# A Review of the Leigh Creek Energy ISG Pre-Commercial Demonstration Facility

## Part 1: Initial Assessment of Detailed Engineering and Environmental Monitoring Plans

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## Summary

Leigh Creek Energy plans a demonstration of a single chamber in situ gasification (ISG) gasifier over 2-3 months. The target coal seam and surrounding strata all have extremely low permeability and there are no natural pathways by which chemicals of potential concern could travel away from the gasifier during operation or after decommissioning. Natural groundwater movements flow to disused surface mine pits, but movement rates are so slow that any chemicals from the gasification would degrade to non-detect levels before they reached the surface. There are no environmental receptors if they did get to the pits. A search has not located any old boreholes in the region of the gasifier that could act as conducts for chemicals.

The underground gasifier is constructed with three wells which are connected to the gasifier chamber, an Inlet Well to supply air, an Outlet Well to extract syngas product gas, and an Observation Well to monitor conditions in the gasifier chamber and provide access to the chamber post demonstration. The Outlet and Observation Wells will be exposed to the most extreme temperatures and have been designed to withstand temperatures of 450ºC, the highest specification ever used in an ISG project. An extensive monitoring network is collecting water quality, pressure and temperature data from close to the gasifier chamber and in shallow near surface boreholes including shallow soil gas samples. Baseline water quality in the overburden materials has been established. Assessing water sampling results need to take into account well construction impacts internal to cased wells, externally in strata damaged during drilling and the effect water monitoring sites have in creating flow paths that do not naturally exist.

Regulations have established a buffer zone around the gasifier at 100m where there can be no change in pre-existing groundwater conditions. The area inside this buffer is intensively monitored to detect any impact of the gasifier and implement appropriate controls.

Operations will use industrial control systems to ensure that the gasifier chamber pressure does not exceed that of surrounding groundwater, the fundamental mechanism for preventing escape of chemicals of potential concern from the gasifier chamber.

This report confirms the suitability of the Leigh Creek site for ISG, highlights issues with the collection and interpretation of water monitoring analyses, confirms the principles underlying the operational guidelines proposed for the demonstration, commends the rigorous regulatory approach to environmental protection and the standard of specifications the company has used for its underground gasifier infrastructure.

# Introduction

Leigh Creek Energy (LCK) propose to demonstrate In Situ Gasification of coal (ISG) within PEL 650. Over the last three years Leigh Creek Energy have prepared and submitted documents to the South Australian Department of Premier and Cabinet (DPC) in support of this proposal which have been subjected to internal government departments' reviews and independent expert review. These have achieved Level 2 approval from DPC, allowing construct of the project to begin on site. Level 3 approval is the final step before the project can commence gasification which involves receipt of satisfactory plans for operating, monitoring, decommissioning and rehabilitating the project.

This review is based on project documents supplied by Leigh Creek Energy as listed in appendix 1, and meetings with government and company staff 10-13th June 2018, including a visit to the project site. It is provided to Energy Resources Division of the Department of the Premier and Cabinet as one part of the process of due diligence by government in deciding if approval will be given to commence the project.

My credentials to carry out this review include almost 40 years university and CSIRO research with 18 years specialisation in underground coal gasification, 12 years as technical director of Carbon Energy Limited directing the only UCG pilot approved by the Queensland Government's Chief Scientist as having fulfilled all the requirements of their Independent Scientific Panel. I have worked most of my professional life in research in safety and environmental management for mining, and have acted in positions – Chief CSIRO Division of Exploration and Mining, Chairman of the London based UCG Association, and Director of the China University of Mining and Technology's International UCG Research Centre in Xuzhou.

# Fitness for purpose

An ISG project involves managing the underground processes of syngas production, and the processing of gas at the surface. Surface activity is essentially no different to existing petroleum and chemical plants and environmental management currently in use in these industries can apply directly to in situ gasification of coal projects.

Underground coal gasification merges petroleum industry and mining techniques with features of coal gasification to create a combination of skills and capabilities unique to the in situ gasification industry. This is an emerging field for regulation and it is appropriate to take a conservative approach until more experience has been gained through the establishment of commercial scale projects.

Environmental control and containment of Chemicals of Potential Concern (COPC) in the underground has three requirements. The first is choosing a site that avoids ground conditions and fluid flow pathways that allow uncontrolled release of gas and COPC from the underground gasifier cavity. The second is ensuring that underground engineering works such as drill holes and well materials, and their installation, will perform at appropriate standards to control and contain all gasification processes. The third is developing and maintaining appropriate operational protocols for syngas production and rehabilitation, and matching surrounding ground conditions and the engineered infrastructure.

## Underground processes in ISG

Potential environmental impacts of underground processes in ISG include escape of by-product COPC into strata or groundwater, and deformation of strata as a cavity is created by extraction (gasification) of coal. Production of COPC with ISG cannot be avoided and it is essential that these chemicals are managed in a way that prevents any unacceptable environmental impacts.

Deformation of strata around ISG cavities is also unavoidable and similar to that experienced at all underground coal mines. It is predicted and managed in the same way. If strata movement at depth continues to the surface causing subsidence with unacceptable impact, it prevents the use of ISG or conventional mining. Computer simulations developed for the mining industry can accurately predict strata movements and surface subsidence, and will be a necessary part of planning in large commercial ISG projects. For small short-term demonstrations such as proposed at Leigh Creek, mining industry experience would indicate that there is no expectation of any surface disturbance from such a small, deep, cavity.

### Managing COPC in an ISG cavity

During gas production the temperature in the gasification zone of ISG is so high that COPC are destroyed. Pyrolysis of coal occurs in cooler parts of the gasifier which releases COPC. Most of these chemicals are carried to the surface with other syngas components where they are destroyed or collected, but a small percentage remain underground in cooler areas marginal to the main gasification processes. The control of these COPC is a prime requirement in ISG. Routes for escape of COPC from a gasifier include being dissolved in water that flows out of the gasifier (advection), diffusing into surrounding groundwater, or flowing in a gaseous state into surrounding strata after groundwater has been displaced by higher pressure gas. If the gasifier pressure is kept lower that that in the surrounding groundwater, groundwater will continuously flow into the gasifier, preventing outflow of COPC, and flushing back any COPC that have diffused into surrounding groundwater. When gas production is ended, a gasifier is decommissioned and steam cleaned, however some COPC will always remain and be found in the water that refills the cavity. These chemicals naturally degrade with time, and rehabilitation strategies should ensure that they have degraded before regional groundwater flow could release the COPC to any environmental receptor.

To assess the fitness of purpose of the plans for the Leigh Creek ISG project, the first step is to establish the characteristics of the location and then review how the company's plans for operation and rehabilitation match the requirements imposed by the site.

## The Leigh Creek Project site suitability for ISG

One of the greatest impediments to insitu coal gasification is finding a site where strata surrounding a coal seam will contain the produced gas and any associated Chemicals of Potential Concern (COPC), and avoid gas loss and the possibility of contaminating groundwater. The documentation produced by LCK in their Environmental Impact Report and supplementary documents on geology and groundwater was based on rigorous investigations of the site included a review of historical mining history, mapping of highwalls in coal and overburden, collation of hydrological records, seismic survey, drill holes to establish geohydrology and geomechanical properties of the site. It has been shown that this is one of the safest sites in the world to undertake in situ coal gasification. This has been confirmed by every independent project reviewer, and is also my determination.

These favourable site characteristics include:

- The coal sits in a small discrete synclinal basin, with no impact on any regional groundwater systems. It is within a disturbed prior mining area that is now isolated from surrounding surface water flows by diversion structures, creating a situation where there are no local environmental receptors for any outputs of the ISG project
- The coal measure sequence of coal seams and overlying and underlying strata has extremely low permeability with no aquifers. This results in no pathways for causing environmental impact away from the ISG gasifier
- Surface and groundwater flows within the now isolated coalfield all drain toward old mine pits, where evaporation exceeds all water inflow and it is an internally drainage sink. There are no aquifers or useful groundwater within the mine area which can be contaminated.
- Surficial strata in the valley of the former Leigh Creek overlies the coal measure sequence, but are now cut off from the regional drainage and are dry apart from intermittent local rainfall events which drain into old mine pits.
- The ISG gasifier cavity will contain low levels of COPC after operations have ceased and the cavity has been cleaned. This cavity is within coal seams which are surrounded by aquicludes which restrict the COPC moving to any environmental receptor. Natural degradation of COPC through biogenic activity and adsorption to minerals will destroy COPC before they can escape from their impervious host rocks.

### Interaction of ISG project stages with site properties

During gas production the gasifier will be surrounded by impervious strata that will prevent gas and other fluid loss. All strata, the coal and surrounding beds have extremely low permeability and fault planes are sealed by clays. Despite the low permeabilities the groundwater piezometric surface is only around 50 metres below surface, providing a suitable pressure for operation of the deep gasifier.

> *During gas production pressure in the gasifier should be held below groundwater pressure preventing flow of gas, water or COPC to surrounding strata which will be further prevented by the extremely low permeability of both coal, roof and floor of the coal seam*.

After production has stopped the gasifier is decommissioned and cleaned. Oxidant injection is stopped, the pressure in the gasifier is reduced, water is injected to cool the cavity as quickly as possible, and COPC are flushed from the cavity with vented steam generated from injected water. Once the cavity has cooled and steam is no longer generated, gas in the cavity is kept below groundwater pressure and the cavity is allowed to fill with groundwater. This will be an extremely slow process given the low permeabilities, taking decades, during which flow is always into the cavity with no movements of COPC away from the cavity.

> *During decommissioning gasifier pressure should be held low while the cavity is being steam cleaned and then filled with groundwater. Any fluid flow is always into the cavity preventing loss of COPC from the gasifier cavity.*

When the cavity is full of water, the contaminated water body becomes part of the regional groundwater movement which flows upwards to the old mine pits. Predicted water movements for the Leigh Creek ISG site suggests travel to the closest pit will take 600-6000 years, probably in the thousands of years.

During cavity filling and water movement towards the pit, two processes are reducing the concentration of chemicals. One is natural degradation by biogenic agents which feed of the organic compounds and the second is adsorption onto the organic rich coal and mudstones. These degradation rates can be predicted from experience and experimentation and it is probable that before COPC in the water could reach the surface pits, their concentration would be reduced to non-detect levels.

If COPC in water did reach the pit, the water will evaporate (evaporation rate greater than water accumulation rate in the pit) and release the volatile organic compounds to air. The concentrations and release rates will be so low that the COPC will not be detectable, and in addition, there are no environmentally significant receptors in the pit areas.

> *Natural attenuation of COPC concentrations will proceed much quicker than regional groundwater flow so COPC in the gasifier cavity will never impact on any environment receptor.*

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| Geological conditions indicate that a ISG cavity in Leigh Creek coal containing COPC will be isolated with no pathway for COPC movement, and no receptor of harm if there was any movement and COPC will naturally attenuate to non- detect levels. On the evidence available with respect to geological and hydrological conditions, there is no feasible mechanism to cause any environmental harm from COPC movement through natural underground processes at such a ISG site. |

# Monitoring for gasifier impacts in underground strata

## The purpose of monitoring

Despite the lack of any known process for contaminant from an in situ coal gasification cavity to impact on any receptor via underground processes, it is advantageous to confirm this situation for a demonstration such as the Leigh Creek ISG project. This could be done with a monitoring program to test for potential gas loss or contaminant escape mechanisms. Although this monitoring might demonstrate in a convincing way that environmental controls are being implemented effectively and the ISG process can be carried out with full environmental compliance at this location, it also raises the possibly of generating contaminant pathways not naturally present.

With new industries such as in situ gasification of coal, there is no international standard or commercial industry experience to guide a regulatory process. On the one hand operators must be held to account and prevent any negative environmental impacts, but on the other, regulations cannot be so restrictive that it interferes with innovative new processes or the management of unexpected events which might occur due to natural features or inadequate equipment specifications. The proposal to follow a similar method to that effectively applied to the successful Carbon Energy UCG project in Queensland is endorsed. This approach involves setting an absolute boundary to any negative environmental impact around the gasification site, which if compromised will result in shutdown of the project. Within this area the operators must monitor for environmental impacts and have the ability to experiment with remedial methods and develop control strategies to deal with any unexpected developments. This supports the essential learning process that allows the development of robust new industries, while maintaining protection of the environment.

This can be achieved with a monitoring network that guarantees identification of any significant environmental impact and processes that might have a material effect on the movement of material released from the ISG gasifier. The focus for monitoring of environmental parameters in the underground is

- Excursions of water borne or gaseous phase COPC from the gasifier into surrounding rock. (There are no aquifers in the strata)
- Changes to groundwater flow paths as indicated by groundwater pressure changes
- Detect increases in concentration of existing soil gases that originate from the gasifier

> Regulation by establishing an absolute compliance buffer zone protecting baseline conditions around the gasifier, in conjunction with sentinel monitoring wells for groundwater pressure, flow and COPC distribution is endorsed

## Generating artificial flow paths with monitoring wells

The most likely locations for water borne COPC which have escaped from the gasifier is in the coal seam being gasified and the overlying and underlying rocks. The concentration of COPC being investigated is very low, generally down at levels of detection for the compounds. This imposes extremely strict criteria for the construction and sampling of the wells. Despite providing careful instruction for drillers, in the author’s experience, a significant number of monitoring wells end up with some internal contaminating factor. Fortunately these often relate to a specific chemical and the well is still useful for the identification of the characteristic coal pyrolysis products representative of coal gasification. They do however provide a ‘dirty’ analytical data set that can give the impression that COPC have escaped to members of the public, when it is not the case. This re-enforces the need for a good set of background groundwater analyses that can confirm if COPC have migrated to the monitoring site.

All strata in the coal measures at Leigh Creek have very low permeability, which has important implications for monitoring. Because any water movements are likely to be only over a short distance, the monitoring wells need to be closer to the gasifier than has been used in previous UCG sites, to have any possibility of detecting events.

Water inflow to monitoring wells will be quite limited and it may not even be possible to get frequent samples if recharge rates are too low. Without intervention, monitoring wells will accumulate very little water, which is exacerbated by the requirement for regular sample removal. This will create an extreme low groundwater pressure point at the base of the water sampling wells which are established close to the gasifier cavity containing COPC. This creates a contaminant pathway and flow mechanism that does not exist naturally, and would not occur without the monitoring well. The purpose of the monitoring well is potentially compromised. Possible outcomes are

- No COPC are detected in the monitoring well and it is conclusively demonstrated that COPC will not move out of the gasifier cavity to nearby areas in the experimental time
- COPC with ISG characteristics are seen in the monitoring wells. This would show that under extreme and unnatural pressure conditions, water containing COPC can be induced to flow between the gasifier and the monitoring point in the experimental time. It would not indicate that this flow would occur if the monitoring well was not present.

- Timing of COPC events can provide data on the hydrological properties of strata and potential for COPC migration

The source of this difficulty is the low pressure established at the base of the monitoring well. While this could be remedied by filling the monitoring well with water, it would make it difficult to obtain a representative water sample.

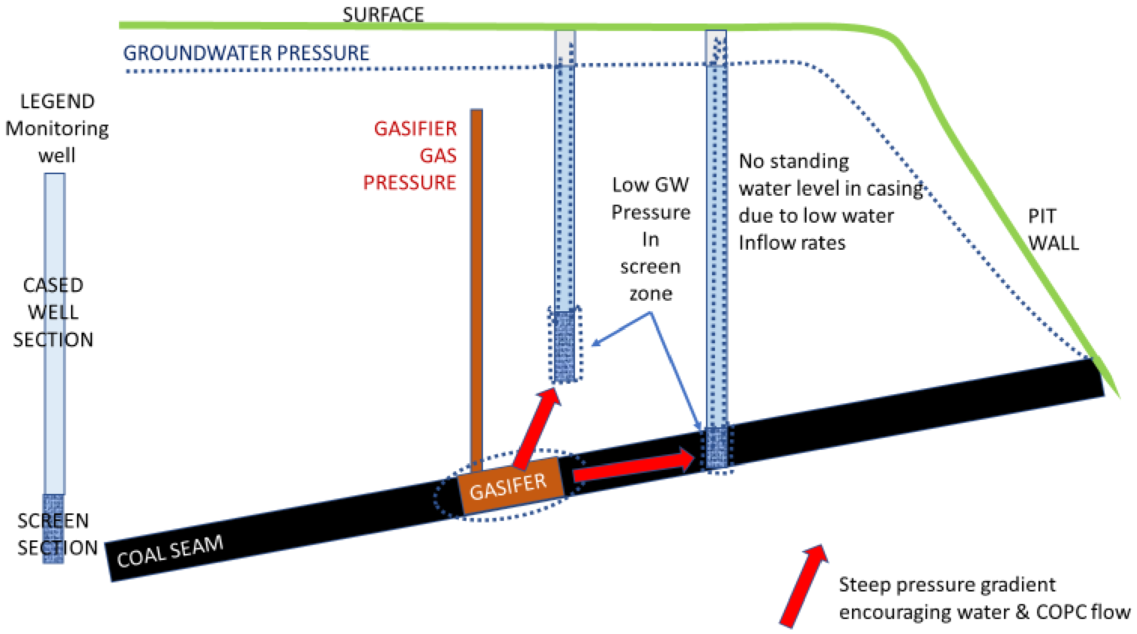


**Figure 1 A cross-section through the Leigh Creek gasifier site illustrating the impact of monitoring wells of fluid flow. A typical monitoring well is cased down to the sample interval where a screen is installed. As no significant standing water level is developed in the well due to low water inflows, the base of the well becomes a low pressure point in surrounding groundwater to which groundwater flow is induced. This creates a potential flow path from the gasifier to the monitoring point that does not naturally exist**.

The operator has proposed using the monitoring points at 50m as environmental indicators but considers that the monitoring well close to the gasifier will be unrepresentative of natural flow conditions and irrelevant as an environmental indicator. This is a reasonably position as the monitoring point very close to the gasifier is at much greater risk than those at 50m. Permeability measurements obtained in strata are very low, which suggests that even with the extreme pressure differential created by the monitoring well at 50m, it is unlikely that these pressure effects will extend as far as the gasifier during the life of the operation. This assumption may not hold if the site continues monitoring during a long term rehabilitation phase.

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| Monitoring wells can create contamination pathways not naturally present and data interpretation should consider impacts on sampling results |

## Surface impacts of a deep ISG gasifier

The presence of in situ coal gasification products have been detected in gas samples from the unsaturated zone overlying UCG sites, eg Rawlins in Wyoming. The chief indicators have been the major constituents of syngas, hydrogen, methane, carbon dioxide and carbon monoxide, which are gases typically found naturally in soil gas, particularly over organic rich deposits or petroleum accumulations at depth. These gases are not considered as COPC as they occur naturally, but their concentrations might increase near gasifiers compared with background values. Diffusion of COPC from the deep gasifier will be detected in the deep monitoring wells long before it can arrive at shallow monitoring wells.

Location of monitoring sites around both the inlet and outlet areas of the gasifier will not discriminate between gas which may have diffused to the surface through strata and gas that has moved through pathways created by faulty well construction.

> Near surface monitoring wells are unlikely to detect any COPC from a deep ISG gasifier, but may possibly experience changes in composition of existing soil gases by addition of syngas components

# Proposed Underground infrastructure and its impact

## Gasifier wells

Constructing an ISG gasifier underground involves a minimum of two boreholes which intersect in the target coal seam. One borehole (Inlet Well) is used to deliver the oxidant to the gasifier, and the second (Outlet Well) carries the product syngas to the surface. An observation well is positioned within the expected gasifier cavity and provides essential information on conditions in the gasifier during operation. The coal is ignited at a point along the Inlet Well where a gasification chamber grows, with the produced gas flowing to the Outlet Well. Temperatures in the gasifier cavity can be up to 1600ºC, and the outlet well and Observation Well are exposed to hot gas.

- Outlet well: This well conducts the hot product gas to the surface, and variation of gas flow in the well is the main method used to control pressure in the gasifier.
  - The well must maintain its gas pressure integrity in the high temperature and pressure that will be experienced at the bottom of the well, closest to the hot gasifier. Designs have incorporated high specification steel casing, special high temperature threads on casing, and high temperature cements, representing best practice for UCG production wells.
  - Outlet well failure has occurred at UCG sites eg Cougar Energy at Kingaroy, and careful supervision and testing of the installation after construction is critical.
  - A water cooling system to keep the temperature of the base of the well within design specification is included. It should be verified that this system will operate in the conditions expected in this well, as high temperatures and vaporisation pressures can lead to failure in these systems.
  - If the gasifier cavity grows rapidly towards the base of the Outlet Well, it could expose the well to extreme temperatures, which could destroy the bottom of the well casing and any cooling and monitoring equipment. Monitoring of gas temperatures should provide warning before significant damage can be done, and adjustments would be made to the demonstration program.

> Outlet Well is vulnerable to construction faults and encroachment by the hot gasifier cavity

- Inlet well: This well is angled from the surface to the coal seam and continues for over 150m in-seam near the base of the coal seam, until it intersects the Outlet Well.
  - The well is lined with cemented casing from surface into the horizontal section within the coal seam. A liner to carry the injected oxidant (air) is inserted into the cased well and extends into the open borehole section beyond the cased section. Ignition of coal will occur at the end of this liner, and the gasifier cavity will grow from this point towards the Outlet Well. Apart from the end of the liner, this well is not exposed to high temperatures and is unlikely to pose any risk to the integrity of the gasifier.
  - It is intended to use a single oxidant injection point location throughout the trial. The design drawings for the Inlet Well (Playford 23 (Inlet) Drilling Program Rev 1 19/04/18) specify the final section of the inlet liner from the end of the cemented cased section at 675m will be slotted casing for 100m to 775m, the position where the coal will be ignited by the ignition tool inserted down the Inlet Well liner. Under this

design, in the section from 675m to 775m, air will be flowing both down the liner and the annulus of the borehole exposing the coal in this section to oxygen. This introduces an uncertainty into the location that the cavity will grow. If air flow rates are high, it will force gasification to advance towards the Outlet Well. With low flow rate the gasification can move in a reverse direction. The coal in this zone could also spontaneously combust anywhere along its length, initiating a new cavity or shifting the gasification location of the original cavity.
    - I have not seen any documentation that indicates intended controls of the injection point position during operation, but as the intention was to only have one cavity in the demonstration, the substitution of an intact liner in place of the slotted section from 675m would limit uncertainty with respect to the location of injection.

> LCK should reassess the design of the Inlet Well liner to maximise control of where the gasifier cavity is located with respect to the Inlet Well

- Observation Well groundwater monitoring well pre-installed to intersect the gasifier
    - This well is a critical component for operational control as it will report the gas pressure within the gasifier. It will directly access the hot gasifier and will be subject to the most extreme conditions of all wells. Specifications for its construction materials are the same as the Outlet Well.
    - The well is intended to provide access to the gasification cavity at the conclusion of production.

> The Observation Well will be exposed to the most extreme conditions in the gasifier and will test the efficacy of specifications to manage high temperature

## Wells monitoring the deep gasifier

- five piezometer monitoring wells with vibrating wire piezometers positioned at multiple depths and located around and above the gasifier.
    - These wells are fully grouted and are unlikely to create any environmental risk in their construction. They provide essential information for determining a safe operating pressure for the gasifier
- four sentinel groundwater monitoring wells sampling from sections in and adjacent to the coal seam approximately 50 m laterally from the gasifier
    - These wells are substituting for compliance wells at the 100m barrier zone. They are fully grouted to above the sample horizon which is protected by a screen and are unlikely to create any environmental risk in their construction. No significant standing water column is expected because of the low permeability of the sample zone, which means the sample zone creates a low pressure area within the regional groundwater which will increase any groundwater movement towards the well. This low pressure affect will be localised to the immediate vicinity of the well because of the low strata permeability and it is not expected to see any impact related to the gasifier. Gas pressure within the well will be measured, which might detect transferred gasifier pressure (if it exceeded groundwater pressure) or the pressure of gases diffusing through groundwater from the gasifier. Both these processes are suppressed by low permeability in the strata and are considered unlikely to affect these sites.
- Gasifier operational monitoring well located as close as possible to the gasifier chamber in the coal seam approximately 10 m laterally from the gasifier
    - This well is an open well for sampling water close to the gasifier cavity. It is expected to accumulate little groundwater and be a low pressure point in the groundwater close to the gasifier. It will potentially create a pressure driven flow path between the gasifier and the monitoring well and could possibly detect COPC drawn from the gasifier. This would take some time to occur and the time involved will provide insight into the potential for COPC to migrate through the coal seam. If COPC was seen in

the well and became a matter of concern, they could be flushed back to the gasifier by pumping water down the well, reversing groundwater flow.

> The gasifier operational monitoring well could induce COPC flow from the gasifier which would not occur without the monitoring well being installed

### Wells monitoring in the near surface

- two sentinel groundwater monitoring wells located in the Main Series Overburden above the gasifier at approximately 80 m below the ground surface
    - Wells to detect if there is any movement of COPC from the gasifier to the surface. It is not expected to see any impact of the gasifier in these locations as groundwater movement which contained COPC would follow regional groundwater flow paths towards the base of the highwall in old surface mine pits and not move to the surface above the gasifier, and diffusion of COPC through water to the surface will be slow due to slow diffusion rates of large organic molecules and the low permeability that inhibits diffusion

- three groundwater monitoring wells located in the Main Series Overburden at approximately 80 m below the ground surface at background locations distant from the gasifier and demonstration plant
    - These wells are to determine the background levels of COPC in shallow strata

- seven soil vapour and seven groundwater monitoring wells located in surficial sediments (Telford Gravels) above the gasifier and around the demonstration plant
    - Environmentally sensitive compounds can occur in the gaseous phase within soil gases, and it would be significant if they can be found in soil gas overlying a deep in situ coal gasifier. It is considered unlikely to occur with such a thick cover of impervious strata overlying the gasifier at Leigh Creek. The only credible route for COPC vapours in these wells would be from failed completions in the Inlet and Outlet or monitoring wells.

> These wells are unlikely to detect COPC from the gasifier at depth. Syngas components may be detected in soil gas.

## Establishing background water quality

Background water compositions are best established before the gasifier commences. The operator has established a long term monitoring site 600m from the gasifier location which has provided a year's consistent compositional data, suggesting it is representative of the water quality within the rocks. The samples already contain significant amounts of the main COPCs associated with UCG projects elsewhere, so it is very important that this has been established over a long period. The rocks of the coal measures are relatively uniform across the coal basin and given the uniformity in lithology it would be expected that associated groundwater would also be consistent, and the long term analyses already obtained will be representative of the area.

It is noted that monitoring wells have only recently been established at the gasifier site, and that it is not uncommon for water sample compositions to take some time to equilibrate to the local in situ groundwater composition after well construction. It is necessary to demonstrate some consistency and stability in analytical results for COPC in these new wells, or else have some other criteria that confidently identifies ISG sourced chemicals, if they want to identify excursions of gasifier cavity water. In the current situation, steps in establishing background water quality could include

- Identify if initial samples analysed after well construction at the gasifier site are representative of the in situ groundwater using relative percentages of chemicals or isotopes.
- The baseline established at the existing long term site is a reasonable basis for natural groundwater conditions at the gasifier location. Assessment of impacts from the gasifier would then be based on variations to these established data sets.

- If samples are not consistent with expectations for background quality, initiate active intervention to establish real in situ groundwater conditions in the monitoring wells at the gasifier site as quickly as possible, for example bailing or pumping out water which has been introduced to strata during well construction.
- It is reasonable to assume that drilling sourced water in a narrow zone immediately around a monitoring well would be removed long before any migration of COPC could occur over 50m from the gasifier, allowing for a period when local baseline conditions will be verified.
- Naturally occurring COPC constituents in groundwater will occur in different ratios to those sourced from ISG, and can be used to distinguish between in situ chemicals and chemicals that were derived from the ISG gasifier.

A Register of monitoring wells should have an up to date status on each well specifying any impact on COPC in samples which results from well construction (both internal and external to the casing) that prevents the samples reflecting actual groundwater quality

Any methodology must not only to be scientifically rigorous, but must also be easily understandable in the light of the public scrutiny of the project.

## Typical COPC with in situ coal gasification

The typical suite of COPC for underground coal gasification should be used as the indicator of gasifier sources COPC. Not all chemicals which are associated with the gasification process have the same potential to migrate into adjacent groundwater. The typical suite of UCG chemicals which were present in groundwater at the Carbon Energy UCG site were averaged and normalized to show the relative proportions of the most significant chemical species with the major component, benzene, set at 100. This gives the “signature” of potential UCG impact for that site, and is important as it allows the differentiation of UCG products from any other chemicals found in the monitoring network.

| Chemical | Relative Proportion |
|---|---|
| Benzene | 100 |
| Toluene | 57.5 |
| Naphthalene | 17.8 |
| Ethylbenzene | 7.9 |
| Xylenes | 6.6 |
| Phenol | 1.1 |
| other phenols | 0.9 |

Although some variation in the suite of chemicals can be expected between locations, the relative proportions are so differentiated that it should have relevance generally.

The proposed monitoring locations in and around the gasifier coal seam proposed by the operators should be adequate to detect any significant migration of COPC through advection of water from the gasifier cavity. As discussed at the beginning of this section, it is not considered likely that COPC bearing water will migrate out of the gasifier, and these wells are expected to verify this position.

Detection of COPC in water samples which are not dominated by benzene are unlikely to originate from an ISG gasifier

# Operating protocols for underground processes in ISG

The bases for operating protocols are compiled in Statement of Environmental Objectives (Waters & Milne April 2018) tables for implementation, controls listed in the Bowtie Risk assessment (Baker D April 2018), and in the Groundwater and Soil Monitoring Plan Section 4 (Vaerenbergh 6 June 2018) There are short comments on gasifier rehabilitation in the report on Rehabilitation of the site (Waters M, 10 May 2018). These short summary documents indicate that there is good understanding of the requirements for safe environmental management of ISG and suggest that best practice will be applied in operations.

Cavity growth

The demonstration plans to operate a single Linear CRIP design gasifier which essentially has a fixed oxidant injection point and a fixed gas extraction point at the bottom of the Outlet Well. The gasification chamber will grow between these two locations, starting at the ignition point in the Inlet Well then expanding and extending toward the Outlet in a tear shape. The anticipated gasifier development has not been described in detail, but it would be expected that during the demonstration the regular reports would describe progress. There are a range of data that can be used to interpret gasifier growth and surrounding changes, including

- Coal gasified – calculated from produced syngas volume and composition
- Temperature changes - sensors around the cavity and in the Outlet and Observation Well
- Groundwater and gas pressure – sensors around the cavity
- Groundwater quality – migration of COPC into monitoring sites

Changes in these parameters should be continuously monitored and the increasing size of the gasifier tracked. Although it is not expected that the lateral growth of the cavity will be known, the size of the cavity will be a guide to interpreting any changes. The comprehensive monitoring will allow the identification of any potential issues such as:

- Cavity encroachment on the base of the Outlet Well. If the cavity spreads right up to the Outlet Well the high temperatures could exceed specifications
- Excessive caving with growth of the cavity upwards into roof strata, and damage to the Observation Well
- Reverse gasification with the gasifier cavity growing up the inlet well

Geotechnical modelling by Ikon has indicated that gasifier pressures should not initiate fractures in surrounding strata and described the stability fields for boreholes. A comment was made in one review that deformation would develop around the cavity with roof fracturing extending up to 50m above the gasifier. No technical analysis has been provided on this, but from my experience in coal mining, 50m is a reasonable assumption. Mine planning software can accurately predict changes in roof rocks but is not essential in this case as it is not credible that damage could have any measurable impact on the surface or ANY significant environmental factor. One objective is to determine any changes to roof strata after conclusion of the demonstration. When this data is gathered it can be compared with computer modelling and the model calibrated for the Leigh Creek site. This would be an important capability in planning future multi-panel ISG at Leigh Creek.

# Appendix 1

# Project Documents

Baker D, In Situ Gasification – Bowtie Assessment, R4 Risk for Leigh Creek Energy, Release 2, 11 April 2018

Burmass A, HAZHOP Report, Leigh Creek Energy, LC02-RPT-002, Revision 0, 26 April 2018

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