

# South Australia Assessment of Leigh Creek Energy UCG Trial Proposal

Energy Resources Division

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Government  
of South Australia

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# Contents

<b>Executive Summary .....</b>	<b>3</b>
<b>1.0 About this document.....</b>	<b>6</b>
<b>2.0 Approval process .....</b>	<b>7</b>
<b>3.0 The Leigh Creek Energy proposal .....</b>	<b>9</b>
3.1 History .....	9
3.2 Site geology and hydrogeology .....	10
3.2.1 Overburden hydraulic conductivity.....	11
3.2.2 Connectivity with Great Artesian Basin.....	12
3.2.3 Regional water wells.....	14
3.3 Composition of produced gases and liquids.....	15
<b>4.0 Additional information .....</b>	<b>17</b>
4.1 Assessment of overburden formation properties.....	17
4.2 Geomechanical assessment .....	19
<i>Results</i> .....	20
4.3 Geophysical assessment .....	23
4.4 Independent expert opinion.....	28
<b>5.0 Issues raised during the consultation period .....</b>	<b>30</b>
5.1 Air and water quality impacts .....	30
5.1.1 Air quality monitoring .....	31
5.1.2 Site contamination .....	31
5.1.3 Groundwater assessment and monitoring .....	32
5.1.4 SEO requirements for air and water quality impacts.....	32
5.2 Linc Energy Chinchilla Trial.....	33

5.3	Aboriginal heritage matters .....	36
5.3.1	SEO requirements for Aboriginal heritage matters.....	37
5.4	Public and rehabilitation liabilities.....	37
5.5	Independent Review of UCG in Scotland, UK.....	38
5.6	Independent Expert Scientific Committee referral .....	39
<b>6.0</b>	<b>Recommendation and further information .....</b>	<b>39</b>
<b>Appendix A: Independent Review of Site Suitability and Subsurface Risks for the Proposed Leigh Creek Energy UCG Demonstration Plant.....</b>		<b>41</b>

## Executive Summary

Leigh Creek Energy has proposed a trial underground coal gasification (UCG) plant at Leigh Creek, within the old mine site. UCG is also referred to as in-situ gasification (ISG), for an explanation of UCG see FAQ brochure on the Department of the Premier and Cabinet - Energy Resources Division (DPC-ERD) web site<sup>1</sup>.

This proposed demonstration plant will involve the establishment of a single gasifier chamber and associated above-ground infrastructure to produce synthesis gas (commonly referred to as syngas) for a short period of time (approximately 2-3 months). The trial will test both the syngas composition and process performance. The results will inform a possible commercial development.

This report details the Department of the Premier and Cabinet - Energy Resources Division's (DPC-ERD) review of the Environmental Impact Report and other information to assess this application.

### Approval process

The review was undertaken as part of Stage 2 of the three-stage approval process under the *Petroleum and Geothermal Energy Act 2000* (PGE Act) that all prospective operators must submit to. These stages are:

1. Licensing: Stage 1 approval grants exclusive rights to an area but does not grant rights to undertake on-ground activities.
2. Environmental Impact Report (EIR) assessment and Statement of Environmental Objectives (SEO) approval: In this stage a draft SEO is prepared on the basis on an EIR. The draft SEO identifies the environmental objectives and conditions that the licensee will be required to achieve to ensure it addresses the risks identified in the EIR. Both the EIR and draft SEO for the Leigh Creek project were the subject of for public consultation. Stage 2 approval is only granted when all relevant issues raised through this public consultation process are addressed.
3. Activity notification and approval: The Stage 3 process requires submission and approval of technical and operational plans in consultation and technical input from co-regulatory bodies such as the Environmental Protection Agency (EPA) and the Department of Environment and Water (DEW). Also notification of intentions to undertake a regulated activity to all relevant landowners. After Stage 3 approval, on-ground activities can begin.

During the Stage 2 consultation process (16 January to 28 February 2018) a number of issues were raised by government and the wider public in a total of 102

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<sup>1</sup> [Frequently Asked Questions brochure on UCG, Department of Premier and Cabinet, South Australia, 2018](#)

submissions. These submissions are available on the DPC-ERD's environmental register<sup>2</sup>, with identities of individuals suppressed for the purpose of confidentiality. Leigh Creek Energy responded to all of these submissions and submitted its revised EIR to the DPC-ERD on 3 April 2018.

### **Key concerns from public consultation**

The key concerns raised in the consultation process were:

- potential contamination of ground water and impacts to local air quality, and in turn potential threats to public health at the nearest township, Copley;
- matters relating to Aboriginal heritage in the Leigh Creek area; and
- concerns regarding the Linc Energy project at Chinchilla in Queensland.

#### *Air and water quality impacts*

Public concerns were expressed regarding the potential of uncontrolled releases of Chemicals of Potential Concern (COPCs) into both the air and ground water.

To ensure no unintended releases of COPCs, Leigh Creek Energy must adhere to the following SEO requirements if they are to be granted Stage 3 approval:

- Monitoring to ensure:
  - No sustained change to background groundwater quality at the boundary of the gasifier buffer zone;
  - No loss of gasification products to the surface or subsurface environment via pre-existing drill holes and/or transmissive geological features; and
  - No sustained increases in levels of COPC's in soil vapour monitoring wells.
- Maintenance of well integrity to prevent loss of gasification products to the surface or subsurface environment;
- Reduction of air pollution and greenhouse gas emissions to as low as reasonably practical; and

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<sup>2</sup> For public submissions: [http://petroleum.statedevelopment.sa.gov.au/\\_data/assets/pdf\\_file/0005/313097/20180301\\_-\\_All\\_Public\\_Submissions\\_incorporated\\_redactions\\_completed.pdf](http://petroleum.statedevelopment.sa.gov.au/_data/assets/pdf_file/0005/313097/20180301_-_All_Public_Submissions_incorporated_redactions_completed.pdf);

For Government submissions: [http://petroleum.statedevelopment.sa.gov.au/\\_data/assets/pdf\\_file/0006/313098/20180409\\_-\\_LCK\\_Government\\_Submissions\\_All\\_Incorporated.pdf](http://petroleum.statedevelopment.sa.gov.au/_data/assets/pdf_file/0006/313098/20180409_-_LCK_Government_Submissions_All_Incorporated.pdf)

- Remediation and rehabilitation of operational areas to agreed standards.

#### *Aboriginal heritage matters*

The Adnyamathanha Traditional Lands Association Native Title Body voiced its strong opposition to the project on the grounds that the proposed location of the demonstration plant forms part of an area of land that is of vital significance to the Adnyamathanha people.

These concerns have been addressed in the final SEO, which stipulates that to be granted Stage 3 approval, Leigh Creek Energy must avoid damage, disturbance or interference to Aboriginal heritage sites, objects and remains by undertaking risk mitigation strategies or obtaining prior approval under relevant legislation.

#### *.Linc Energy Chinchilla trial*

Much concern has been expressed by members of the public regarding the current charges laid against Linc Energy Ltd and the former company CEO and Executives for allegedly failing to ensure their ISG project at Chinchilla complied with the Queensland *Environmental Protection Act 1994*.

DPC-ERD investigated the circumstances surrounding this situation and are satisfied that the scenario at Leigh Creek is vastly different to that at Chinchilla, in terms of geology and operations. This understanding was confirmed by the independent opinion sought by DPC-ERD from the subject matter expert to the QLD Department of Environment and Science in the investigation and prosecution of Linc Energy.

### **Recommendation**

DPC-ERD recommends Stage 2 approval, based on:

- its detailed review of the EIR and draft SEO;
- Leigh Creek Energy's responses to comments submitted as a result of the public consultation;
- an independent geotechnical assessment commissioned by the DPC-ERD to evaluate the geological integrity and the potential for transmissive faults to the surface within the overburden rock stratum above the targeted coal within which the proposed gasification trial will be undertaken;
- advice from world recognised UCG experts from the Lawrence Livermore National Laboratories in the United States; and
- an independent opinion from the UCG subject matter expert to the QLD Department of Environment and Science in the investigation and prosecution of Linc Energy.

## 1.0 About this document

This document summarises the main findings of the Energy Resources Division within the Department of the Premier and Cabinet (DPC-ERD) in relation to the potential issues and environmental risks associated with the Leigh Creek Energy (LCK) underground coal gasification (UCG) trial proposal.

Information from the Environmental Impact Report (EIR)<sup>3</sup> submitted by Leigh Creek Energy and additional information acquired by the DPC-ERD as the lead regulator of this project was used along with public submissions and advice from other co-regulatory agencies and independent geo-mechanics and UCG experts to inform the approval process for the Statement of Environmental Objectives (SEO)<sup>4</sup> under the *Petroleum and Geothermal Energy Act 2000* (PGE Act) for this proposal.

This document sets out the approval process (section 2.0) and provides a summary of the Leigh Creek Energy proposal (section 3.0). A summary of the supplementary information collected in the assessment of this proposal (section 4.0) and issues raised in public consultation (section 5.0) is also presented, along with the final recommendation from DPC-ERD (section 6.0).

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<sup>3</sup> [Leigh Creek Energy PEL650 EIR ISG Demonstration Plant](#)

<sup>4</sup> [Leigh Creek Energy PEL650 SEO](#)



## 2.0 Approval process

At the outset, it is important to clarify the process for regulatory approval under the PGE Act.

The approval process consists of three stages<sup>5</sup>:

1. Licensing
2. Environmental impact report (EIR) assessment and approval of statement of environmental objectives (SEO) and conditions that the proponent will need to demonstrably achieve
3. Activity notification and approval.

### *Stage 1: Licensing*

The licensing stage involves the licence application and grant process, where a proponent applies for the appropriate licence to give them the right to undertake regulated activities within a licence area. A licence granted under this stage is not a right to do any on-ground activities; rather it is simply an exclusive right to an area within which the licensee can then apply for approval to undertake activities. Only parties with the adequate demonstrated financial and technical capacity to invest and safely conduct regulated activities are eligible to become PGE Act licence holders.

On-ground activities can only be undertaken subsequent to approvals granted under Stages 2 and 3, which address the environmental and operational aspects of activities.

LCK was granted its exploration licence, PEL 650, in November 2014. Stage 2 and 3 approvals was granted to LCK only for the purpose of undertaking exploration and appraisal drilling to evaluate the geological and geotechnical nature of the coal resource and characteristics of encapsulating rocks. The results of the appraisal drilling and subsequent information in response to the comments received from the public consultation process informed the final EIR and SEO for LCK's pilot UCG trial submitted on 4 April 2018.

### *Stage 2: Statement of environmental objectives assessment and approval*

The grant of a PGE Act licence does not provide an automatic entitlement to land access to conduct operations. Rather, regulated activities under the PGE Act (under section 96) may not be carried out unless an approved SEO is in place, prepared on the basis of an EIR. The EIR describes the specific features of the environment where the activities will take place and identifies all potential impacts, the risks relating to the activity and the proposed risk-mitigation strategies. The SEO identifies

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<sup>5</sup> See the DPC-ERD's approvals flowchart: [Exploration and Production Flowchart September 2015](#)

the environmental objectives and conditions (assessment criteria) that the licensee will be required to achieve to ensure it addresses the risks identified in the EIR.

Examples of the information and potential impacts that the EIR and final SEO are expected to address include:

- Impacts and disturbance to Aboriginal sites;
- Impacts on aquifers, including pressure and contamination;
- Impacts on groundwater use;
- Contamination of surface water and shallow groundwater and soil;
- Impacts on native vegetation and native fauna and stock;
- Disturbance to existing land uses (e.g. within reserves under the *National Parks and Wildlife Act 1972*, pastoral land, etc.) or to local heritage features;
- Air pollution and greenhouse gas emissions;
- Impacts on the health and wellbeing of the local community; and
- Remediation and rehabilitation requirements.

### *Stage 3: Activity notification and approval*

Once the relevant SEO, in this case the SEO pertaining to the 2 to 3-month UCG trial, is gazetted in accordance with Part 12 of the PGE Act, the proponent has to proceed to the third and final approval stage to obtain approval to commence on-ground activities. This entails submission to DPC-ERD for evaluation and approval of all technical and engineering designs relating to this activity to ensure the design and intended construction and monitoring of all surface facilities, pipelines, underground gasification chamber and wells are in accordance with recognised industry standards and fit for the purpose for achieving the requirements of the final approved SEO objectives and conditions. This Stage 3 approval process will also include, evaluation and approval of the licensee's Environmental, Health and Safety Management Systems, monitoring plans, shut down and decommissioning plans, environmental assessments, environmental management plans, rehabilitation plans, cultural heritage assessments and emergency response procedures that are critical to the demonstrable achievement of the SEO objectives.

Under Stage 3, the licensee is also required to notify all relevant landowners about its intentions to undertake any regulated activity and to clearly describe pursuant to the requirements under Part 10 of the PGE Act, the nature of its activities to be undertaken, the potential impacts those activities may have on the landowner and the right of the landowner to dispute such entry including any compensation that may arise from such activities.

## 3.0 The Leigh Creek Energy proposal

### 3.1 History

The potential for underground coal gasification (UCG) in the Leigh Creek Coal mine in the Telford Basin has been of interest since the early 1980s. In March 1983, a preliminary investigation into potential target areas for UCG within the Leigh Creek Telford Basin<sup>6</sup> was undertaken. The investigation was based predominately on a three-week desk-top review of existing data and one field trip.

In October to December 1984, a drilling program was undertaken by the then Department of Mines and Energy and supervised by Golder Associates<sup>7</sup> to quantify through acquisition of field data, roof and floor rock strength and permeability, existing water levels and coal seam permeability and continuity. The main purposes of the program were to establish:

- continuity of the Main Series coal seam to give confidence to proposed gasification panel layouts, and to inferred coal reserves; and
- basic strength and permeability characteristics of the coal seam and overburden and under burden rocks to be used in assessing the consequences of panel development on water flows and rock stability.

On the basis of this initial work, Leigh Creek Energy (LCK) applied for and was granted exploration licence PEL 650 in November 2014 for the specific purpose to undertake a preliminary demonstration trial to ascertain the technical feasibility for UCG within the Telford Basin. Since July 2016, LCK has undertaken a program of exploratory and appraisal drilling solely for the acquisition of geo-technical and hydrological data to inform their environmental impact and technical assessment for the potential of undertaking such a trial.

LCK completed its appraisal drilling (under an existing relevant SEO) in December 2017 to evaluate the geological and geotechnical nature of the coal resource as well as the characteristics of encapsulating rocks. The results of the appraisal drilling and subsequent information in response to the comments received from the public consultation process (16 January to 28 February 2018) informed the final EIR<sup>8</sup> and SEO<sup>9</sup> for LCK's pilot UCG trial submitted on 4 April 2018.

A number of issues were raised by government and the wider public in a total of 102 submissions. These submissions are available on the Energy Resources Division's

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<sup>6</sup> March 1983, Murray-Wallace, Report Book Number 83/34:

[Underground Gasification of Inaccessible Leigh Creek Coal Measures](#)

<sup>7</sup> [Golder May 1985 Leigh Creek UCG geotech investigation](#)

<sup>8</sup> [Leigh Creek Energy PEL650 EIR ISG Demonstration Plant](#)

<sup>9</sup> [Leigh Creek Energy PEL650 SEO](#)

environmental register<sup>10</sup>. LCK responded to these submissions accordingly and submitted its revised EIR document to DPC-ERD on 3 April 2018. (See Section 7.4 and Appendix E and F of their EIR<sup>11</sup>.)

### 3.2 Site geology and hydrogeology

The proposed LCK pre-commercial-demonstration trial site is situated in the Telford Basin, also known as Lobe B, which contains the old Leigh Creek Coal mine site. As with a number of other basins, such as Copley Basin or Lobe A as it is also known in the context of the Leigh Creek Coal mine, the Telford Basin sits within the Adelaide Geosyncline fractured rock province (Figure 1), a siltstone, shale and limestone basement rock also known as the Adelaidean meta-sediments of the Adelaide Geosyncline<sup>12</sup>. The Telford Basin location is surrounded on all sides by fractured rock aquifers. Historical, pre-mining, groundwater flow direction within the Telford Basin have been permanently altered with the construction of the Leigh Creek open pit coal mines. The direction of groundwater flow in the region surrounding the open pits is towards the open pits.

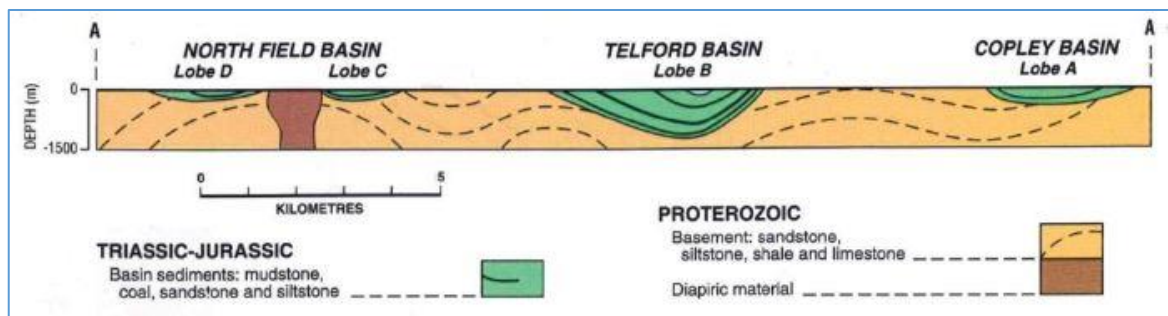


Figure 1: Cross-section of Telford, Copley and other Basins within the Adelaidean Basement<sup>13</sup>

A closer look of the Telford Basin cross-section (Figure 2) reveals the overburden and underlying mudstones and interbedded upper series and main series coals.

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<sup>10</sup> [Public Submissions; Government submissions](#)

<sup>11</sup> [Leigh Creek Energy PEL650 EIR ISG Demonstration Plant](#)

<sup>12</sup> [Pages 98 to 101, The Geology of South Australia, Geological Survey of South Australia, Bulletin 54](#)

<sup>13</sup> [Page 100, The Geology of South Australia, Geological Survey of South Australia, Bulletin 54](#)

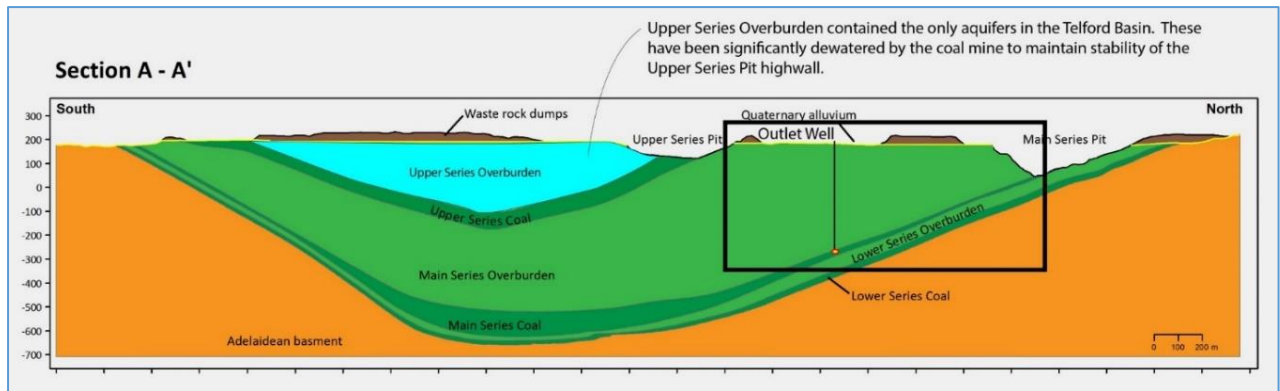


Figure 2: South-North cross-section of Telford Basin<sup>14</sup>

### 3.2.1 Overburden hydraulic conductivity

Flow (recovery) testing and pressure (injection) testing in various well bores over the years<sup>15</sup> within the Telford Basin (summarised in Table 1) reveals that the hydraulic conductivity within the Main Series Overburden (MO) and Lower Series Overburden (LO) mudstones can range between about  $1 \times 10^{-11}$  to  $9.5 \times 10^{-8}$  meters per second (1.3E-3 to 10 milli-darcies). As a measure of scale, a typical permeability of cement is less than 1E-3 milli-darcies<sup>16</sup>.

Table 1: Measured Hydraulic Conductivities within Telford Basin

Source	Drill Hole	Strata	K (meters/second)	K (milli-darcies) <sup>17</sup>
AWE 2017	Playford 5	MO	1.27E-11	1.32E-3
AWE 2017	Playford 6	MC/LO	1.74E-11	1.80E-3
Golder, 1985	BH3964	MO	1.00E-09	0.10
Golder, 1985	BH3967	MO	4.00E-09	0.42
SMEC 2017-18	Playford 2	LO	7.80E-09	0.81
SMEC 2017-18	Playford 2	MO	9.10E-09	0.95
SMEC 2017-18	Playford 2	MO	1.44E-08	1.5
SMEC 2017-18	Playford 2	MO fault	1.94E-08	2.0
SMEC 2017-18	Playford 2	MO	2.14E-08	2.2
SMEC 2017-18	Playford 2	MO	9.49E-08	9.9

Legend: Permeability (K); Main Series Coal (MC); Main Series Overburden (MO); Lower Series Overburden (LO)

It is important to note that the higher order of magnitude numbers sourced from the SMEC 2017–18 pressure (injection) tests conducted in Playford 2 are a result of the

<sup>14</sup> Page 71, [Leigh Creek Energy PEL650 EIR ISG Demonstration Plant](#)

<sup>15</sup> 1) AWE, 2017 Appendix A, [Leigh Creek Energy PEL650 EIR ISG Demonstration Plant](#);

2) SMEC 2017-18, Playford 2 Water Pressure testing Results, Appendix B, page 11, ibid

3) [Golder May 1985 Leigh Creek UCG geotech investigation](#)

<sup>16</sup>

[https://www.researchgate.net/publication/251711781\\_Interface\\_debonding\\_as\\_a\\_controlling\\_mechanism\\_for\\_loss\\_of\\_well\\_integrity\\_Importance\\_for\\_CO\\_2\\_injector\\_wells](https://www.researchgate.net/publication/251711781_Interface_debonding_as_a_controlling_mechanism_for_loss_of_well_integrity_Importance_for_CO_2_injector_wells)

<sup>17</sup> milli darcy equal to 1 thousandth of a darcy

well bore effects, where increased permeability is created within two to three borehole radii due to the destructive process of drilling. This has the potential to substantially increase the permeability immediately around the borehole, in turn resulting in higher injection rates through this enhanced permeability zone. A more representative magnitude of permeability or hydraulic conductivity is more likely to be in the range of the numbers obtained from the AWE-2017 and Golder, 1985 longer term recovery (flow) tests.

Nevertheless, the observed magnitude of the milli-darcy hydraulic conductivity numbers within the Main Series Overburden (MO) indicate a very tight and in some parts almost impermeable aquitard. This would reasonably infer that the overburden and underburden mudstone, respectively above and below the coal, is not conducive to significant flow of either water or gas away from any proposed underlying gasification chamber.

### 3.2.2 Connectivity with Great Artesian Basin

The Adnyamathanha – Telford Basin 2 million surface geology map (Figure 3) gives the reader a plan view of how the geology in the vicinity of the Leigh Creek coal mine appears. The coloured shapes represent the name and distribution of the individual rock units present now at the Earth's surface. The legend on the right side of the map lists all the rocks that are seen in the map in order from youngest to oldest.

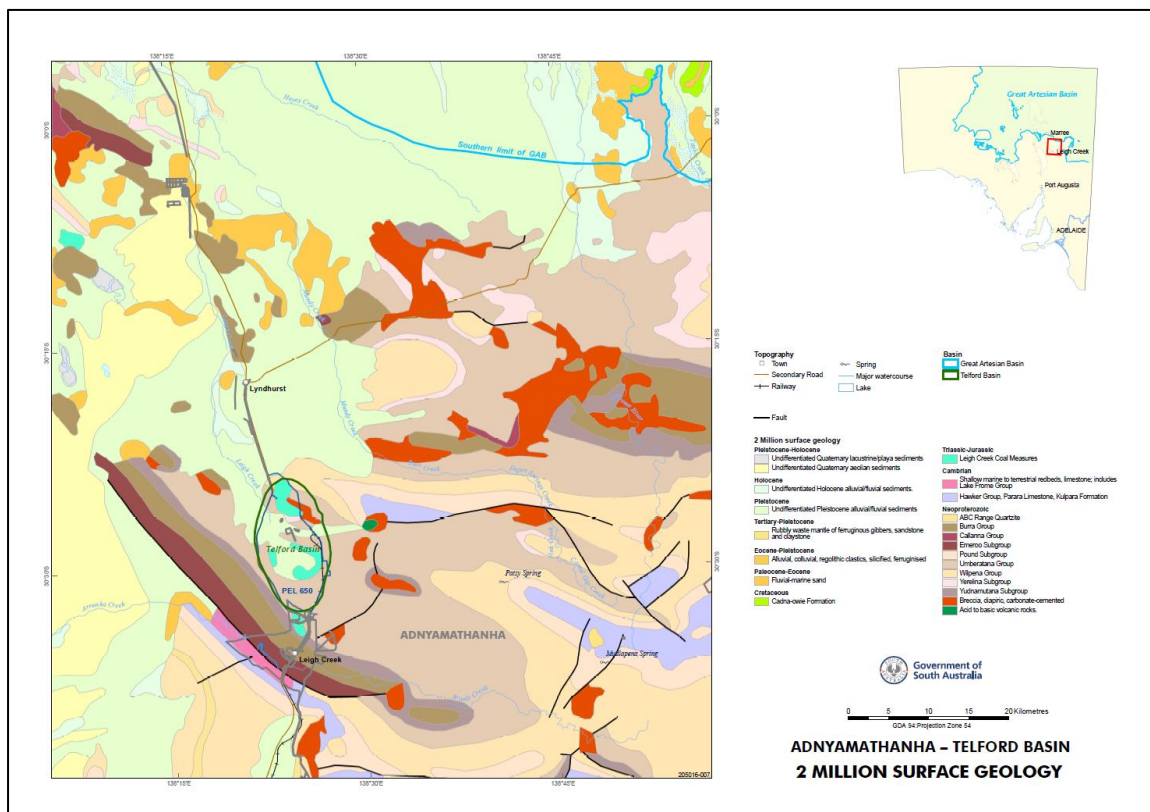


Figure 3: Adnyamathanha – Telford Basin 2 million surface geology map a plan view of the geology in the vicinity of the Leigh Creek coal mine



The bright green shapes in the centre of the map represent the Leigh Creek Coal Measures and associated mudstones located in the Telford Basin. These rocks were deposited between 240 and 150 million years ago during the Triassic to Jurassic periods. They were deposited directly on top of a group of rocks represented in various shades of brown often referred to as the Adelaidean meta-sediments.

The Adelaidean meta-sediments are Neoproterozoic in age, meaning that they were deposited between 700 and 540 million years ago. The purple and pink coloured rocks that can be seen near to but not intersecting the Leigh Creek Coal Measures were deposited directly above the Adelaidean meta-sediments during the Cambrian period 540 to 500 million years ago.

Around 515 to 500 million years ago, prior to the Leigh Creek Coal Measures being deposited, the deeply buried Adelaidean and Cambrian rocks were deformed and faulted by an event known as the Delamerian Orogeny. 'Orogeny' is a geological term meaning 'mountain building'. As a result of this event, the Adelaidean and Cambrian rocks in the Ranges and in the vicinity of the mine were folded, tilted and fractured and began to exhume or unearthen and then subsequently began to erode.

In the 250 million years between the Cambrian rocks and the Leigh Creek Coal Measures being deposited, thick sequences of other rocks were also deposited above the Cambrian all across the region. However, throughout this same period of time the Flinders Ranges themselves were being exposed and eroded, so the younger rocks which were deposited above the Cambrian everywhere else were either never deposited in the Ranges or in the Leigh Creek mine area, or were completely eroded away before the Coal Measures were deposited. By the time the Leigh Creek Coal Measures were deposited, the Ranges already existed as a significant mountain range. The full area over which the coals themselves were deposited is not completely known as they have also been eroded through time, and are now only present within small, discrete, isolated basins including the Telford Basin.

The rocks that host the Great Artesian Basin aquifer were deposited after the Leigh Creek Coal Measures, around 150 to 70 million years ago during the Jurassic and Cretaceous periods. These rocks are present under the plains to the north and east of the northern Flinders Ranges in the Eromanga Basin, but do not occur as far south as the Leigh Creek mine area or anywhere within the Ranges. If they were ever present in the Ranges or the mine area, they have been completely eroded away. As a result, the Leigh Creek Coal Measures in the Telford Basin do not anywhere coincide with the GAB and there is no practicable connection between them.

Concerns expressed in some submissions regarding the connectivity of the Telford Basin and the underlying Adelaidean units to GAB are therefore unfounded. The GAB boundary is well north of Lyndhurst as shown by the blue line in the Telford Basin surface geology map (Figure 3).

### 3.2.3 Regional water wells

Figure 4 shows the location of recorded water wells (note: not all of these wells are operational) surrounding the Telford Basin. Regional groundwater flow in the fractured rock aquifers hosted within the Adelaidean basement is towards the northwest consistent with the regional topography. The majority of the wells presented in Figure 4 are located up-gradient (opposite direction to groundwater flow direction) of the Telford Basin. Well depths (outside those drilled for the coal mine) range from around 10 m up to 200 m deep. Well yields are variable ranging from less than 0.5 litres per second (L/s) to over 10 L/s. Higher yields are likely to be associated with secondary porosity developed through localised fracturing and faulting in the rock matrix.

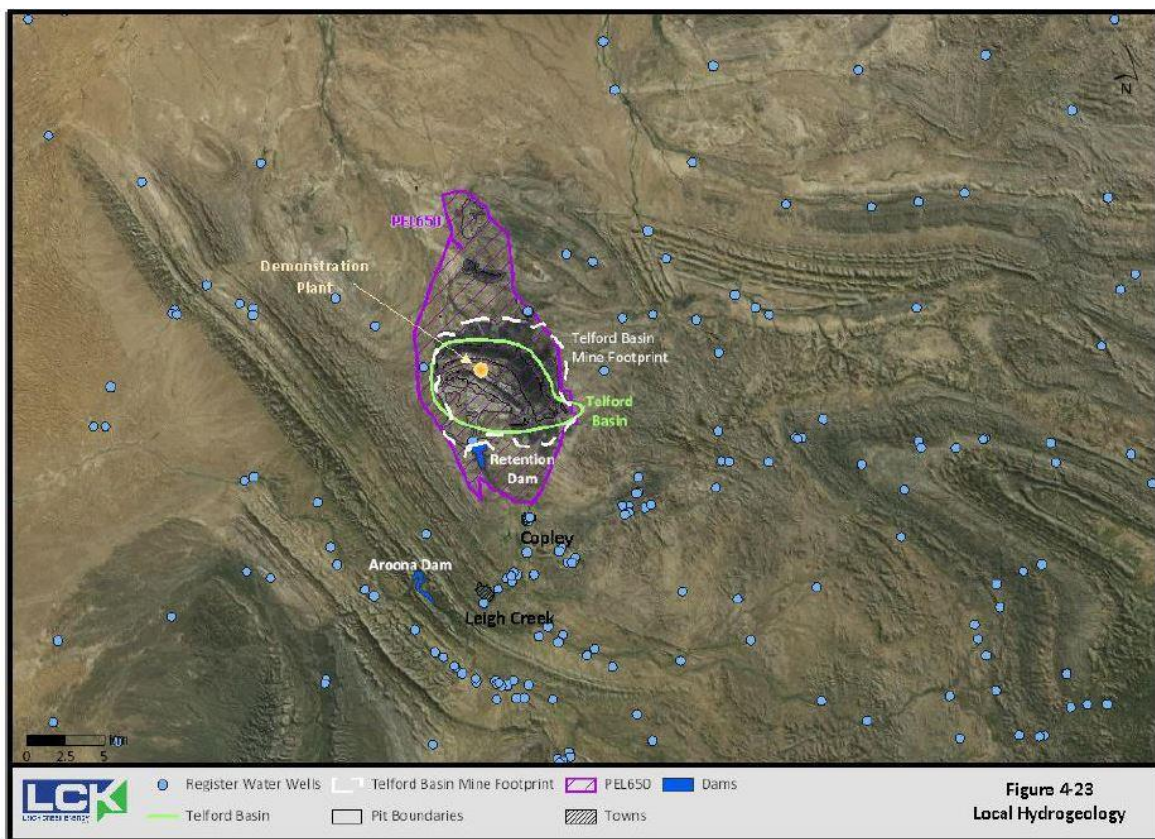


Figure 4: Water wells (blue dots) within Leigh Creek Region<sup>18</sup>

<sup>18</sup> Page 93, [Leigh Creek Energy PEL650 EIR ISG Demonstration Plant](#)



### 3.3 Composition of produced gases and liquids

Table 2, extracted from the LCK EIR, shows typical components found in the gas and liquid phases.

Table 2: Typical components found in the gas and liquid phases as adapted from LLNL's Camp and White<sup>19</sup>

Phase	Group	Details
Gas phase components (non-condensables)	Major syngas constituents (concentrations of up to tens of percent by volume)	<ul style="list-style-type: none"> <li>• carbon monoxide</li> <li>• carbon dioxide</li> <li>• hydrogen</li> <li>• water</li> <li>• methane</li> <li>• nitrogen (can be more than 40% in systems where air is injected)</li> </ul>
	Minor syngas constituents (approx. 1% or less by volume)	<ul style="list-style-type: none"> <li>• light hydrocarbons (range from ethane and ethylene compounds to volatile condensables (e.g. hexane and toluene)</li> <li>• hydrogen sulphide</li> <li>• ammonia</li> <li>• trace species</li> </ul>
Condensable organic components ('tars')	Hydrocarbons	<ul style="list-style-type: none"> <li>• paraffinic hydrocarbons</li> <li>• olefinic hydrocarbons</li> <li>• aromatic hydrocarbons (e.g. benzene, toluene, ethylbenzene, xylene, naphthalene)</li> <li>• mixed aromatic-aliphatic ring structures (e.g. tetralin, fluorine, indane)</li> </ul>
	Oxygen-containing organics	<ul style="list-style-type: none"> <li>• phenolics</li> <li>• dihydroxybenzenes</li> <li>• trihydroxybenzenes</li> <li>• furans</li> <li>• ketones (e.g. acetone, butanone, cyclopentanone)</li> </ul>
	Nitrogen-containing compounds	<ul style="list-style-type: none"> <li>• aliphatic amines</li> <li>• nitrogen-containing heterocyclic organics</li> <li>• nitrogen-containing amines</li> <li>• aromatic amines (e.g. aniline)</li> </ul>
	Sulphur-containing compounds	<ul style="list-style-type: none"> <li>• carbonyl sulphide</li> <li>• methyl mercaptan</li> <li>• sulphur-containing heterocyclic aromatics (e.g. thiopen, benzothiophenes)</li> </ul>

As illustrated in Figure 5, the condensable organic material typically is recovered through separation processes at the surface and disposed of either through thermal destruction or other appropriate means. The gas phase material is what is referred to as the syngas stream and is used as either power generation fuel directly into burners and/or for the production of chemical products.

<sup>19</sup> [Underground Coal Gasification: An Overview of Groundwater Contamination Hazards and Mitigation Strategies March 2015](#)

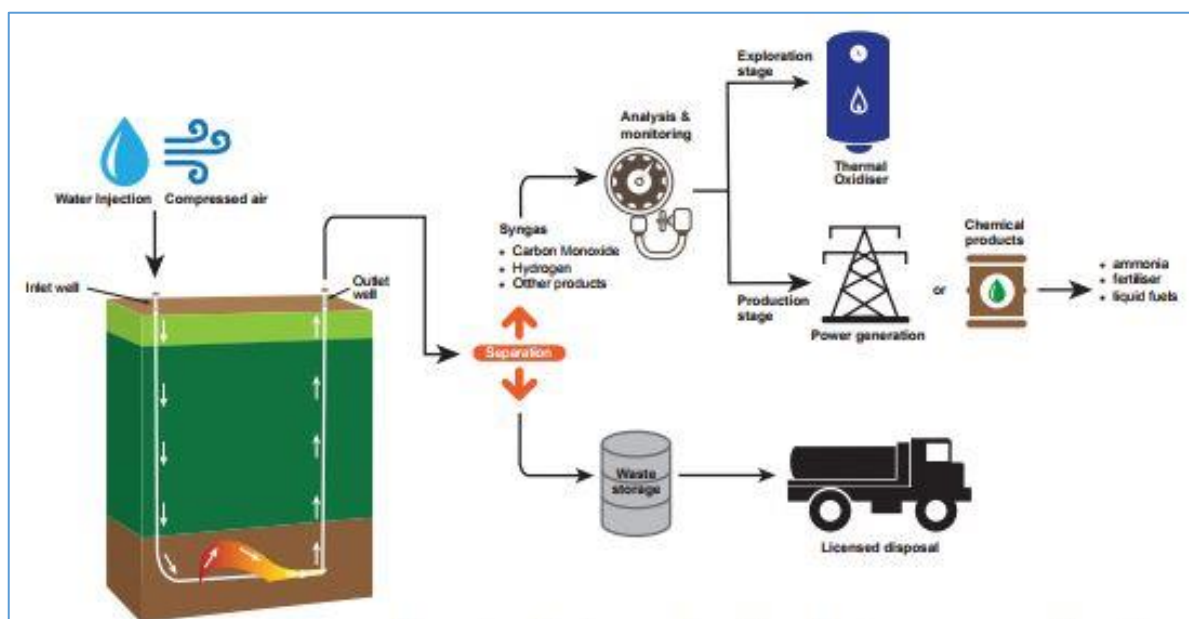


Figure 5: UCG Process Flow Diagram<sup>20</sup>

Typical compositions of syngas as experienced from trials in the United States are provided in Table 3. In the case of the LCK pre-commercial demonstration plant, all gas and liquid phase materials will be thermally destroyed, with the exception of short periods of cold venting during initiation or shutdown of the chamber or emergency situations.

Table 3: Tonnage-weighted average dry product gas composition (mol%) of almost all U.S. field tests done on bituminous or sub-bituminous coal from Hanna 1 through Rocky Mountain 1<sup>21</sup>.

Species	Air-blown	Oxygen-steam
N <sub>2</sub> + Ar	53.87%	2.30%
O <sub>2</sub>	0.20%	0.00%
H <sub>2</sub>	13.49%	33.37%
CH <sub>4</sub>	4.50%	9.82%
CO	10.69%	9.82%
CO <sub>2</sub>	15.99%	42.08%
C <sub>2</sub> + HCs	0.45%	1.00%
NH <sub>3</sub> + NO <sub>x</sub>	0.60%	1.30%
S oxides	0.20%	0.30%

<sup>20</sup> [Frequently Asked Questions brochure on UCG, Department of Premier and Cabinet, South Australia, 2018](#)

<sup>21</sup> [A Review of Underground Coal Gasification Research and Development in the United States, David W. Camp Lawrence Livermore National Laboratory, June 2017](#)

## 4.0 Additional information

### 4.1 Assessment of overburden formation properties

The Lawrence Livermore National Laboratories (LLNL) in the USA advised DPC-ERD of the favourable and unfavourable characteristics for locating a suitable UCG site (Table 4)<sup>22</sup>, noting that site selection is very important, and that the permeability field strongly affects the amount of gas escape and contaminant transport to protected groundwater.

*Table 4: Favourable and unfavourable characteristics for locating a UCG site (from Camp and White presentation provided at UCG workshop in Brisbane on 7–8 Nov 2013)*

Favourable	Unfavourable
<ul style="list-style-type: none"><li>• Valuable/protected groundwater is non-existent or shallow</li><li>• Thick low-permeability strata above cavity</li><li>• Low dip, anticline</li><li>• No/few/small fractures, joints or transmissive faults</li><li>• Mapped and properly closed boreholes</li><li>• Strong rock supports economically-wide cavity with minimal vertical collapse</li></ul>	<ul style="list-style-type: none"><li>• Valuable/protected groundwater close to UCG</li><li>• No robust low-permeability strata in between</li><li>• Dip, syncline</li><li>• Fractures, joints, transmissive faults</li><li>• Unmapped or improperly closed boreholes</li><li>• Weak rock – excessive vertical collapse for economical cavity width</li></ul>

The characteristics listed in Table 4 are consistent with the attributes identified and recommended by the Independent Scientific Panel, established by the Queensland Government to evaluate, analyse and assess various technical and environmental factors associated with the three UCG trials in Queensland<sup>23</sup>, for the future selection of appropriate sites for UCG. Namely:

- Coal seam at sufficient depth to ensure that any potential environmental contamination can be predicted to have minimal environmental consequences. With deeper coal, there are fewer useable aquifers in proximity to proposed UCG chambers.
- Sealing horizons overly the gasification chamber, such that there is a very low probability of gases and liquids generated within the UCG chamber moving into valuable aquifers or to the surface.
- Coal seam sufficiently thick to sustain gasification with reasonable likelihood of economic viability.
- Rank of coal should be lignite to non-swelling bituminous coal.
- Hydraulic head sufficient to contain efficient gasification. In other words, maintaining the pressure in the gasification chamber below the surrounding aquifer pressure. This will allow water to enter the gasification chamber, as

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<sup>22</sup> [Camp & White, LLNL; IEA 3rd UCG Workshop, Brisbane, 7–8 November 2013; Revised 9 May 2014](#)

<sup>23</sup> [Independent Scientific Panel Report on Underground Coal Gasification. Pilot Trials. June 2013, page 16](#)

water is an essential component of the reaction in the gasification process from which hydrogen is generated. The lower pressure in the chamber is also essential to ensure all reaction by-products in particular all chemicals of potential concern (COPC's) are contained within the chamber.

- Coal seam capped by impermeable rock.
- Target coal located so that there is sufficient thickness between the target coal seam/measure and any valuable aquifer higher up the geological succession.
- Sufficiently distant from rivers, lakes, springs and seeps to avoid contamination should chemical escape the cavity.
- Absence of faults or intrusions (near to the site) that may be pathways for the leakage of UCG generated gases and/or fluids. This is dependent on the size of the cavity.
- Sufficient distance from the nearest town and/or intensive surface infrastructure (e.g. irrigation or feedlots) and areas of significant environmental value (e.g. world heritage forests or wetlands) to avoid contamination should COPC's escape the cavity and to minimise impacts of odours.

DPC-ERD used these criteria in its assessment of early drafts of the EIR submitted by LCK. In consultation with the LLNL, DPC-ERD established that LCK's proposed UCG pre-commercial demonstration location within the Telford Basin was potentially favourable against most of these characteristics subject to addressing some salient uncertainties relating to characterising the:

1. presence or absence of flow paths from the proposed UCG chamber to valuable overlying aquifers and/or to the surface; or
2. susceptibility of rocks overlying the UCG chamber to faulting or fracturing, and the risk of initiating fractures or reactivating existing faults in response to UCG. Either reactivating or initiating faults and fracture zones could create flow paths from the proposed UCG chamber to valuable overlying aquifers and/or to the surface.

Figure 6 is a simple diagram of what is meant by transmissive gas and fluid flow paths from a UCG chamber. In response to these uncertainties, LCK gathered further geo-technical data including the presence or absence of any flow paths due to faults and/or fractures on the overlying overburden at the proposed UCG chamber site through the drilling of 3 additional wells. This data was then incorporated into the independent geophysical assessment undertaken by DPC-ERD as detailed under section 4.3.

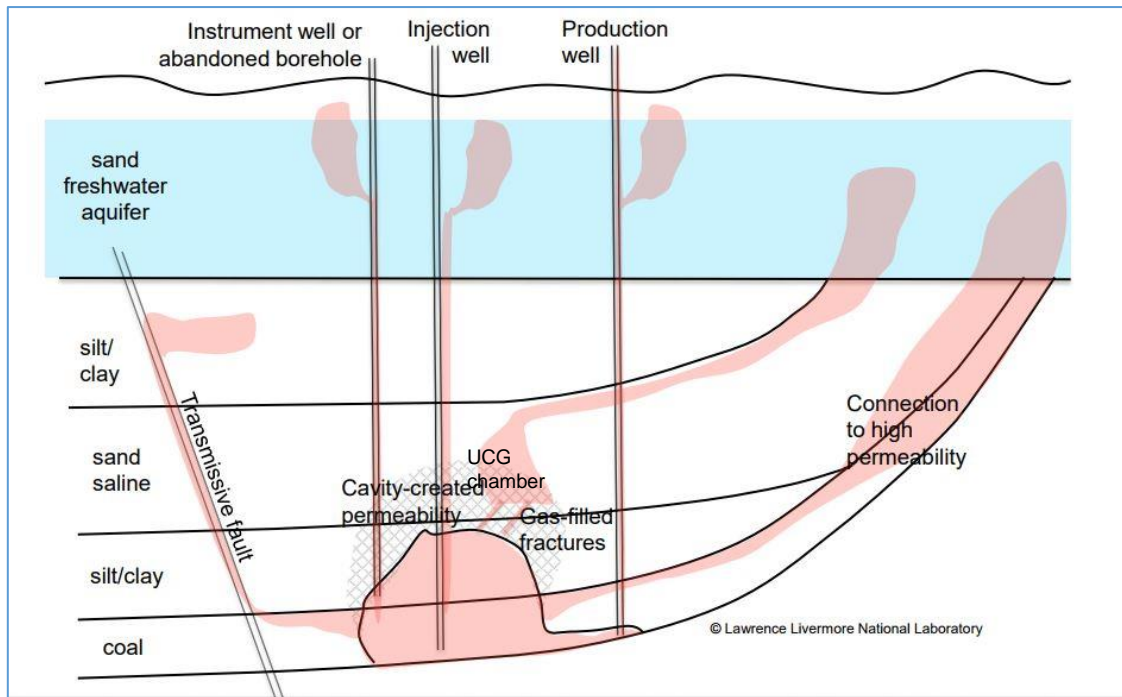


Figure 6: Potential natural (e.g. faults, high permeability strata and bedding planes) and man-made (e.g. poorly constructed wells) transmissive flow paths<sup>24</sup>

## 4.2 Geomechanical assessment

The DPC-ERD engaged Ikon Science<sup>25</sup> to conduct a geomechanical assessment of the proposed site utilising to assess the risk of creating new fractures or opening existing ones, which would allow the gas to move into the overlying Telford Gravels, a potential water table aquifer (although likely discontinues at the demonstration plant site due to dewatering of mine pits) and/or the surface.

Ikon Science investigated the strength of the rocks overlying the gasification chamber and assessed the likely operating limits with modelling.

The mechanical strength of the rocks was measured by:

- wellbore measurements of acoustic properties to define rock elasticity before fractures or faults evolve in response to force;
- wellbore measurements to define at what pressure rocks are susceptible to physical break-down (faulting and/or fracturing);
- images of boreholes to determine rock fabrics including but not limited to where boreholes are non-cylindrical – and have enlarged – and the orientation of that borehole enlargement, along with faults and fracture zones (strain features); and

<sup>24</sup> [Camp and White presentation at the 7-8 November 2013 UCG Brisbane workshop](#)

<sup>25</sup> [Geomechanical Model for Leigh Creek, South Australia Ikon Science, 19 January 2018](#)

- lab tests on wellbore rock samples that further characterise stress orientations and magnitudes that enable reliable predictions of faults and/or fracturing.

Ikon Science used these measurements to assess:

- the orientation of faults and fracture zones;
- the forces (stress) required to exceed measured rock strengths; and
- the relevance of existing fault and fracture zone orientation to the predictability of rocks to become susceptible to the reactivation of faults and fracture zones, and the potential for inducing new faults and/or fracture zones.

## *Results*

Ikon Science determined that the mudstone overlying the coal seam would develop fractures at pressures of 9,400 kPa (1363 psi) or above. The operating pressure for the gasification chamber will be 3,400 to 3,600 kPa (493 to 522 psi), well below the threshold value.

In summary, the findings revealed that the in-situ effective stress regime of the overburden mudstone is such that the likelihood of initiating any failure of the mudstone and/or reactivating any faults that may be present is highly unlikely. This is explained below and diagrammatically in Figure 7<sup>26</sup>.

Measurements of rock characteristics and the implications of rock characterisation are well-understood by relevant experts. Ikon Science is a relevant expert in the assessment of the properties and predictability of rocks to become susceptible to the reactivation of faults and fracture zones, and the potential for inducing new faults and/or fracture zones. Key measurements and assessment tools that determine the forces that can predictably cause rocks to fault and/or fracture include:

- Measurements of the mechanical strength of rocks. The information that was used by Ikon Science in its analysis included:
  1. wellbore measurements of acoustic properties to define rock elasticity before fractures or faults evolve in response to force;
  2. wellbore measurements to define at what pressure rocks are susceptible to physical break-down (faulting and/or fracturing);
  3. images of boreholes to determine rock fabrics including but not limited to where boreholes are non-cylindrical – and have enlarged – and the orientation of that borehole enlargement, along with faults and fracture zones (strain features); and
  4. lab tests on wellbore rock samples that further characterise stress orientations and magnitudes that enable reliable predictions of faults and/or fracturing.

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<sup>26</sup> [Geomechanical Model for Leigh Creek, South Australia Ikon Science, 19 January 2018](#)

- Assessment of the mechanical strength of rocks. Based on this information Ikon Science provided its assessment of:
  1. the orientation of faults and fracture zones;
  2. the forces (stress) required to exceed measured rock strengths; and
  3. the relevance of existing fault and fracture zone orientation to the predictability of rocks to become susceptible to the reactivation of faults and fracture zones, and the potential for inducing new faults and/or fracture zones.

Figure 7 characterise the susceptibility of rocks to reactivating existing faults and/or fracture zones and creating new faults and/or fracture zones. Such diagrams are used to plan construction designs to assure facility stability.

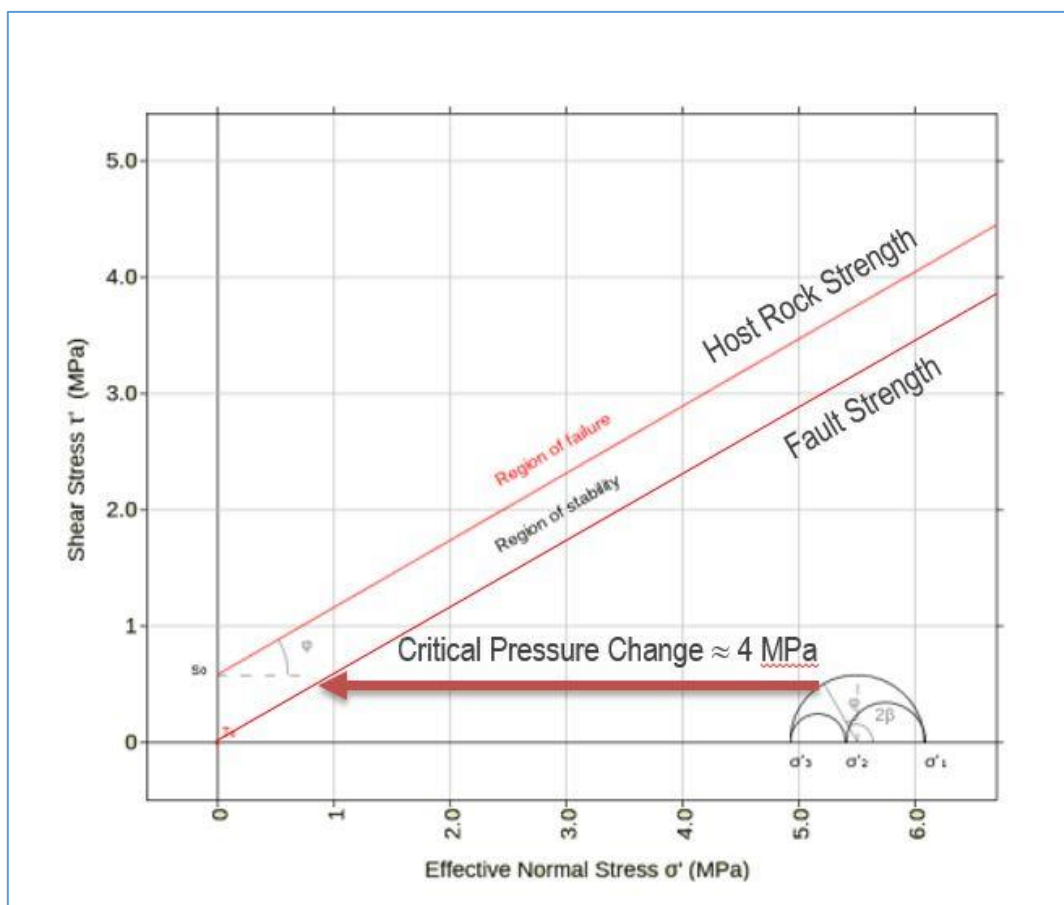


Figure 7: Ikon Science's diagram (page 7) showing relationship between sub-surface overburden stress and strength lines for rocks overlying the proposed pilot UCG chamber and the predictable measurements of subsurface stresses within the overburden rock depicted by the plotted semi-circles known as Mohr's circle.

The vertical (Y) axis on Figure 7 is from lower to higher shear force or stress acting on an angled plane in the rock. The horizontal (X) axis on Figure 7 is from lower to higher pull-apart (extension or normal) force or stress also known as the effective stress. Effective stress is the geological stress of the rock at that depth minus the pore pressure in the rock at that depth.



- The susceptibility of local rocks to faulting and/or fracturing is the left-most sloping line labelled 'Host Rock Strength (Stronger)'. This line is positioned per measurements of local rock properties.
- The susceptibility of local faults and/or fracture zones to reactivation (additional movement) the right-most sloping line labelled 'Fault Strength (Weaker)'. This line is positioned per measurements of local rock properties. This is the line representing the ratio of effective normal stress to shear stress for pre-existing faults and fracture zones becoming susceptible to reactivation. If the effective normal (pull-apart or extensional) stress is reduced, it reduces the amount of shear (scissors) stress that faults and fracture zones can withstand before reactivation. If stress on the 'host rock' is constant, and pore pressure increases, the probability increases for reactivating faults and fracture zones (for a constant shear stress).
- The half-circles represent measurements of subsurface forces within the overburden rock. These are a form of Mohr's circles<sup>27</sup>.

Figure 7 illustrates the tool for assessing whether or not controllable and monitored pressures within the proposed UCG chamber will be less than pressures that can predictably reactivate and/or create new faults and/or fracture zones in overlying rocks.

Ikon Science has independently determined the rock strength lines for both the mudstone (host rock) that overlies the proposed pilot UCG chamber and pre-existing faults are highly unlikely to be affected by planned and controllable operating conditions within LCK's proposed pilot UCG chamber.

Risks of UCG gases moving outside the pilot UCG chamber and the well(s) that penetrate the pilot UCG chamber can be mitigated with fit-for-purpose well construction and monitoring pressures to enable shut-down prior to pressures in the pilot UCG chamber exceeding the safe operating envelope. Real time monitoring of the pressures in and around the gasification chamber will be undertaken in accord with an approved monitoring and response plan as required by the approved Statement of Environmental Objectives for this trial. The pilot UCG chamber will be operating at a safe level below natural hydrostatic pressure within the coal, such that a critical pressure change is unlikely to be achieved<sup>28</sup>. This will be assured by the required real-time monitoring of pressure within the UCG chamber. Therefore, any risk of initiating any faults or fractures or reactivating any faults or fracture zones that may be present above the proposed gasification chamber is considered

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<sup>27</sup> For a relatively detailed description of Mohr's circles see: [https://en.wikipedia.org/wiki/Mohr%27s\\_circle](https://en.wikipedia.org/wiki/Mohr%27s_circle).

<sup>28</sup> The change in pressure per unit of depth, typically in units of pounds per square inch per foot (psi/ft) or kilopascals per metre (kPa/m). Pressure increases predictably with depth in areas of normal pressure. All evidence supports the location of the Leigh Creek UCG trial to be 'normally pressured'. The normal hydrostatic pressure rate of increase with depth (gradient) for freshwater is 0.433 psi/ft, or 9.792 kPa/m. For details – see: [http://www.glossary.oilfield.slb.com/en/Terms/h/hydrostatic\\_pressure.aspx](http://www.glossary.oilfield.slb.com/en/Terms/h/hydrostatic_pressure.aspx)



demonstrably as low as reasonably practicable under the expected operating conditions.

Separately, DPC-ERD's independent inspection of the drill core recovered from LCK's Playford 2A well drilled through the overlying mudstone revealed a mostly homogenous and consolidated formation in line with the acoustic borehole log interpretations from Playford 2 in Ikon Science's independent geo-technical analysis.

### *Implications*

It will be important to ensure that operating pressures are maintained below the fracturing threshold. This can be achieved by putting operating standards and monitoring in place to enable the gasification chamber to be shut down in advance of exceeding critical operating pressure. The monitoring and management plans to ensure that operating pressures will be maintained below this threshold will be developed and submitted to DPC-ERD for review and assessment in conjunction with the EPA and DEWNR as part of the Stage 3 approval process. Well design and construction will also contribute to maintaining safe operating pressures. Well designs demonstrating the well will be constructed to meet relevant industry standards and will be fit for purpose will also be submitted for DPC-ERD expert review and approval as part of the Stage 3 approval process.

## **4.3 Geophysical assessment**

DPC-ERD undertook its own internal evaluation of available geophysical data acquired through the drilling of wells Playford-2, 2A and 2B, along with data, reports and information acquired from Alinta Energy and the Government's mineral resources data archives to assess for the presence or absence of potential significant flow paths within the overburden formation above the gasification chamber,

The analysis revealed no significant features or potential leak paths within the overburden mudstone above the proposed location of the trial gasification chamber. The main source of data underpinning this conclusion was obtained from the three additional wells drilled by LCK at the request of DPC-ERD as shown in Figure 8 in both plan and cross-sectional view, Playford 2 labelled as DH5; Playford 2A (DH6) and Playford 2B (DH7).

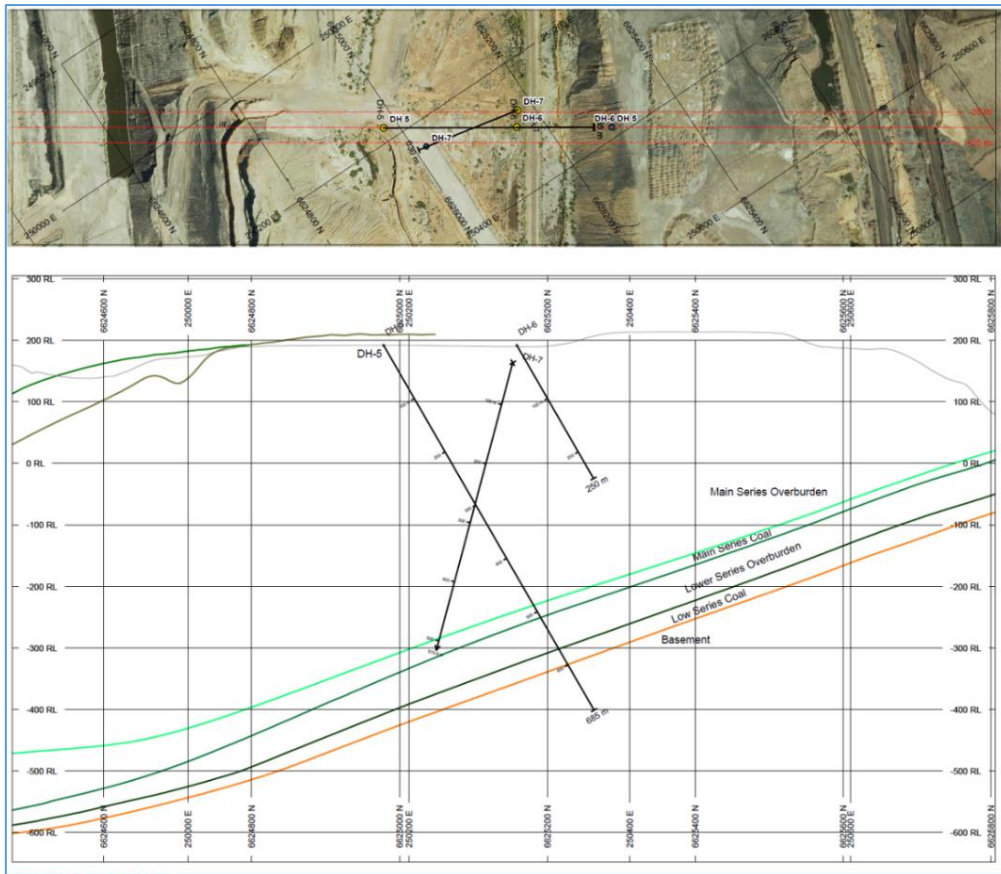


Figure 8: Location of Playford 2 (DH5); 2A (DH6) and 2B (DH7)

Significant structural features interpreted in wells Playford 2 and 2A from the bore hole televiewer (BHTV) logs, illustrated by the dark and light brown disks respectively, have been inferred to be the major fault known to exist within the Telford Basin (Figure 9).

Figure 10 illustrates the location of this major inferred fault, known as the master fault relative to the current wells drilled and the main series coal mine pit.

Figure 11 contains the cross-plots of the gamma ray, resistivity and sonic logs providing a cross-sectional view of the geology across the Playford 2B, 2 and 2 wells. This cross-sectional view illustrates the location of the inferred fault as shown by the red line and the offset of the main series coal observed between wells 2 B and 2 as shown by the dark grey colour.

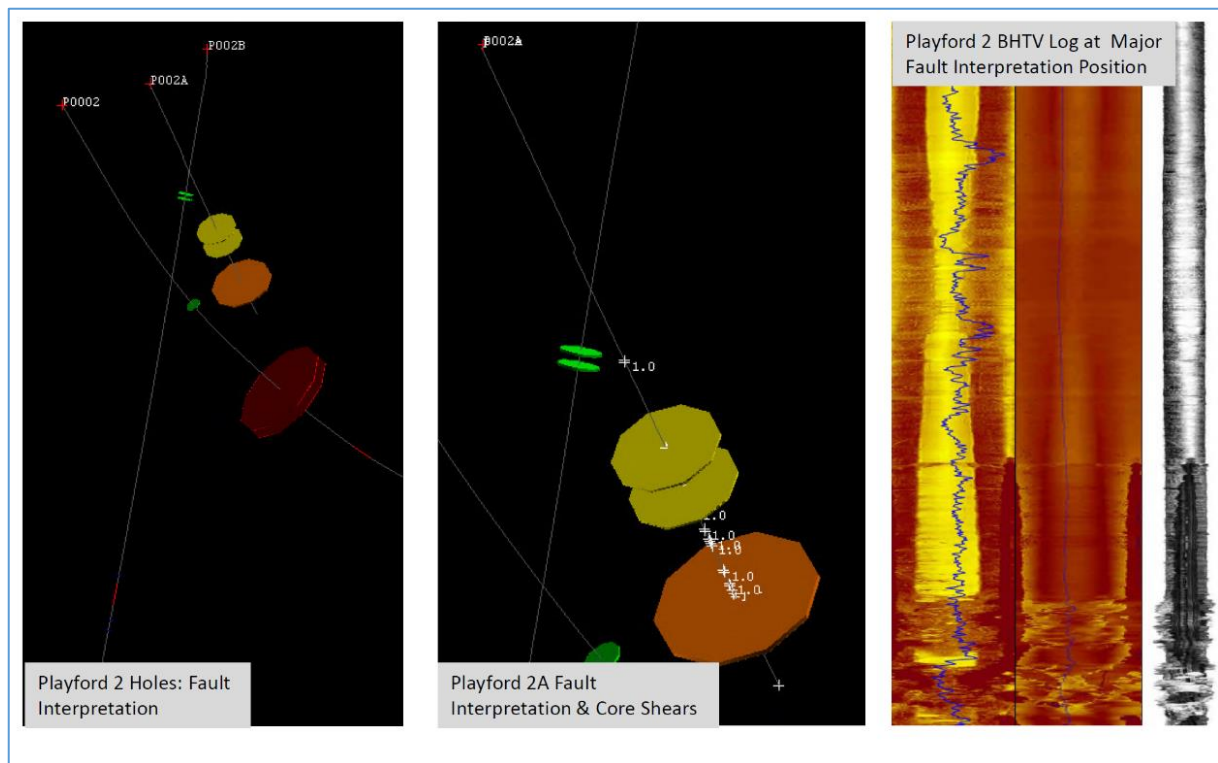


Figure 9: Inferred existence of major fault within Playford 2 and 2A from bore hole tele-viewer.

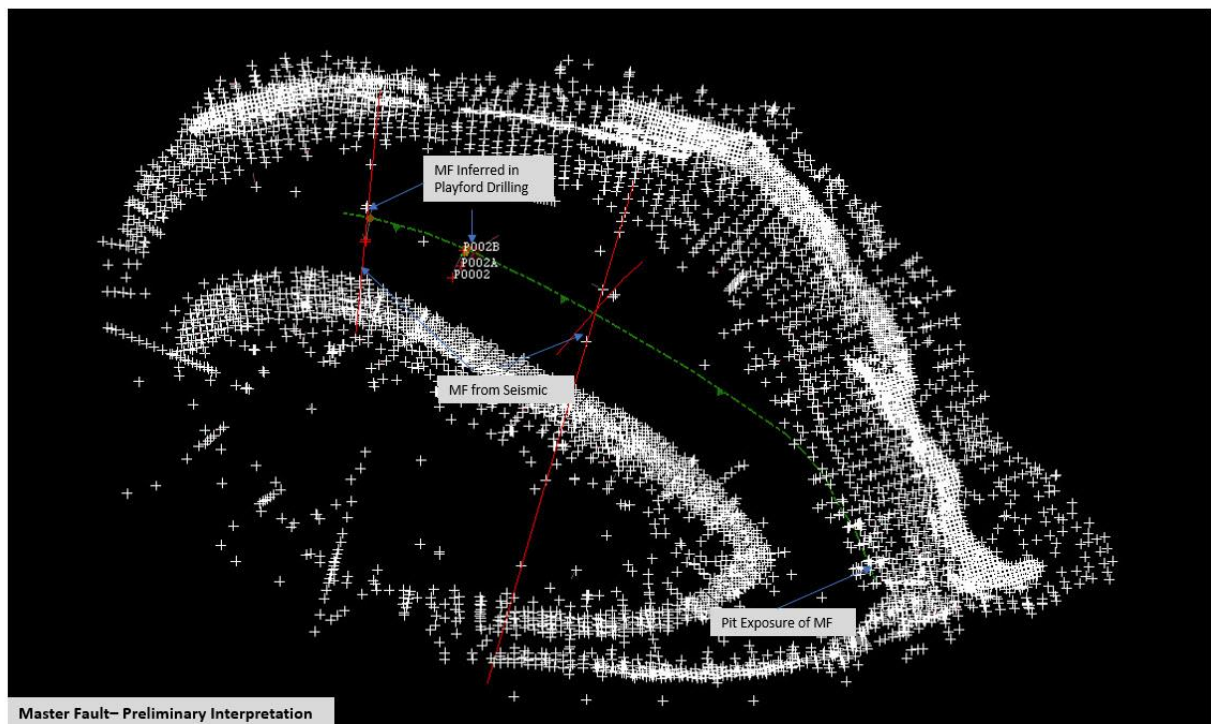


Figure 10: Plan view of the inferred Master Fault

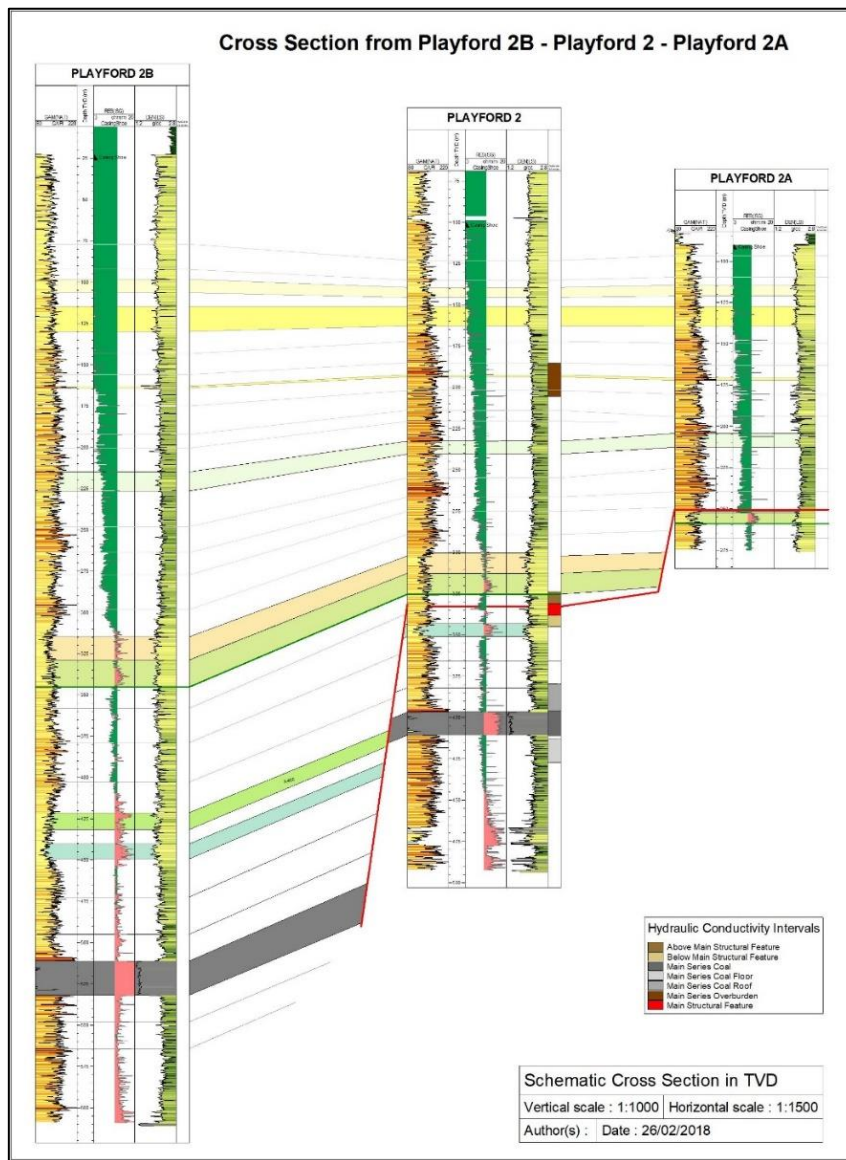


Figure 11: Inferred existence of Major Fault within Playford 2 and 2A.

Based on this interpreted information, it was important to understand whether the inferred fault constitutes a potential transmissive flow path through the overburden mudstone for any contaminants of potential concern (COPCs). To address this matter LCK undertook a number of hydraulic conductivity tests across this feature and the overburden in Playford 2. On the log plot of Playford 2 (Figure 11), the locations within the main series coals, overburden rock and within the structural feature (fault) where hydraulic conductivity tests were undertaken in this well are shown by the brown, light brown, grey and red blocks. The objective of these hydraulic conductivity tests was to evaluate the relative transmissivity of the structural feature (fault) to that of the overburden matrix rock and hence in turn whether it would be a potential transmissive pathway for COPCs. The results revealed that the measured hydraulic conductivity of this feature is of a magnitude consistent with that of the surrounding main series overburden rock (Figure 12).



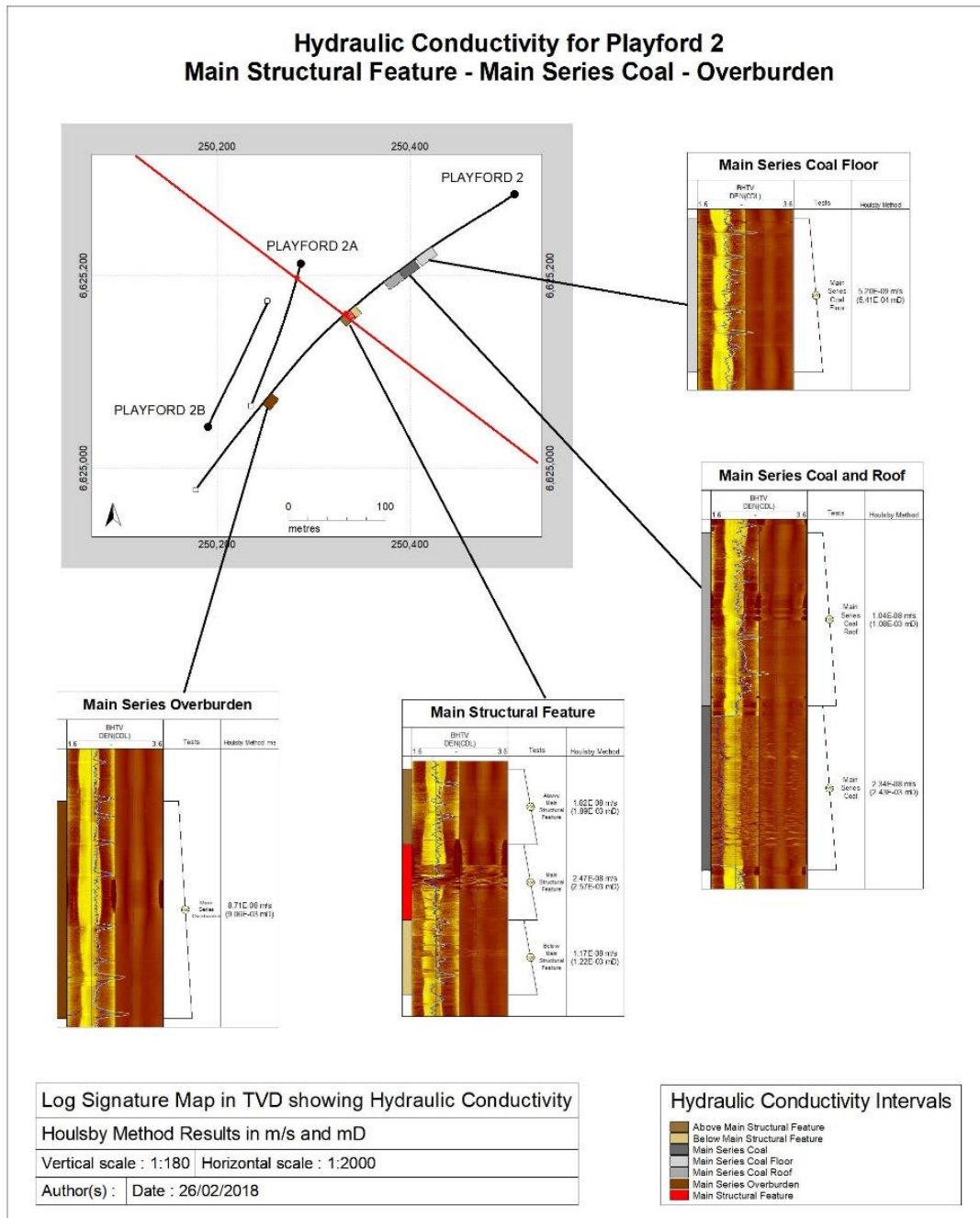


Figure 12: Measured Hydraulic Conductivities within Playford 2

Notwithstanding the relative consistency of the low hydraulic conductivity within the fault and the surrounding overburden rock matrix and the absence of any evidence from the drilling results of the likely presence of any other potential transmissive flow paths within the overburden, the gasifier location will be located at least 100 m from the inferred fault location. This buffer zone requirement whereby no sustained

change to background groundwater quality is specified as a preventative measure under objective 3 in the SEO<sup>29</sup>.

#### **4.4 Independent expert opinion**

DPC-ERD engaged Dr Gary Love to review the physical aspects of the subsurface at the LCK site that are primary factors in containment of the UCG process, and to provide an expert statement on the suitability of this site for the purpose of UCG. Dr Love is a recognised Australian expert in the field of UCG who amongst other credentials detailed in his expert statement report he has appraised numerous potential sites for UCG both in Australia and internationally. Since 2014, he has acted as a fact witness and subject matter expert to the Queensland Department of Environment and Science (formerly Department of Environment and Heritage Protection) in the investigation and prosecution of Linc Energy, and has given evidence in the committal and trial.

The review also considers relevant operational risk factors described in the EIR, specifically the approach to well design and the definition of the safe operating pressure envelope, and the Linc Energy Limited UCG program in Queensland and the relevance of that experience to the proposed LCK operation.

In summary, his findings detailed in his expert statement<sup>30</sup> (Appendix A) include:

##### *Environmental risks*

The review determined that the proposed demonstration plant site fulfils preferred criteria<sup>31</sup> to limit the primary risks associated with UCG. Suitable depth, very low formation permeabilities, robust geomechanical properties and physical separation from potential receptors, all combine to present a geological framework within which UCG could be contained with acceptable risk. The review considers residual containment risks around proximity to extensional faults in the basin as low based on geotechnical assessments carried out by both LCK and DPC-ERD.

##### *Operational risks*

The review also considered secondary risks associated with UCG containment related to operational activities, including induced fracture pathways, well leakage, and operation at pressures exceeding the prevailing hydrostatic formation pressure. The author notes that geotechnical studies have concluded that roof fracturing

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<sup>29</sup> Page 10, [Leigh Creek Energy PEL650 SEO](#)

<sup>30</sup> [Expert Statement of site suitability LCKE Project](#)

<sup>31</sup> [Moran, C.J., da Costa, J and Cuff, C. \(2013\). Independent Scientific Panel Report on Underground Coal Gasification Pilot Trials. Queensland Independent Scientific Panel for Underground Coal Gasification June 2013](#)

associated with goaf development<sup>32</sup> could extend up to five times the gasifier height, but given this is a relaxation feature post-cavity development, and that the overburden unit is itself of very low permeability, this is not likely to have material risk to the demonstration or to the longer term rehabilitation of the cavity.

Well leakage risk cannot be completely eliminated due to the temperature of the UCG process, and the casing stresses that may be induced through thermal cycling of the outlet well. However, the author notes that LCK has used leading practices with regards to UCG well design to minimise this risk, including the use of high temperature casing, premium gas-tight threads, high temperature cements, and high temperature well heads. Pressure testing of wells and running of cement bond logs as part of well construction practices will provide adequate assurance of well integrity.

Correct operating pressures are a risk factor for UCG, and the LCK demonstration project has a clear definition of the operating pressure guided by the installation of vibrating wire piezometers. The author notes that LCK has indicated an automated system may be used to ensure that pressures in the chamber remain below the surrounding formation pressure, which ensure that risk of gas loss and COPC excursion remains low. The formation breakover pressure of the overlying strata has been defined by independent assessment, and is more than twice the operating pressure nominated by LCK. As a result, the review considers the risk of fracturing due to pressurisation is low.

### *Linc Energy operation*

The environmental legacy of the Linc Energy Ltd UCG program in Queensland has been highlighted as a concern in stakeholder consultation for the LCK demonstration project (see section 5.2). The author believes it is unreasonable to draw an association between these projects due to material differences related to the site suitability, operational practices and the level of regulatory oversight. It is the author's opinion that the LCK project has presented robust science to clearly show a much lower risk than the Linc operation, and is focused on a transparent demonstration of environmental performance as a key step to commercialising its assets.

### *Conclusion*

In the opinion of the author, the Leigh Creek site represents one of the strongest opportunities for low risk commercial UCG anywhere in the world. On the merits of

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<sup>32</sup> A goaf is a part of a mine from which the mineral has been partially or wholly removed or the waste left in old workings.

the site suitability and operational assurances, the 2 to 3 month demonstration plant carries minimal risk and should be approved through the Stage 2 process.

## 5.0 Issues raised during the consultation period

### 5.1 Air and water quality impacts

Public concerns were expressed regarding the potential of uncontrolled releases of Chemicals of Potential Concern (COPCs). One of the main aims of the EIR and SEO process is to demonstrate how the licensee can assure that the gasification process and its products (syngas) remain contained within the underground chamber to begin with and within the production wells and surface facilities prior to their total destruction within the oxidiser. The critical receptors identified in the EIR include the ground water and surrounding air quality, hence the need to ensure the objectives pertaining to these receptors detailed in the SEO are achieved.

Critical to addressing this aim as detailed in the EIR and SEO is the requirement for development and implementation of fit-for-purpose monitoring plans which can measure in real time pressure and temperature at and adjacent to the underground gasification chamber and water quality and air quality in terms of COPCs both sub-surface and surface. Before any Stage 3 approval is granted, subject to the final Stage 2 approval and gazettal of the SEO for the 2 to 3 month trial, LCK will be required to submit as part of the Stage 3 approval process these monitoring plans which will entail DPC-ERD in consultation with its co-regulatory colleagues in particular the EPA and DEWNR and if required external independent expert review and endorsement.

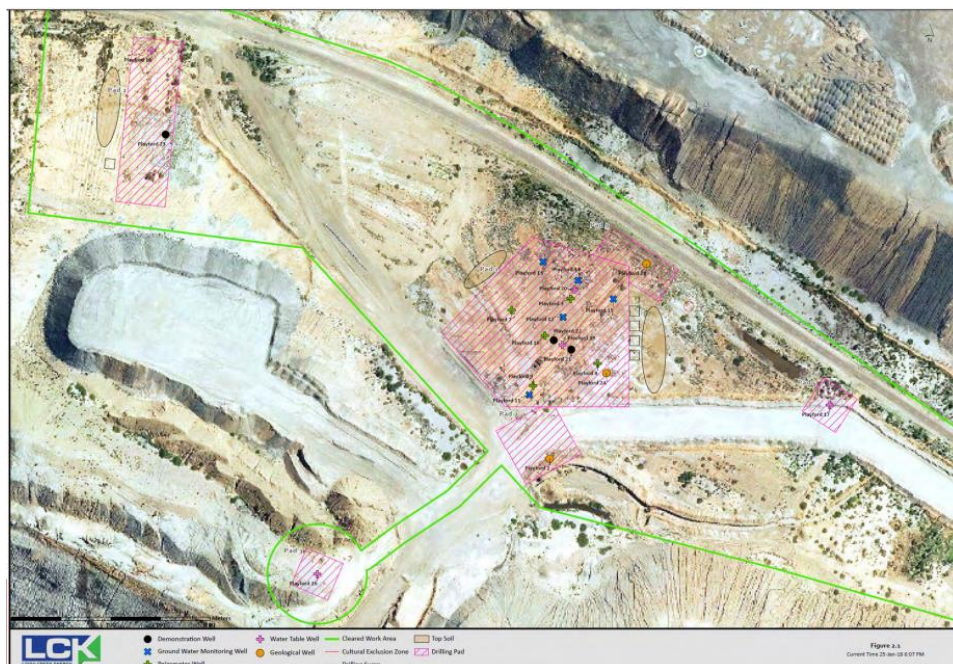


Figure 13: Proposed monitoring well locations at the proposed UCG demonstration plant location



Figure 13 provides an indication of the proposed groundwater quality, pressure, temperature and soil vapour monitoring well locations in relevance to the location of the proposed UCG demonstration plant. A critical component of these plans will be the need to detail the actions required to be undertaken in the case of detected abnormal readings outside the critical operating range that will ensure safe operation against the requirements stipulated in the approved SEO objectives and assessment criteria.

To assist in appeasing community concerns with potential uncontrolled COPC releases, DPC-ERD in keeping with its transparent reporting requirements against SEO obligations, will upload on its web site the finalised Groundwater Monitoring Plan (GMP) along with all real time measurements against the critical parameters detailed in the approved GMP.

#### **5.1.1 Air quality monitoring**

The EPA confirmed its satisfaction with LCK's response to the EPA's comments on the EIR regarding the adequacy of the emission dispersion modelling and the conservativeness of the methodology adopted<sup>33</sup>. The EPA noted that the LCK approach to deriving the most appropriate meteorological data for the modelling was well thought out and appropriately applied. Given the large separation from sensitive receivers, particularly with regards to public health standards, the EPA accepted LCK's response as an adequate resolution of its initial question.

The EPA encouraged that with regards to the nuisance impact of emissions to the Copley community, particularly as a result of potential H<sub>2</sub>S emissions, that LCK should provide Copley residents with some form of explanatory note that alerts them the potential intermittent odour that they will detect on occasion and that the predictions are that the concentration H<sub>2</sub>S will be significantly below the public health standards and not of any health concern. In response, DPC-ERD requested this requirement be included in the SEO under Objective 10.

#### **5.1.2 Site contamination**

The EPA confirmed that it is satisfied with LCK's response to its comments regarding the site contamination issue in the EIR<sup>34</sup>. Furthermore, a critical component of ensuring any long-term potential of site contamination is avoided, is the ability to demonstrate effective decommissioning of the gasifiers. This will be assessed by DPC-ERD with the EPA as part of the Stage 3 approval process.

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<sup>33</sup> Appendix F: [Summary of Government Agency Consultation Submissions, Leigh Creek Energy, Environmental Impact Report, ISG Demonstration Plant, 3<sup>rd</sup> April 2018](#)

<sup>34</sup> *ibid*

### 5.1.3 Groundwater assessment and monitoring

The EPA confirmed that it was satisfied with LCK's responses to the majority of its comments on the groundwater assessment matters detailed in the EIR. The EPA also advised that it was satisfied to defer addressing all remaining questions that it has<sup>35</sup> to the Stage 3 approval process assessment of the Groundwater Monitoring Plan (GMP). The EPA advised its involvement at this stage will allow it to have confidence that the proposed operations can be and will be monitored in a manner that is industry best practice and that protects the environment. DPC-ERD will closely engage with the EPA and DEWNR as soon as the draft GMP is submitted as part of the Stage 3 approval process. The GMP review will also incorporate the soil vapour monitoring and real time pressure and temperature monitoring program which will also be a critical part of the integrated monitoring program to ensure no loss of gasification products to the subsurface or surface environments.

### 5.1.4 SEO requirements for air and water quality impacts

A critical component of the final approved SEO is to ensure the protection of the surface and subsurface environments from unintended releases of COPCs, in particular with regard to air quality and ground water. To that end, the relevant objectives and their respective assessment criteria and controls detailed in Table 1 of the final approved SEO<sup>36</sup> were established and made the subject of the independent expert's scope of review, the review of which as detailed in Dr Love's report (Appendix A) is included here for convenience.

Environmental Objective	Comments
2. No sustained change to background groundwater quality at the boundary of the gasifier buffer zone (i.e. containment is achieved).	<ul style="list-style-type: none"><li>• No aquifers in the vicinity of the gasification zone means that groundwater is limited to impermeable rock units (aquitards).</li><li>• Oxidant injection rate and outlet well flow rate play a role in both gas quality and gasifier pressure. It is assumed that an automated system would have control over production well backpressure, and that downstream systems would cope with automated adjustments to production flow.</li><li>• Real-time monitoring of wells and near-gasifier pressures provides necessary insights to maintain safe operating conditions and identify anomalies.</li><li>• Abnormal / emergency operations plan should include contingency for emergency venting in the event of outlet well blockage. The observation well should be high temperature construction and allow for emergency routing to the production skids/cold vent if required.</li></ul>

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<sup>35</sup> ibid

<sup>36</sup> [Leigh Creek Energy PEL650 SEO](#)

	<ul style="list-style-type: none"> <li>Proposed decommissioning utilises “clean cavern concept”, which is best practice.</li> <li>Groundwater monitoring wells around and above the gasifier provide for adequate for monitoring.</li> </ul>
3. No loss of gasification products to the surface or subsurface environment via pre-existing drill holes and/or transmissive geological features	<ul style="list-style-type: none"> <li>Reliance on completeness of historic borehole data is a risk – soil vapour monitoring will provide some mitigation.</li> <li>Consideration could be made to locate some vapour monitoring wells up-dip of the gasifier zone.</li> <li>Work to characterise transmissivity of inferred faults is sound.</li> </ul>
4. Well integrity is maintained to prevent loss of gasification products to the surface or subsurface environment.	<ul style="list-style-type: none"> <li>Well designs and proposed construction methodologies utilise very high standards and leading practices.</li> <li>CBL provide verification of cement seals.</li> <li>Leak monitoring most important during changes to thermal load (heat up and cool down).</li> <li>Emergency response plan should be independently reviewed as part of Stage 3 Approval.</li> <li>Well abandonment methodologies should include casing inspection to determine whether squeeze cementing is required to manage damaged casing – lack of aquifers may preclude the need for complex abandonment.</li> </ul>
5. No gasifier induced subsidence measured at surface	<ul style="list-style-type: none"> <li>Monthly survey of monuments is more than adequate.</li> <li>Risk of subsidence expressed at surface is low.</li> </ul>
10. Air pollution and greenhouse emissions reduced to as low as reasonably practical.	<ul style="list-style-type: none"> <li>Well integrity – see point 4.</li> <li>Venting protocols, including cold venting, are adequate to minimise emissions.</li> </ul>
14. Remediate and rehabilitate operational areas to agreed standards.	<ul style="list-style-type: none"> <li>Proposed decommissioning utilises “clean cavern concept”, which is best practice.</li> </ul>

Furthermore, as part of the final Stage 3 approval process LCK will be required to demonstrate how it will achieve these objectives including the effectiveness of its proposed monitoring plans, to the satisfaction of DPC-ERD and where relevant to the EPA and DEWNR before approval can be granted.

## 5.2 Linc Energy Chinchilla Trial

Much concern was expressed by members of the public regarding the current charges laid against Linc Energy Ltd and the former company CEO and Executives for allegedly failing to ensure their ISG project at Chinchilla complied with the Queensland *Environmental Protection Act 1994*.

As the lead regulator, DPC-ERD liaised with the Queensland Government on this matter to understand any potential environmental implications in our consideration of

any such proposal in South Australia. To understand and ensure implementation of the lessons learned from Linc Energy's UCG project in Chinchilla, DPC-ERD and the South Australian EPA visited the Department of Environment and Heritage Protection in Queensland in late August 2017, including a site visit to the Chinchilla UCG site, to get a clearer understanding of the evidence underpinning the allegations of wilful and unlawful serious environmental harm. Based on this visit and its assessment of the facts underpinning the prosecution case, the DPC-ERD can say that the scenario at Chinchilla and that at Leigh Creek are vastly different.

Furthermore, these key differences between the Linc Chinchilla operations and the proposed LCK demonstration plant are supported by Dr Gary Love's independent expert report (Appendix A) as provided here.

<b>Chinchilla Operations</b>	<b>Proposed LCKE Demonstration</b>
Site operations were commercially driven, operating 5 gasifiers over a period of more than 12 years under a "black box" approach.	LCKE primary focus is environmental performance, demonstrated through a discrete 3 month operation with transparency to the regulator and general public.
Regulator considered the operations R&D, had limited engagement with the company and restricted reporting triggers to water bore quality at the boundary of the site.	Regulator is closely engaged with the proponents, has developed a technical understanding of the technology and risks, and has undertaken a rigorous assessment process.
Site characteristics that contributed to environmental risk: <ol style="list-style-type: none"> <li>1. Shallow at 125m</li> <li>2. Permeable coal seam that was a local aquifer</li> <li>3. Anthropogenic fracture permeability in the coal and immediate roof material</li> <li>4. CSG bearing coal</li> <li>5. Nearby water users of the coal seam aquifer</li> </ol>	Site characteristics that minimise environmental risk: <ol style="list-style-type: none"> <li>1. Deep at 540m (more than 4 times Chinchilla site)</li> <li>2. Very low permeability of coal (an aquitard)</li> <li>3. Fractures and fracturing risk deemed low through comprehensive geotechnical investigations</li> <li>4. Non-gas bearing coal</li> <li>5. Aquitard has no value for groundwater users</li> </ol>
Operational actions that contributed to environmental risk: <ol style="list-style-type: none"> <li>1. Operating pressure was neither declared by proponent nor prescribed by regulator</li> <li>2. Operating pressures exceeded containment pressures</li> <li>3. Hydraulic fracturing – intentional and unintentional</li> <li>4. Proponents set well design standards which were largely inadequate</li> <li>5. Progressive depressurisation of coal seam water levels</li> </ol>	Operational actions that will reduce environmental risk: <ol style="list-style-type: none"> <li>1. Operating pressures declared by proponent based on verifiable data</li> <li>2. Operating pressures automatically set to stay below hydrostatic pressure (key safety feature)</li> <li>3. Low risk of hydraulic fracturing (known breakover pressure)</li> <li>4. Well designs aligned to industry standards</li> <li>5. Depressurisation highly localised due to low permeability</li> </ol>

6. No monitoring requirements, triggers or actions of the process area	6. Strict monitoring requirements for groundwater, air and soil in process area
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Notwithstanding this negative publicity regarding UCG as a result of the Linc Energy trial in Queensland, it is also important to recognise that the 19 July 2016 letter from the Queensland Chief Scientist regarding the Carbon Energy project at Bloodwood Creek noted that<sup>37</sup>:

*It is fair to say that Carbon Energy has taken a robust, science-based approach to the process evaluation and its keyseam technology is different from other technologies...*

*It is clear that Carbon Energy has contributed to the collective understanding of Underground Coal Gasification and the conditions under which the operation is likely to be both safe and successful...*

*It is therefore apparent that a combination of the right technology, the right conditions and robust science-based controls means that successfully tested technologies like keyseam might well have a role in exploiting energy elsewhere...*

This statement by the Chief Scientist suggests that, like many other industrial processes and activities, under suitable conditions UCG can be undertaken safely. DPC-ERD believe that key factors necessary for realising such suitable conditions is proper site selection and deployment of fit for purpose technology and monitoring, both of which the PGE Act approval process seeks to assure.

On 9 April 2018<sup>38</sup>, Linc Energy was found guilty of wilfully and unlawfully causing environmental harm between 2007 and 2013 at Chinchilla. The Crown prosecutor successfully maintained that the Linc Energy CEO was aware of guidelines to safely manage UCG operations but had never directed staff to follow mandated practices. This outcome results from a company's management failing to follow good industry practice and meet its duty of care obligations. The risk mitigation, monitoring and reporting required by LCK's SEO will require safe operating conditions. Vigilant oversight by the South Australia's regulator and requirements for LCK to deploy good industry practices will combine to preclude any such repeat in LCK's pilot UCG project.

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<sup>37</sup> [19th July 2016 Queensland Chief Scientist Letter Confirms Technology](#)

<sup>38</sup> See: <http://www.abc.net.au/news/2018-04-09/court-linc-energy-guilty-serious-environmental-harm-ucg-plant/9632964>

### **5.3 Aboriginal heritage matters**

DPC-ERD and all South Australian Government agencies continue to recognise and respect the sensitivities of all Aboriginal heritage matters in the State and the importance that these are appropriately addressed through the regulatory process, both during the approval stage and the compliance monitoring and enforcement stages. To this end, DPC-ERD reached out to the lead (prescribed) native title body, the Adnyamathanha Traditional Lands Association (ATLA) to address any such issues and will continue to respectfully and sensitively engage with ATLA on this matter.

In its final submission to the EIR and draft SEO, ATLA raised strong opposition to the project mainly on Aboriginal heritage grounds as the proposed location of the demonstration plant forms part of an area of land that is of vital significance to the Adnyamathanha people.

In response to this serious objection, DPC-ERD sought immediate assistance and advice from both the Commercial, Environment & Native Title Section within the South Australian Crown Solicitor's Office (CSO) and the Department of the Premier and Cabinet's Aboriginal Affairs and Reconciliation Division (DPC-AAR). LCK articulated its risk management requirements for the protection of Aboriginal heritage within the SEO. The key requirement of this risk management strategy is liaising with ATLA, as the prescribed body corporate representing the Adnyamathanha native title holders, and undertaking work area clearances with representatives of ATLA. CSO and DPC-AAR suggested that the SEO needed to more accurately reflect this risk management strategy and to that end, CSO liaised with LCK's lawyer to ensure this was the case.

### 5.3.1 SEO requirements for Aboriginal heritage matters

As extracted from the final approved SEO<sup>39</sup>, the following requirements were incorporated into the SEO in relation to the protection of Aboriginal heritage.

Environmental objectives	Assessment criteria	Guide to how objectives can be achieved
1. Avoid damage, disturbance or interference to Aboriginal heritage sites, objects and remains by undertaking risk mitigation strategies or obtaining prior approval under relevant legislation.	<p>By way of a risk mitigation strategy, areas of proposed land disturbance have been subject to a cultural heritage Work Area Clearance and land disturbance will be undertaken in accordance with conditions of the cultural heritage clearance.</p> <p>Any Aboriginal heritage sites, objects and remains discovered during operations have been appropriately reported and responded to, consistent with the <i>Aboriginal Heritage Act 1988</i>.</p>	<p>All new land disturbance contained within cultural heritage Work Area Clearance area.</p> <p>Signage and fencing (where required) will be installed to delineate approved areas.</p> <p>Areas of sensitivity (e.g. cultural heritage exclusion areas, if present) flagged and / or fenced off where necessary to prevent disturbance.</p> <p>Training and induction for all personnel on cultural heritage issues and the importance of remaining within designated / approved areas.</p> <p>If suspected cultural heritage material is discovered during operations, investigations are undertaken with the Adnyamathanha Traditional Lands Association to identify an appropriate course of action.</p> <p>If Aboriginal sites, objects and remains are discovered, the discovery is reported to the Department of State Development, Aboriginal Affairs and Reconciliation.</p>

### 5.4 Public and rehabilitation liabilities

Comments in the submissions were also made with regards to whether the LCK proposal would be subject to taking out adequate public liability insurance. One of a number of mandatory conditions under the PGE Act for the granting of all licenses is the requirement for the licensee to hold an appropriate level of public liability insurance commensurate to the risk associated with the proposed activities under that relevant licence. In the case of the PEL 650 licence, LCK holds a minimum of \$20 million in public liability insurance. This insurance is to cover all regulated activities carried out by the licensee and includes sudden and accidental pollution. DPC-ERD deem \$20 million sufficient for the activities currently proposed by LCK at this time. Furthermore, DPC-ERD has relevant arrangements in place to ensure

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<sup>39</sup> [Leigh Creek Energy PEL650 SEO](#)

adequate security bonds to cover total liabilities for site rehabilitation are held prior to any Stage 3 activity approvals being granted. This will continue to be reviewed and increased should any future activities be considered for approval.

Further to this, the licensee is also required to hold a further \$10 million in Control of Well insurance. These requirements are stipulated within the publicly available licence register<sup>40</sup>.

## **5.5 Independent Review of UCG in Scotland, UK**

A number of submissions referred to the findings of the Scottish Government commissioned Independent Review of UCG undertaken by Professor Campbell Gemmell<sup>41</sup> as evidence to warrant any decision to not permit this proposal to proceed. With respect to Professor Campbell Gemmell's report, it is worth noting two very important reasons for Professor Gemmell's recommendation to the Scottish Government:

- Given the apparent limited published material that Professor Gemmell was able to source, it was not possible for him to assemble or analyse sufficiently detailed information for all aspects of UCG, especially industry performance in relation to environment, health and safety issues; and
- Given apparent deficiencies in Scotland's regulatory and public policy systems and the reasonable expectations of the Scottish public in relation to engagement, operator performance and management of the whole life-cycle of UCG technologies' use, it was extremely difficult to conceive of UCG progressing into use at the time of Professor Gemmell's assessment.

He also concluded that establishing credible baselines, firm planning and licensing conditions and subsequently enforcing robust regulatory, monitoring and liabilities management arrangements would be paramount to the realisation of any successful UCG project. It is exactly for these reasons articulated in Professor Gemmell's report that here in South Australia through the PGE Act, licensees are required to undertake sufficient exploration, appraisal and site assessments to enable informed evidence- and fact-based regulatory decisions on any proposal for any UCG project in this state.

Therefore, DPC-ERD remains committed to upholding the integrity of the open and transparent regulatory provisions under the PGE Act as demonstrated through the

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<sup>40</sup> [PGE Act licence register](#)

<sup>41</sup> [Independent Review of Underground Coal Gasification – Report, Campbell Gemmell](#)



Stage 2 SEO approval process for the LCK UCG trial proposal to which this report pertains.

## **5.6 Independent Expert Scientific Committee and Environmental Protection and Biodiversity Conservation Act 1999 (EPBC ACT) Referrals**

The National Partnership Agreement, South Australian Protocol and relevant guidelines that governs the referral process for the Independent Expert Scientific Committee (IESC) can be found on DPC-ERD's website<sup>42</sup>.

DPC-ERD concluded there was no basis for this pilot project to be referred to the IESC given that its assessment of the LCK project revealed that there will be very low risk of any significant impacts to water resources or matters of national environmental significance (MNES).

If a pre-commercial demonstration proves technically successful and commercially attractive, and LCK decide to proceed to full scale development, then DPC-ERD as is usual protocol, will give appropriate consideration to IESC and/or EPBC Act referral for any such proposal as part of the Stage 2 approval process under the PGE Act. Generally, it is the proponent or licensee who makes the EPBC Act referral.

Under the EPBC Act, a referral can only be made by:

- the person proposing to take the action (which can include a person acting on their behalf); or
- a Commonwealth, state or territory government, or agency that is aware of a proposal by a person to take an action, and that has administrative responsibilities relating to the action.

A referral must be made by the person proposing to take an action if the person thinks that the action will have, or is likely to have a significant impact on a matter protected by Part 3 of the EPBC Act. This test also applies to a government agency who has administrative responsibilities in relation to the action. DPC-ERD in consultation with the Mineral Resources Division, who have experience in the referral process, reached a view that this proposal will not satisfy the significant

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<sup>42</sup> [South Australian National Partnership Agreement on Coal Seam Gas and Large Coal Mining Development](#)

impact criteria under the EPBC Act MNES significance impact guidelines<sup>43</sup> and therefore a referral is not warranted.

## **6.0 Recommendation and further information**

The Energy Resources Division recommends Stage 2 approval, based on:

- its detailed review of the EIR and draft SEO;
- Leigh Creek Energy's responses to comments submitted as a result of the public consultation;
- an independent geotechnical assessment commissioned by the Energy Resources Division to evaluate the geological integrity and the potential for transmissive faults to the surface within the overburden rock stratum above the targeted coal within which the proposed gasification trial will be undertaken;
- advice from world recognised UCG experts from the Lawrence Livermore National Laboratories in the United States; and
- an independent opinion from a key UCG expert in Australia on the suitability of the Leigh Creek Telford Basin for safe UCG operations.

For all enquiries regarding this assessment, DPC-ERD can be contacted through the Director of Engineering Operations, Michael Malavazos at [michael.malavazos@sa.gov.au](mailto:michael.malavazos@sa.gov.au).

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<sup>43</sup> <http://www.environment.gov.au/epbc/publications/significant-impact-guidelines-11-matters-national-environmental-significance>

# Appendix A: Independent Review of Site Suitability and Subsurface Risks for the Proposed Leigh Creek Energy UCG Demonstration Plant

Gary J. Love

## Summary

A review has been conducted of the site suitability and associated subsurface risks for a proposed demonstration of underground coal gasification (UCG) by Leigh Creek Energy Ltd (LCKE) in the Telford Basin near Leigh Creek. This review takes into account physical aspects of the subsurface that are primary factors in containment of the UCG process, and the way in which those factors have been assessed to define environmental risk. It also considers relevant operational risk factors described in the Environmental Impact Report, specifically the approach to well design and the definition of the safe operating pressure envelope. Specific mention has also been made of the Linc Energy Limited UCG program in QLD and the relevance of that experience to the proposed LCKE operation.

The proposed demonstration plant site in the Telford Basin fulfils preferred criteria<sup>44</sup> to limit the primary risks associated with UCG. Suitable depth, very low formation permeabilities, robust geomechanical properties and physical separation from potential receptors, all combine to present a geological framework within which UCG could be contained with acceptable risk. Residual containment risks around proximity to extensional faults in the basin are considered low based on geotechnical assessments carried out by both the proponent and the Department of the Premier and Cabinet Energy Resources Division (DPC-ERD).

Secondary risks associated with UCG containment relate to operational activities and include induced fracture pathways, well leakage, and operation at pressures exceeding the prevailing hydrostatic formation pressure. Geotechnical studies have concluded that roof fracturing associated with goaf development could extend up to 5 times the gasifier height. Given this is a relaxation feature post-cavity development, and that the overburden unit is itself of very low permeability, this would not be anticipated to have material risk to the demonstration, nor longer term rehabilitation of the cavity.

Well leakage risk cannot be completely eliminated due to the temperature of the UCG process, and the casing stresses that may be induced through thermal cycling of the outlet well. LCKE has utilised leading practices with regards to UCG well design to minimise this risk, including the use of high temperature casing, premium gas-tight threads, high temperature cements, and high temperature well heads. Pressure testing of wells and running of cement bond logs as part of well construction practices will provide adequate assurance of well integrity.

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<sup>44</sup> Moran, C.J., da Costa, J and Cuff, C. (2013). Independent Scientific Panel Report on Underground Coal Gasification Pilot Trials. Queensland Independent Scientific Panel for Underground Coal Gasification June 2013.

Correct operating pressures are a risk factor for UCG, and the LCKE demonstration project has a clear definition of the operating pressure guided by the installation of vibrating wire piezometers. The proponent has indicated an automated system may be utilised to ensure that pressures in the chamber remain below the surrounding formation pressure, which ensure that risk of gas loss and COPC excursion remains low. The formation breakover pressure of the overlying strata has been defined by independent assessment, and is more than twice the operating pressure nominated by LCKE. The risk of fracturing due to pressurisation is considered low.

The environmental legacy of the Linc Energy Ltd UCG program in QLD has been highlighted as a concern in stakeholder consultation for the LCKE demonstration project. It is unreasonable to associate the LCKE project with the Linc project due to material differences related to the site suitability, operational practices and the level of regulatory oversight. The LCKE project has presented robust science to clearly show a much lower risk than the Linc operation, and is focused on a transparent demonstration of environmental performance as a key step to commercialising its assets.

In the opinion of the author, the Leigh Creek site represents one of the strongest opportunities for low risk commercial UCG anywhere in the world. On the merits of the site suitability and operational assurances, the 2-3 month demonstration plant carries minimal risk and should be approved through the Stage 2 process.

## **Background**

This advice statement is in response to a request from the DPC-ERD to provide independent review of critical subsurface aspects of the proposed Leigh Creek Energy Limited (LCKE) underground coal gasification (UCG) demonstration plant. Specifically, subsurface aspects related to managing environmental risks that have been presented by the proponents in the Stage 2 Approval Process under the PGE Act. Mention is also made of the relevance of the Linc Energy legacy issues, which have been highlighted in the public consultation phase. For clarity, the commonly used term UCG is referred to as in situ gasification (ISG) by LCKE.

The review is based on the author's experience in UCG and related disciplines, and includes regulatory insights gained from involvement as a fact witness and subject matter expert with the investigation and trial of Linc Energy Ltd by the QLD Department of Environment and Science. The following documents have been reviewed in compiling this advice statement.

- Leigh Creek Energy Statement of Environmental Objectives – ISG Demonstration Plant, Report prepared by JBS&G Australia Pty Ltd and Leigh Creek Energy Limited, April 2018
- Leigh Creek Energy Environmental Impact Report – ISG Demonstration Plant, Report prepared by JBS&G Australia Pty Ltd and Leigh Creek Energy Limited, April 2018
- Geomechanical model, Leigh Creek, South Australia. Report prepared by Ikon Science for DPC, January 2018.
- Assessment of Leigh Creek Energy (LCK) UCG Trial Environmental Impact Report, Draft report prepared by DPC-ERD, April 2018

Every effort has been made to provide clear guidance around risks, however the subsurface is inherently uncertain and there may be undefined structural features and other elements that impact the outcomes of this review. Assumptions are made that commitments made by the operator around control of the UCG process, including the operating pressure, are warranted.

### Environmental Objectives and Assessment Criteria

The Statement of Environmental Objectives (SEO) includes measures of assessment to gauge the effectiveness of controls being implemented. With regards to Table 1 in the LCKE demonstration plant SEO (pp. 8 – 18), comments on salient points related to the subsurface features are provided in the table below. The controls around subsurface risks are considered adequate for LCKE to meet the SEO criteria.

Environmental Objective	Comments
2. No sustained change to background groundwater quality at the boundary of the gasifier buffer zone (i.e. containment is achieved).	<ul style="list-style-type: none"> <li>• No aquifers in the vicinity of the gasification zone means that groundwater is limited to impermeable rock units (aquitards).</li> <li>• Oxidant injection rate and outlet well flow rate play a role in both gas quality and gasifier pressure. It is assumed that an automated system would have control over production well backpressure, and that downstream systems would cope with automated adjustments to production flow.</li> <li>• Real-time monitoring of wells and near-gasifier pressures provides necessary insights to maintain safe operating conditions and identify anomalies.</li> <li>• Abnormal / emergency operations plan should include contingency for emergency venting in the event of outlet well blockage. The observation well should be high temperature construction and allow for emergency routing to the production skids/cold vent if required.</li> <li>• Proposed decommissioning utilises “clean cavern concept”, which is best practice.</li> <li>• Groundwater monitoring wells around and above the gasifier provide for adequate for monitoring.</li> </ul>
3. No loss of gasification products to the surface or subsurface environment via pre-existing drill holes and/or transmissive geological features	<ul style="list-style-type: none"> <li>• Reliance on completeness of historic borehole data is a risk – soil vapour monitoring will provide some mitigation.</li> <li>• Consideration could be made to locate some vapour monitoring wells up-dip of the gasifier zone.</li> <li>• Work to characterise transmissivity of inferred faults is sound.</li> </ul>
4. Well integrity is maintained to prevent loss of gasification products to the surface or subsurface environment.	<ul style="list-style-type: none"> <li>• Well designs and proposed construction methodologies utilise very high standards and leading practices.</li> <li>• CBL provide verification of cement seals.</li> <li>• Leak monitoring most important during changes to thermal load (heat up and cool down).</li> </ul>

	<ul style="list-style-type: none"> <li>• Emergency response plan should be independently reviewed as part of Stage 3 Approval.</li> <li>• Well abandonment methodologies should include casing inspection to determine whether squeeze cementing is required to manage damaged casing – lack of aquifers may preclude the need for complex abandonment.</li> </ul>
5. No gasifier induced subsidence measured at surface	<ul style="list-style-type: none"> <li>• Monthly survey of monuments is more than adequate.</li> <li>• Risk of subsidence expressed at surface is low.</li> </ul>
10. Air pollution and greenhouse emissions reduced to as low as reasonably practical.	<ul style="list-style-type: none"> <li>• Well integrity – see point 4.</li> <li>• Venting protocols, including cold venting, are adequate to minimise emissions.</li> </ul>
14. Remediate and rehabilitate operational areas to agreed standards.	<ul style="list-style-type: none"> <li>• Proposed decommissioning utilises “clean cavern concept”, which is best practice.</li> </ul>

### Air and Groundwater Quality Impacts

Air and groundwater risks associated with UCG are well-articulated in the EIR and supporting studies. There are two main mechanism of potential contamination from UCG, both of which have been considered:

1. Primary contamination through loss of syngas from the gasification process, which can result in (a) condensation of liquid hydrocarbons such as tars and oils, (b) release of combustible gases such as CO and H<sub>2</sub> to the environment, and (c) condensation of contaminated water, and
2. Secondary leaching of residual products such as tars, oils, char and ash into groundwater.

For any subsurface activity where COPC may be generated, there is a relationship between the source, transport pathways and potential receptors in determining risk. For the LCKE demonstration plant, the source will be the gasification chamber. During operations, the primary mechanism of contamination risk is loss of syngas, with control measures required to prevent syngas from migrating away from the chamber margins, upwards through the annulus of wells or along vertical structures. Where syngas breaches to the surface, impacts to air quality become relevant.

Risks of subsurface syngas migration at the LCKE demonstration plant are managed through the following controls:

1. The site has been selected due to very low permeability of the formation, which will contain the process;
2. There is significant vertical and lateral separation from potential receptors, and there are no known aquifers connected to the gasification target zone;
3. Potential fracture transport pathways have been mapped, their behaviour quantified and a suitable buffer distance has been included in locating the gasifier;
4. Site selection has taken historic bores into consideration to minimise risk of gas migration under buoyancy, and a suitable buffer distance has been defined;

5. There are appropriate well designs including high temperature cement blends to ensure well integrity and minimise gas loss through casing strings and along the annulus of wells;
6. A safe operating pressure has been defined on robust hydrogeological and geotechnical data, and is intended to be controlled with an automated system to prevent overpressurisation;
7. Transparent and rigorous monitoring requirements for groundwater, air and soil vapour have been put in place, presumably with triggers for reporting and actions, and
8. The demonstration has a relatively short duration and is at a small scale.

The potential for post-burn leaching and mobilisation of COPC from the residues is reduced by limiting loss of syngas (and condensable components) during the gasification phase and effective decommissioning of the gasifier. The controls on syngas loss are described above. The decommissioning phase proposed by LCKE utilises established “clean cavern concept” principles first described in the US Department of Energy UCG program in the 1980’s. This involves halting injection and rapid depressurisation to encourage faster groundwater ingress, which has the effect of (1) rapid cooling of the gasifier to below the pyrolysis temperature (halting further generation of COPC), and (2) high steam generation which has the effect of stripping residual COPC from the chamber walls and rubble pile for recovery at surface.

The LCKE demonstration plant includes the use of a coil tubing (capillary) water injection line, recognising that the very low permeability of the formation is unlikely to yield the required water ingress for rapid cooling. This approach of adding additional water demonstrates good understanding of the requirements for proper chamber shutdown and decommissioning, and is considered a good control mechanism for reducing secondary contamination risk.

Work has been conducted to characterise the Telford Basin in a regional groundwater context. This demonstrates completeness in the approach, however the risks to regional water users, most of which are up-gradient of the site, are negligible due to the small scale, hydraulic isolation and the distances to these receptors.

### **Relevance of Linc Energy Chinchilla UCG Comparisons**

The author has direct experience with the Linc Energy UCG operations and is able to provide commentary on the relevance of the Chinchilla legacy issues to the LCKE demonstration project. The issues at the Chinchilla site were a result of unrealistic expectations of the UCG process, driving operational practices that exceeded the natural geological containment of the site. Those practices, related to matters currently before the courts, were argued to be part of the research and development process and were not disclosed to regulators due to the site’s reporting requirements being limited to four water bores on the boundary. UCG operations at Chinchilla were therefore largely unregulated.

In one aspect, the original Linc Energy trial (Gasifier 1) demonstrated that a UCG pilot could be operated with minimal environmental risk. The process was operated below the hydrostatic pressure of the surrounding strata, ensuring that inward flow of water was sustained, and flow of COPC away from the gasifier was minimised. Substantiating data was published, and at the time, the project was reported as a successful example of UCG.



However the target coal seam, a permeable local aquifer with secondary fracture permeability (from hydraulic fracturing), meant that water influx to the process was high. This had three implications:

1. The high production of water from the process created drawdown of the aquifer water levels, progressively reducing the confining pressures in the aquifer;
2. The drawdown of coal seam aquifer pressure caused the desorption of natural coal seam gas (CSG), which resulted in a mixture of free gas and water that compromised the surrounding water seal, and
3. The syngas quality had excess hydrogen (from H<sub>2</sub>O), which pushed it out of spec for the desired end use (gas-to-liquids).

Point three above became a problem for Linc due to the considerable investment in the gas-to-liquids plant. In order to inhibit water influx, gasifiers were operated over the hydrostatic pressure, which resulted in the loss of syngas and COPC to the environment. A cycle was perpetuated where displacement of groundwater by gas accelerated the desorption of CSG, which continued to erode containment of the system and increase gas loss to the environment.

One feature that exacerbated the impacts of gas loss was the presence of multiple sub-vertical pathways, including natural fractures, induced fractures, leaking wells and historic unsealed boreholes. Syngas that was driven out laterally within the coal seam under pressure exploited these pathways to ascend to the near surface where they impacted soils over a large area which included farmland. It was only during the latter stages of operations at the site that the regulator became aware of potential issues, and investigations commenced.

It is unreasonable to use the Linc Energy example as a criticism of all UCG projects, and every new project should be considered on its merit in the context of current best practices. In the Linc case, it is noted that the basic features of the site were suited to the first trial. It was the only when the commercial requirements exceeded the natural capacity of the site that problems developed.

The approach by LCKE is wholly different from Linc. What is proposed in the current approvals process for LCKE is a short test where the primary driver is to demonstrate environmental performance. The author endorses that approach from a commercialisation perspective, as the barriers to commercialisation of UCG are not technical, rather developing an informed regulatory framework for commercialisation based on sound science.

Some of the important differences between the Linc Energy case and the LCKE demonstration plant are provided in the table below.

### **Overall Site Suitability**

The site selected by LCKE for a proposed UCG demonstration plant in the abandoned Leigh Creek mining area of the Telford Basin has been chosen with due consideration for a range of risk factors, and in the

opinion of the author demonstrates good understanding of the technology, its proper application, and the commercialisation requirements. In summary, the proponents LCKE have:

- Selected a site that meets established best practice criteria for minimising environmental risks;
- Demonstrated, through modern methodologies, appropriate characterisation of critical hydrogeological and geotechnical parameters that allow subsurface risks to be understood with an acceptable level of confidence;
- Demonstrated an understanding of subsurface operational risks and proposed a series of controls to meet their prescribed environmental objectives (SEO), and
- Engaged with the DPC-ERD in a collaborative manner, which has allowed the regulator to build awareness of the issues and provide the necessary guidance to manage risks effectively;

The proponents are technically well positioned, and understand the need to demonstrate environmental performance to build regulatory and community confidence in UCG. On balance, the potential future benefits of developing the Leigh Creek mining area through UCG outweigh the risks of the demonstration plant, which are well managed by appropriate site selection and operational assurances. On the basis of the material reviewed and in the limitations of the subsurface aspects considered, the author endorses a Stage 2 approval for the LCKE demonstration plant.

**The key differences between the Linc Chinchilla operations and the proposed LCKE demonstration plant.**

<b>Chinchilla Operations</b>	<b>Proposed LCKE Demonstration</b>
Site operations were commercially driven, operating 5 gasifiers over a period of more than 12 years under a “black box” approach.	LCKE primary focus is environmental performance, demonstrated through a discrete 3 month operation with transparency to the regulator and general public.
Regulator considered the operations R&D, had limited engagement with the company and restricted reporting triggers to water bore quality at the boundary of the site.	Regulator is closely engaged with the proponents, has developed a technical understanding of the technology and risks, and has undertaken a rigorous assessment process.
<p>Site characteristics that contributed to environmental risk:</p> <ul style="list-style-type: none"> <li>6. Shallow at 125m</li> <li>7. Permeable coal seam that was a local aquifer</li> <li>8. Anthropogenic fracture permeability in the coal and immediate roof material</li> <li>9. CSG bearing coal</li> <li>10. Nearby water users of the coal seam aquifer</li> </ul>	<p>Site characteristics that minimise environmental risk:</p> <ul style="list-style-type: none"> <li>6. Deep at 540m (more than 4 times Chinchilla site)</li> <li>7. Very low permeability of coal (an aquitard)</li> <li>8. Fractures and fracturing risk deemed low through comprehensive geotechnical investigations</li> <li>9. Non-gas bearing coal</li> <li>10. Aquitard has no value for groundwater users</li> </ul>
<p>Operational actions that contributed to environmental risk:</p> <ul style="list-style-type: none"> <li>7. Operating pressure was neither declared by proponent nor prescribed by regulator</li> <li>8. Operating pressures exceeded containment pressures</li> <li>9. Hydraulic fracturing – intentional and unintentional</li> <li>10. Proponents set well design standards which were largely inadequate</li> <li>11. Progressive depressurisation of coal seam water levels</li> <li>12. No monitoring requirements, triggers or actions of the process area</li> </ul>	<p>Operational actions that will reduce environmental risk:</p> <ul style="list-style-type: none"> <li>7. Operating pressures declared by proponent based on verifiable data</li> <li>8. Operating pressures automatically set to stay below hydrostatic pressure (key safety feature)</li> <li>9. Low risk of hydraulic fracturing (known breakover pressure)</li> <li>10. Well designs aligned to industry standards</li> <li>11. Depressurisation highly localised due to low permeability</li> <li>12. Strict monitoring requirements for groundwater, air and soil in process area</li> </ul>

## Statement of Qualification

I, Gary J. Love do hereby certify that:

- I hold a Bachelor of Science with First Class Honours in Applied Geology from Curtin University of Technology, Australia, graduating in 1999.
- I hold a Doctor of Philosophy in Geology from Curtin University of Technology, Australia, graduating in 2003.
- I hold a Master of Engineering in Groundwater Management from University of Technology, Sydney, graduating in 2009.
- I am a Fellow of the Geological Society of London, a member of the International Association of Hydrogeologists and a member of the Australian Institute of Geoscientists.
- Since 2005 I have been employed in various roles that have included the geological and hydrogeological assessment of coal basins, with those roles comprising drilling supervision, mine dewatering, water resource assessment and exploration.
- I have almost 10 years experience with novel in situ technologies for coal, including underground coal gasification and microbiological stimulation of biogenic CSG.
- Between 2008 and 2010 I was employed by Linc Energy Limited as a hydrogeologist in the UCG technical team. During that time I completed my Masters Thesis on the Chinchilla site, developing a model for groundwater and gas interactions around Gasifier 3.
- I have appraised numerous potential sites for UCG in Australia, India, Bangladesh, Indonesia, Vietnam, Botswana, South Africa, China, Hungary and the USA.
- In 2011 I was engaged by New York private equity firm Mt Kellett Capital to complete the subsurface due diligence on the Swanhills Synfuels UCG – EOR project in Alberta Canada.
- Since 2014, I have acted as a fact witness and subject matter expert to the QLD Department of Environment and Science (formerly Department of Environment and Heritage Protection) in the investigation and prosecution of Linc Energy, and have given evidence in the committal and trial.
- Based on my qualifications, work experience and professional standing I am a 'qualified person' to undertake review of subsurface aspects of underground coal gasification.
- I undertook work in 2016 as a consultant to Drill Path Pty Ltd, which completed preliminary work related to well designs for LCKE. There has been no commercial engagement with LCKE since that time, and the author has no financial interest in LCKE or the proposed project.



Gary J. Love BSc (Hons) ME PhD FGS

9<sup>th</sup> April, 2018

