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

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**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[1] 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 Energy and Minerals Energy Resources Division (DEM-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.

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 ensures 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,


[1] 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.

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 is 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 shown 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 DEM-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). | • No aquifers in the vicinity of the gasification zone means that groundwater is limited to impermeable rock units (aquitards).<br>• 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.<br>• Real-time monitoring of wells and near-gasifier pressures provides necessary insights to maintain safe operating conditions and identify anomalies.<br>• 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.<br>• Proposed decommissioning utilises "clean cavern concept", which is best practice.<br>• Groundwater monitoring wells around and above the gasifier provide for adequate for monitoring. |
| 3. No loss of gasification products to the surface or subsurface environment via pre-existing drill holes and/or transmissive geological features | • Reliance on completeness of historic borehole data is a risk – soil vapour monitoring will provide some mitigation.<br>• Consideration could be made to locate some vapour monitoring wells up-dip of the gasifier zone.<br>• Work to characterise transmissivity of inferred faults is sound. |
| 4. Well integrity is maintained to prevent loss of gasification products to the surface or subsurface environment. | • Well designs and proposed construction methodologies utilise very high standards and leading practices.<br>• CBL provide verification of cement seals.<br>• Leak monitoring most important during changes to thermal load (heat up and cool down).<br>• Emergency response plan should be independently reviewed as part of Stage 3 Approval.<br>• 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. |

| | |
|---|---|
| 5. No gasifier induced subsidence measured at surface | • Monthly survey of monuments is more than adequate.<br>• Risk of subsidence expressed at surface is low. |
| 10. Air pollution and greenhouse emissions reduced to as low as reasonably practical. | • Well integrity – see point 4.<br>• Venting protocols, including cold venting, are adequate to minimise emissions. |
| 14. Remediate and rehabilitate operational areas to agreed standards. | • Proposed decommissioning utilises "clean cavern concept", which is best practice. |

**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 $H_2$ 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 $H_2O$), 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 DEM-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.**

| **Chinchilla Operations** | **Proposed LCKE Demonstration** |
|---|---|
| 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:<br>1. Shallow at 125m<br>2. Permeable coal seam that was a local aquifer<br>3. Anthropogenic fracture permeability in the coal and immediate roof material<br>4. CSG bearing coal<br>5. Nearby water users of the coal seam aquifer | Site characteristics that minimise environmental risk:<br>1. Deep at 540m (more than 4 times Chinchilla site)<br>2. Very low permeability of coal (an aquitard)<br>3. Fractures and fracturing risk deemed low through comprehensive geotechnical investigations<br>4. Non-gas bearing coal<br>5. Aquitard has no value for groundwater users |
| Operational actions that contributed to environmental risk:<br>1. Operating pressure was neither declared by proponent nor prescribed by regulator<br>2. Operating pressures exceeded containment pressures<br>3. Hydraulic fracturing – intentional and unintentional<br>4. Proponents set well design standards which were largely inadequate<br>5. Progressive depressurisation of coal seam water levels<br>6. No monitoring requirements, triggers or actions of the process area | Operational actions that will reduce environmental risk:<br>1. Operating pressures declared by proponent based on verifiable data<br>2. Operating pressures automatically set to stay below hydrostatic pressure (key safety feature)<br>3. Low risk of hydraulic fracturing (known breakover pressure)<br>4. Well designs aligned to industry standards<br>5. Depressurisation highly localised due to low permeability<br>6. Strict monitoring requirements for groundwater, air and soil in process area |

**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.

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