhole pressure on sealed fractures will be simulated by cycling the confining pressure in the experiments. Some sealing experiments on microannuli will be conducted on model wellbore samples. The scaled model wellbore sample is constructed by cementing a suitable steel tube in the hole of a hollow cylinder of rock sample. A microannulus is created by moving the steel pipe prior to the cement being completely cured. Sealing and evaluation is then conducted similar to that for the planar micro fractures. The performance of the CSIRO materials will be compared with the baseline performance of Portland cement. Some tested samples with sealed fractures will be cut or cored for observation under microscope and/or SEM and for measuring the strengths of the sealed fracture.

5. Project Inputs

Research

In the process of conceiving and developing this document, a brief literature review was conducted on the materials and technologies for sealing microfractures/microannuli. The review revealed that in addition to squeeze cementing, other methods exist to repair small casing leaks, such as pressure activated sealant technology (Chivvis et al. 2009, Johns et al. 2006). The working principle of pressure activated sealant is that a pressure differential causes the liquid sealant to polymerize into a flexible solid which can plug a leak. The liquid sealant only polymerizes at the point of differential pressure which can be created by a pressure drop through a leak. As the polymerization reaction proceeds, the hardened sealant plates-out on edges of the leak to gradually seal it off. The resulting seal is a flexible plug across the leak site. However, this method may not be applicable to seal microfractures/microannuli because sufficient differential pressure cannot be created within these micro features to activate the polymerization process.

The University of New Mexico and Sandia National Laboratory recently reported a study on application of a polymer nanocomposite material for restoring well seal integrity (Genedy et al. 2017). The study evaluated the effectiveness of the material in penetrating and sealing micro annulus in wellbores, bonding strength with steel and microstructure of the interface with Portland well cement. However, the study was limited to the ambient conditions and the performance of the new material under more realistic downhole environment was not evaluated.

The initial brief literature review showed that there is not currently a suitable material available that meets industry's need in permanently sealing the micro fractures and microannuli that may exist in the annulus behind a casing. A preliminary assessment on the novel materials developed by CSIRO for applications in building and oil and gas industries demonstrates that, at least some of them, such as the hybrid inorganic polymer system, organic polymer systems and the polymer composite materials, are the potential candidates to perform the role, based on their physical, chemical and mechanical properties. The main objective of the project is therefore to experimentally investigate the suitability of these material in sealing the minute fractures under downhole pressure and temperature condition. Specifically, the project will seek to answer some of the critical questions using the candidate materials as the sealing material for leaking wells:

- Injectivity and penetration. If the slurry of candidate materials can be injected into minute fractures (say, aperture <150 um) deeply, and what injection pressure is required without inducing new fractures?
- Sealability. What is the hydraulic conductivity of the sealed fractures and the maximum pressure differential (or gradient) that the seal can sustain?
- Strength. How well the material can be bonded to the cement/steel/rock? What is the strengths of the sealed fracture and how quickly the strengths can be developed?
- Effect of downhole conditions. How sealed fracture is affected by downhole pressure and temperature change, in terms of its hydraulic conductivity and strengths?

Other critical questions, such as durability of the seal and its interaction with the surrounding formation environment, will be considered in this project, but it is unlikely to be fully answered due to the limited scope of this project.

In conceiving and developing this document, discussions were held with oil and gas and service/manufacturing companies as well as within CSIRO. This included discussions with

- Grant Lintern, formerly drilling and completions technical authority/adviser at Woodside (now retired), and Peter Brazier, regional manager of ITF (Industry Technology Facilitator, now merged with the Oil & Gas Technology Centre) on geopolymer application as an alternative material for oil and gas well plugging and abandonment
- Russell Furner, R&D solutions and Aaron Begley, Matrix composites & Engineering (both in WA) on application of geopolymer as an alternative material for oil and gas well cementing
- Internally within CSIRO, discussions were held between staff members, i.e., Kwesi Gagoe-Crentsil (now with ARC Nanocomm at Monash University) and Shiqin Yan on geopolymer materials, Colin Wood on organic polymer systems, Wendy Tian on polymer composite materials and Bailin Wu on well integrity

Resources and collaborations

Researcher	Time Commitment (project as a whole)	Principle area of expertise	Years of experience	Organisation
Bailin Wu	55 days	Geomechanics and well integrity	30+	CSIRO
Colin Wood	12 days	Oil and gas field chemistry – HPHT organic polymer	10+	CSIRO
Wendy Tian	12 days	Material science – Polymer composite materials & resins	20+	CSIRO
Shiqin Yan	12 days	Material science - geopolymer	20+	CSIRO
Cameron Huddlestone-Holmes	12 days	Geology & well drilling and completions	20+	CSIRO
David Down	90 days	Engineering & lab testing	20+	CSIRO
Buu (Nguyen) Dao	23 days	Material science - resins	30+	CSIRO

Subcontractors (clause 9.5(a)(i))	Time Commitment (project as a whole)	Principle area of expertise	Years of experience	Organisation
N/A				

Budget Summary

Source of Cash Contributions	2019/20	2020/21	2021/22	% of Contribution	Total
GISERA	$170,620	$108,113	$0	75%	$278,733
- Federal Government	$84,172	$53,336	$0	37%	$137,508
- NT Government	$22,749	$14,415	$0	10%	$37,164
- Origin Energy	$22,749	$14,415	$0	10%	$37,164
- Santos	$22,749	$14,415	$0	10%	$37,164
- Pangaea Resources	$18,199	$11,532	$0	8%	$29,732
Total Cash Contributions	**$170,620**	**$108,113**	**$0**	**75%**	**$278,733**

Source of In-Kind Contribution	2019/20	2020/21	2021/22	% of Contribution	Total
CSIRO	$56,873	$36,038	$0	25%	$92,911
Total In-Kind Contribution	**$56,873**	**$36,038**	**$0**	**25%**	**$92,911**

Cultural Monitoring Program

The cultural monitor program is considered mutually beneficial, increases engagement and participation of the local traditional owners and provides additional safeguards against the research proponent or other fieldworkers inadvertently entering into a sacred site or other culturally sensitive area. Cultural monitors are engaged via the NLC whenever a company or operator goes out in the field.

In GISERA projects where CSIRO researchers are being escorted onto leases by company representatives who have organised permit access, those company procedures will apply.

For all other GISERA projects (particularly environmental and social projects) where CSIRO researchers are not being escorted by industry, CSIRO will work with the NLC to apply this practice.

6. Project Impact Pathway

<table>
<tr><th>Activities</th><th>Outputs</th><th>Short term Outcomes</th><th>Long term outcomes</th><th>Impact</th></tr>
<tr><td>Literature review and performance criteria</td><td>State-of-the-art review on existing materials and technologies in sealing microfractures/microannuli; CSIRO internal brainstorm session to identify candidate materials</td><td>An up to date understanding on materials, technologies and best practices in industry in sealing minute fractures in cement sheath and interfaces; Shortlist CSIRO materials</td><td rowspan="4">• The project will improve industry’s knowledge on most suitable materials and technologies in sealing minute fractures in cement sheath and on interfaces that are conduits for gas migration
• Better technology to seal minute fractures around the well will relieve community’s concern on fugitive gas emission from wellbore.</td><td rowspan="4">Environment impacts
• Better technology to seal minute fractures will reduce fugitive gas emissions from onshore wells</td></tr>
<tr><td>Bench top screening & evaluation</td><td>Performance evaluation of the selected CSIRO materials for sealing microfractures/microannuli under ambient condition.</td><td>Materials short listed for further evaluation</td></tr>
<tr><td>Performance evaluation under downhole condition</td><td>Performance of short listed materials under downhole pressure and temperature condition</td><td>Suitable materials are identified for full scale borehole evaluation and other assessment</td></tr>
<tr><td>Final report</td><td colspan="2">Final report comprehensively describing the materials evaluated, their performance and mechanisms in sealing microfractures/microannuli, experimental results and analyses and recommendations for further evaluation and assessment prior to field trial.</td></tr>
</table>

7. Project Plan

Project Schedule

ID	Activities / Task Title (should match activities in impact pathway section)	Task Leader	Scheduled Start	Scheduled Finish	Predecessor
Task 1	Literature review and performance criteria	Bailin Wu	September 2019	January 2020	
Task 2	Bench top screening and performance evaluation	Bailin Wu	February 2020	June 2020	Task 1
Task 3	Performance evaluation under downhole condition	Bailin Wu	July 2020	November 2020	Task 2
Task 4	Final report	Bailin Wu	December 2020	December 2020	Tasks 1, 2 & 3

Task description

Task 1

TASK NAME: Literature review and performance criteria

TASK LEADER: Bailin Wu

OVERALL TIMEFRAME: September 2019 – January 2020

BACKGROUND: Squeezing cement slurry has been a common operation to repair defects in primary cementing. However, such method has been proved ineffective in many cases in sealing minute fractures in the cement sheath and along the interfaces between the cement and casing or between the cement and formation rock. This review is to gain a better understanding on the current industry practices, operational requirements, the conditions that materials will need to tolerate, and any new materials the industry may be used to fix the problem.

In addition to the review, a brain storming session will be organised among the project team members and technical experts from industry and government to identify candidate materials for sealing microfractures /microannuli and to establish a set of material performance criteria.

TASK OBJECTIVES: To gain a good understanding on the current industry practices; to establish performance criteria that are required for new materials to meet; and to identify candidate CSIRO materials

TASK OUTPUTS AND SPECIFIC DELIVERABLES: A comprehensive review report documenting current industry practice in repairing defects in primary cementing, also documenting properties and performance of the identified candidate CSIRO materials for other applications

Task 2

TASK NAME: Bench top screening & evaluation

TASK LEADER: Bailin Wu

OVERALL TIMEFRAME: February 2020 to June 2020

BACKGROUND: The identified candidate materials will be evaluated for their performance in sealing microfractures in a bench top setup in ambient condition. The planar fractures will be formed by shimming up two flat plates (rock, cement, steel, or perspex) with a variety of fracture apertures. Their performance will then be evaluated and compared with the baseline performance of the Portland cement.

TASK OBJECTIVES: To screen the candidate materials for their suitability in sealing planar microfractures prior to more elaborated performance evaluation under downhole condition

TASK OUTPUTS AND SPECIFIC DELIVERABLES: Short listed materials for further evaluation under downhole pressure and temperature condition.

Task 3

TASK NAME: Performance evaluation under downhole condition

TASK LEADER: Bailin Wu

OVERALL TIMEFRAME: July 2020 to November 2020

BACKGROUND: The materials passing the benchtop screening testing are evaluated further under simulated downhole pressure and temperature condition. The materials will be evaluated for their sealing capability for both planar microfractures and curved microannuli on model wellbore samples. The microannuli between cement and steel, and between cement and rock will be tested. The hydraulic conductivity and strengths of the sealed microfractures and microannuli will also be assessed.

TASK OBJECTIVES: To further evaluate performance of the selected CSIRO materials in sealing both microfractures and microannuli under realistic downhole pressure and temperature condition.

TASK OUTPUTS AND SPECIFIC DELIVERABLES: Suitable materials are identified for their capability to seal both planar microfractures and microannuli under downhole pressure and temperature condition. Recommendation is made for further evaluation using full size well model prior to field trial.

Task 4

TASK NAME: Final report

TASK LEADER: Bailin Wu

OVERALL TIMEFRAME: 1 December 2020 to 30 December 2020

BACKGROUND: The final report will describe the experimental results for bench top screening tests and the evaluation tests under the downhole pressure and temperature condition, the strengths of the sealed microfractures and microannuli, ranking of the CSIRO materials for their suitability in sealing planar microfractures and microannuli.

TASK OBJECTIVES: To document the experimental methods and results from the study

TASK OUTPUTS AND SPECIFIC DELIVERABLES: Final report with detailed description on the methods and results from the study, and the recommendations for further study prior to field trial.

Project Gantt Chart

Task	Task Description	Task Leader	Sep-19	Oct-19	Nov-19	Dec-19	Jan-20	Feb-20	Mar-20	Apr-20	May-20	Jun-20	Jul-20	Aug-20	Sep-20	Oct-20	Noc-20	Dec-20
1	Literature review and performance criteria	Bailin Wu																
2	Bench top screening & evaluation	Bailin Wu																
3	Performance evaluation under downhole condition	Bailin Wu																
4	Final report	Bailin Wu																

8. Technical Reference Group

A range of subject matter experts from industry (including Santos, Origin and Pangaea) and government (including DENR and DPIR) will be invited to participate in the technical reference group. The group will have strong levels of experiences on drilling and completions of gas wells, well cementing and well integrity.

9. Communications Plan

Stakeholder	**Objective**	**Channel** (e.g. meetings/media/factsheets)	**Timeframe** (Before, during at completion)
Traditional Owner communities	To pursue relations with Traditional Owner communities (via cultural monitors)	Engagement with TO communities – as a wider context as part of CSIRO communications (considered mutually beneficial)	Ongoing
Government and Industry	To facilitate a deeper understanding of research findings and implications for policy, programs, planning, and other initiatives	Knowledge transfer sessions and through stakeholder workshops and meetings.	From commencement of project and with updates as they come to hand.
Regional Community/Wider public	To communicate project objectives and key messages from the research	Fact sheets (including development of one at commencement of project which will explain the objective of the project – this will be updated periodically as project progresses). Project progress reported on GISERA website to ensure transparency for all	From commencement of project and with updates as they come to hand. As required.

		stakeholders including regional communities. Participation in roadshows, community workshops and meetings and other engagements where appropriate. Maps and visuals - Key findings communicated with the use of maps and visual cues incorporated.	As required Towards completion
Regional Community/ Wider public, Government, Scientific community and Industry	To provide a comprehensive review report documenting current industry practice in repairing defects in primary cementing, also documenting properties and performance of the identified candidate CSIRO materials	Literature review	September 2019
Regional Community/ Wider public, Government, Scientific community and Industry	To provide a detailed description on the methods and results from the study, and the recommendations for further study prior to field trial.	Final Report	At completion
Industry	Awareness of the technical approach	SPE conference	End of 2020

10. Budget Summary

Expenditure	2019/20	2020/21	2021/22	Total
Labour	$202,993	$124,151	$0	$327,144
Operating	$24,500	$20,000	$0	$44,500
Subcontractors	$0	$0	$0	$0
Total Expenditure	**$227,493**	**$144,151**	**$0**	**$371,644**

Expenditure per Task	2019/20	2020/21	2021/22	Total
Task 1	$80,338	$0	$0	$80,338
Task 2	$147,156	$0	$0	$147,156
Task 3	$0	$133,395	$0	$133,395
Task 4	$0	$10,755	$0	$10,755
Total Expenditure	**$227,493**	**$144,151**	**$0**	**$371,644**

Source of Cash Contributions	2019/20	2020/21	2021/22	Total
Federal Government (37%)	$84,172	$53,336	$0	$137,508
NT Government (10%)	$22,749	$14,415	$0	$37,164
Origin Energy (10%)	$22,749	$14,415	$0	$37,164
Santos (10%)	$22,749	$14,415	$0	$37,164
Pangaea (8%)	$18,199	$11,532	$0	$29,732
Total Cash Contributions	**$170,620**	**$108,113**	**$0**	**$278,733**

In-Kind Contributions	2019/20	2020/21	2021/22	Total
CSIRO (25%)	$56,873	$36,038	$0	$92,911
Total In-Kind Contributions	**$56,873**	**$36,038**	**$0**	**$92,911**

	Total funding over all years	Percentage of Total Budget
Federal Government Investment	$137,508	37%
NT Government Investment	$37,164	10%
Origin Energy	$37,164	10%
Santos	$37,164	10%
Pangaea Resources	$29,732	8%
CSIRO Investment	$92,911	25%
TOTAL	**$371,644**	**100%**

Task	Milestone Number	Milestone Description	Funded by	Start Date (mm-yy)	Delivery Date (mm-yy)	Fiscal Year Completed	Payment $ (excluding CSIRO contribution)
Task 1	1.1	Literature review & brainstorm session	GISERA	Sept-19	Jan-20	2019/20	$60,254
Task 2	2.1	Bench top screening & evaluation	GISERA	Feb-20	Jun-20	2019/20	$110,367
Task 3	3.1	Performance evaluation under downhole condition	GISERA	Jul-20	Nov-20	2020/21	$100,046
Task 4	4.1	Final report	GISERA	Dec-20	Dec-20	2020/21	$8,066

11. Intellectual Property and Confidentiality

Background IP (clause 11.1, 11.2)	**Party**	**Description of Background IP**	**Restrictions on use (if any)**	**Value**
	CSIRO	Hybrid Inorganic Polymers Systems. US Patent 7771688B2		
	CSIRO	Method for chemically absorbing to carbonate surfaces. International Publication Number WO2013/091023A2		
	CSIRO	Chemistry for fines fixing and water control, International patent application PCT/AU2017/050870		
Ownership of Non-Derivative IP (clause 12.3)	CSIRO			
Confidentiality of Project Results (clause 15.6)	Project results will not be confidential			
Additional Commercialisation requirements (clause 13.1)	Not applicable			
Distribution of Commercialisation Income (clause 13.4)	Not applicable			
Commercialisation Interest (clause 1.1)	**Party**		**Commercialisation Interest**	
	CSIRO		Not applicable at this stage	
	Origin Energy		Not applicable at this stage	
	Santos		Not applicable at this stage	
	Pangaea Resources		Not applicable at this stage	

12. References

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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
28/07/2020	Delays as a result of COVID-19 Pandemic restrictions.	Milestone 2 extended by 2 months to Aug-20.	
28/09/2020	Delays as a result of COVID-19 Pandemic restrictions, resulting in extended Stage 4 lock down in Melbourne.	Milestone 3 and 4 extended by 2 months to February 2021	
30/06/2021	Closure of laboratory facilities during COVID-19 shutdown, and unavailability of material to construct specific equipment	Removal of milestone 3 and reduction associated budget	

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 Regional 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	Activities / Task Title (should match activities in impact pathway section)	Task Leader	Scheduled Start	Scheduled Finish	Predecessor
Task 1	Literature review and performance criteria	Bailin Wu	September 2019	January 2020	
Task 2	Bench top screening and performance evaluation	Bailin Wu	February 2020	June 2020	Task 1
Task 3	Performance evaluation under downhole condition	Bailin Wu	July 2020	February 2021	Task 2
Task 4	Final report	Bailin Wu	December 2020	February 2021	Tasks 1, 2 & 3

Project Schedule Report

Task 1

TASK NAME: Literature review and performance criteria

TASK LEADER: Bailin Wu

OVERALL TIMEFRAME: September 2019 – January 2020

BACKGROUND: Squeezing cement slurry has been a common operation to repair defects in primary cementing. However, such method has been proved ineffective in many cases in sealing minute fractures in the cement sheath and along the interfaces between the cement and casing or between the cement and formation rock. This review is to gain a better understanding on the current industry practices, operational requirements, the conditions that materials will need to tolerate, and any new materials the industry may be used to fix the problem.

In addition to the review, a brain storming session will be organised among the project team members and technical experts from industry and government to identify candidate materials for sealing microfractures /microannuli and to establish a set of material performance criteria.

TASK OBJECTIVES: To gain a good understanding on the current industry practices; to establish performance criteria that are required for new materials to meet; and to identify candidate CSIRO materials

TASK OUTPUTS AND SPECIFIC DELIVERABLES: A comprehensive review report documenting current industry practice in repairing defects in primary cementing, also documenting properties and performance of the identified candidate CSIRO materials for other applications

PROGRESS REPORT:

The literature review *Sealant technologies for remediating cement-related oil and gas well leakage* has been completed and is available for viewing on the GISERA website.

Task 2

TASK NAME: Bench top screening & evaluation

TASK LEADER: Bailin Wu

OVERALL TIMEFRAME: February 2020 to June 2020

BACKGROUND: The identified candidate materials will be evaluated for their performance in sealing microfractures in a bench top setup in ambient condition. The planar fractures will be formed by shimming up two flat plates (rock, cement, steel, or perspex) with a variety of fracture apertures. Their performance will then be evaluated and compared with the baseline performance of the Portland cement.

TASK OBJECTIVES: To screen the candidate materials for their suitability in sealing planar microfractures prior to more elaborated performance evaluation under downhole condition

TASK OUTPUTS AND SPECIFIC DELIVERABLES: Short listed materials for further evaluation under downhole pressure and temperature condition.

PROGRESS REPORT: This milestone is now complete

- Approximately 25 bench top fracture sealing experiments are completed, two of them under elevated temperature (70 deg C)

- A novel apparatus for evaluating shear bonding strength on sealed fractures has been developed, installed within an existing Instron loading frame, and calibrated
- Approximately 10 permeability measurements on selected sealed fracture samples have been completed
- Approximately 10 shear bonding strength tests on selected sealed fracture samples have been completed
- Based on the results of sealing experiments, permeability, shear bonding strength of sealed fractures, one geopolymer formulation and one thermal activated polymer resin are shortlisted for further evaluation under simulated downhole conditions in Task 3 (next task).

Task 3

TASK NAME: Performance evaluation under downhole condition

TASK LEADER: Bailin Wu

OVERALL TIMEFRAME: July 2020 to 28 February 2021

BACKGROUND: The materials passing the benchtop screening testing are evaluated further under simulated downhole pressure and temperature condition. The materials will be evaluated for their sealing capability for both planar microfractures and curved microannuli on model wellbore samples. The microannuli between cement and steel, and between cement and rock will be tested. The hydraulic conductivity and strengths of the sealed microfractures and microannuli will also be assessed.

TASK OBJECTIVES: To further evaluate performance of the selected CSIRO materials in sealing both microfractures and microannuli under realistic downhole pressure and temperature condition.

TASK OUTPUTS AND SPECIFIC DELIVERABLES: Suitable materials are identified for their capability to seal both planar microfractures and microannuli under downhole pressure and temperature condition. Recommendation is made for further evaluation using full size well model prior to field trial.

PROGRESS REPORT: This milestone will no longer proceed.

Task 4

TASK NAME: Final report

TASK LEADER: Bailin Wu

OVERALL TIMEFRAME: 1 December 2020 to 28 February 2021

BACKGROUND: The final report will describe the experimental results for bench top screening tests and the evaluation tests under the downhole pressure and temperature condition, the strengths of the sealed microfractures and microannuli, ranking of the CSIRO materials for their suitability in sealing planar microfractures and microannuli.

TASK OBJECTIVES: To document the experimental methods and results from the study

TASK OUTPUTS AND SPECIFIC DELIVERABLES: Final report with detailed description on the methods and results from the study, and the recommendations for further study prior to field trial.

PROGRESS REPORT: This milestone is complete.

The final report titled Advancing new fracture sealing materials to assist mitigating fugitive gas emission from well casings has been publicly released and is now available on the GISERA website.