

LNG FROM CSG—CHALLENGES AND OPPORTUNITIES

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ABSTRACT

There are huge potential resources of coal seam gas (CSG) around the world, particularly in Russia, Canada, China, USA, and Australia. In recent years, there has been considerable interest in the production of LNG from CSG as evidenced by the projects currently being developed in Eastern Australia and China.

Commercialisation of CSG production has been demonstrated, primarily in the USA, Canada and Australia. These commercial operations are relatively small compared with the very large upstream developments required to support a world-scale base load LNG facility. For example, an LNG facility producing one mtpa of LNG from CSG may require in the region of 500 wells spread over a vast area.

This paper addresses a number of the key technical challenges faced by developers of CSG-to-LNG projects. The design, construction and operational logistics associated with the wellhead and feed pipeline developments are reviewed with particular focus on the integration of the upstream development with the LNG plant and the design of the LNG liquefaction facility. These challenges include the high demand reliability required to ensure the CSG wells are not shut-in (which leads to water flooding), the impact of feed gas composition on the facility configuration and the suitability of the resultant low heating value LNG product for the LNG market

INTRODUCTION

Interest in the commercial-scale production of LNG from coal seam gas has increased dramatically in the last two years, particularly in Queensland, Australia where several projects are under development with the prospect of becoming the world's first CSG-to-LNG base load export facility. Domestic gas supplies in several countries, notably the USA, Canada and Australia, already utilise coal seam gas to supplement conventional natural gas sources.

This upsurge in interest in the development and exploitation of coal seam gas as a potentially plentiful alternative source of energy is now fuelling a wider search for coal seam gas in other parts of the world, a proportion of which is likely to be monetised by the production of LNG for export.

BACKGROUND

Coal seam gas (CSG), also known as coal bed methane (CBM), is a form of methane-rich natural gas which is found in geologic structures associated with deposits of coal. The presence of this flammable 'coal gas' was known to the Chinese in antiquity, but its reputation was really forged in the coal mines of the Industrial Revolution in which explosive mixtures of 'firedamp' (methane) and air caused many terrible accidents involving great loss of life. Its feared reputation rightly persists but its potential value to mankind as a natural alternative source of energy began to be appreciated in the last quarter of the 20th century.

The main constituent of CSG is methane, accompanied by carbon dioxide and some nitrogen, plus traces of ethane. Other customary 'natural gas' components such as propane and heavier hydrocarbons, condensate liquids and hydrogen sulphide, are entirely absent. The relative proportions of methane and carbon dioxide can be quite variable from region to region, but commercially attractive CSG resources will generally have a methane content in excess of 90 mol%. Typical CSG and natural gas compositions are compared in Figure 1.

Gas Composition (mol %)	CSG (typical)	Natural Gas (typical)
Methane	95.0	83.0
Carbon Dioxide	3.0	2.5
Nitrogen	2.0	1.5
Ethane	Trace	6.5
Propane	Absent	3.0
Butanes	Absent	1.5
Condensate (C5+)	Absent	0.5
Hydrogen Sulphide	Absent	1.5

Figure 1. Typical Compositions of CSG and Natural Gas

Methane is a natural by-product of the degradation of organic material and in terms of its association with coal deposits, it is the younger – and therefore shallower – bituminous coal beds which hold the highest reserves of recoverable CSG. The most productive coal seams occur at

depths between 200 – 1,000 m and this means that CSG wells are shallow when compared to conventional oil and gas wells.

The manner in which the CSG is held within a coal seam is quite different to that of natural gas within a 'conventional' reservoir, and it is worthwhile describing the differences because they have important consequences on the methods and nature of CSG extraction.

In conventional reservoirs, hydrocarbons are trapped in porous rock strata, such as sandstone, through which they are able to migrate with relative ease, enabling gas, oil and water phases to separate into separate layers within the reservoir which are then accessed by drilling to the appropriate level. High fluid mobility means few wells are required.

Coal, however, is not a permeable rock in the conventional sense, and fracture lines (or 'cleats') provide the only channels through which gas is able to migrate through the seam (see Figure 2). Furthermore, the methane was formed in-situ within the solid coal matrix and is held in place by hydrostatic pressure exerted by groundwater which commonly saturates coal seams. Considerable quantities of water must be removed first to allow the CSG to desorb, but even then the rate of gas diffusion from within the solid coal matrix is slow and its subsequent migration is hindered by low pressure differential and by the constricted nature of the cleats. These factors mean that a large number of wells are required to extract commercial quantities of CSG, resulting in downhole well spacings in the range 500 to 1,500 m – a very different arrangement to conventional gas wells. The manner in which the CSG is held within the coal matrix does, however, have one big upside – a given volume of coal can hold up to seven times as much methane as an equal volume of conventional reservoir rock.

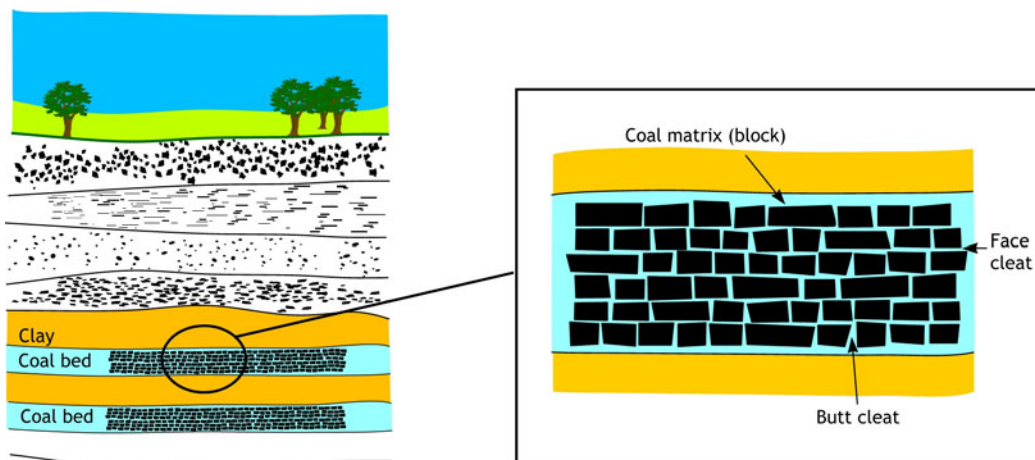


Figure 2. Representative Diagram of Coal Seam Indicating Presence of 'Cleats'

In terms of coal reserves with the potential to yield CSG, the largest proven reserves are currently believed to be in Russia, Canada, China, the USA and Australia, but there is burgeoning interest in exploration for commercial reserves of CSG around the world and evaluation programs are underway in locations as diverse as India, Bolivia, New Zealand, South Africa, Indonesia and the United Kingdom.

PREVAILING SITUATION

The last quarter of the twentieth century witnessed the first large-scale efforts to extract and use CSG to supplement natural gas supplies for domestic consumption. Serious drilling operations specifically intended to recover CSG began in the USA in the 1980s, and this relatively unappreciated fossil fuel now contributes approaching 10% of domestic gas consumption in the USA, and up to 20% in Australia, meaning that CSG production is now an established technology.

Unsurprisingly, the first developments of CSG reserves took place in areas conveniently close to existing natural gas distribution networks, meaning that sufficient demand and the infrastructure required to distribute the CSG product (in blend with natural gas) were already in place – such as in the USA, Canada and Australia. Tax breaks have been selectively used to promote development of this alternative indigenous source of energy. What's been missing until relatively recently, however, has been any 'driver' to seek alternative ways to monetize CSG via, for example, LNG production and export. Key inhibiting factors have been the relatively low production levels of CSG (and sufficiency of domestic outlets), the absence of established LNG players in the CSG development business and, perhaps, the absence of coal/CSG reserves (and abundance of conventional gas reserves) in the Middle East. Nevertheless, the situation outside the Middle East appears to be changing rapidly. Efforts to explore for and evaluate CSG reserves are yielding very positive results, particularly in Australia, and as a consequence the world is beginning to appreciate that global CSG reserves may be comparable to those of conventional natural gas. China has recently announced the start up of a small-scale plant to produce LNG from CSG for in-country use and the past two years have seen much activity in Queensland, Australia as established oil and gas majors (e.g. Shell, BG Group, PETRONAS, and ConocoPhillips) have moved to secure stakes in CSG reserves and in competing CSG-to-LNG projects proposed to be constructed around the port of Gladstone. CSG to LNG has suddenly come to life.

So what are the challenges and opportunities which face this novel application and combination of established technologies? The following sections aim to provide an overview of the answers to this question.

COAL SEAM GAS EXTRACTION

Current indications are that the first major projects proposed to monetize CSG via LNG, specifically those proposed for the eastern seaboard of Australia, will be based on medium-scale LNG plants producing in the range 1.5 to 4.0 millions of tonnes per annum of LNG. There are several reasons for selecting a medium-scale production target.

Firstly, the number of CSG wells required to support an LNG plant at the upper end of this range is substantial. At least several hundred wells are required to support initial production, and a rolling program of well development will be required to maintain production as the field ages and gas production declines from older wells (refer to Figure 3).

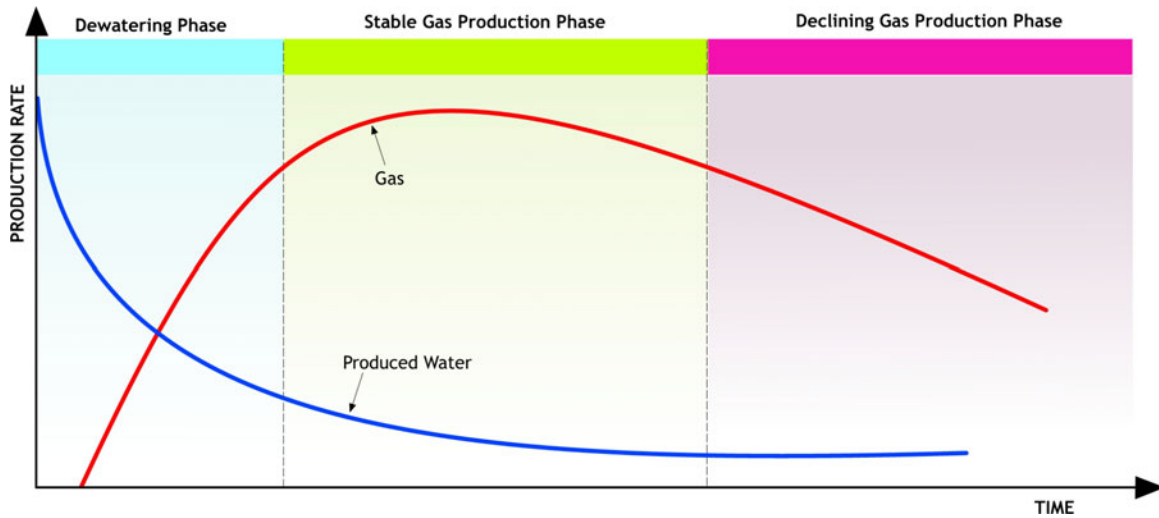


Figure 3. Typical Production Profile for a CSG Well

In total, approximately 3,000 wells may be required to service an LNG plant over a lifetime of say 20 years, individual well life being in the range from five to more than 20 years. Though each well (illustrated in Figure 4) is shallow and of relatively small diameter (typical range 100 to 300 mm) and may take only one week to drill, nevertheless drilling and completing so many wells is a time-consuming task. Thus it can be argued that field development logistics alone favour selection of a modest LNG train size (towards the lower end of the current 'commercial' range of train sizes), at least for the first train.

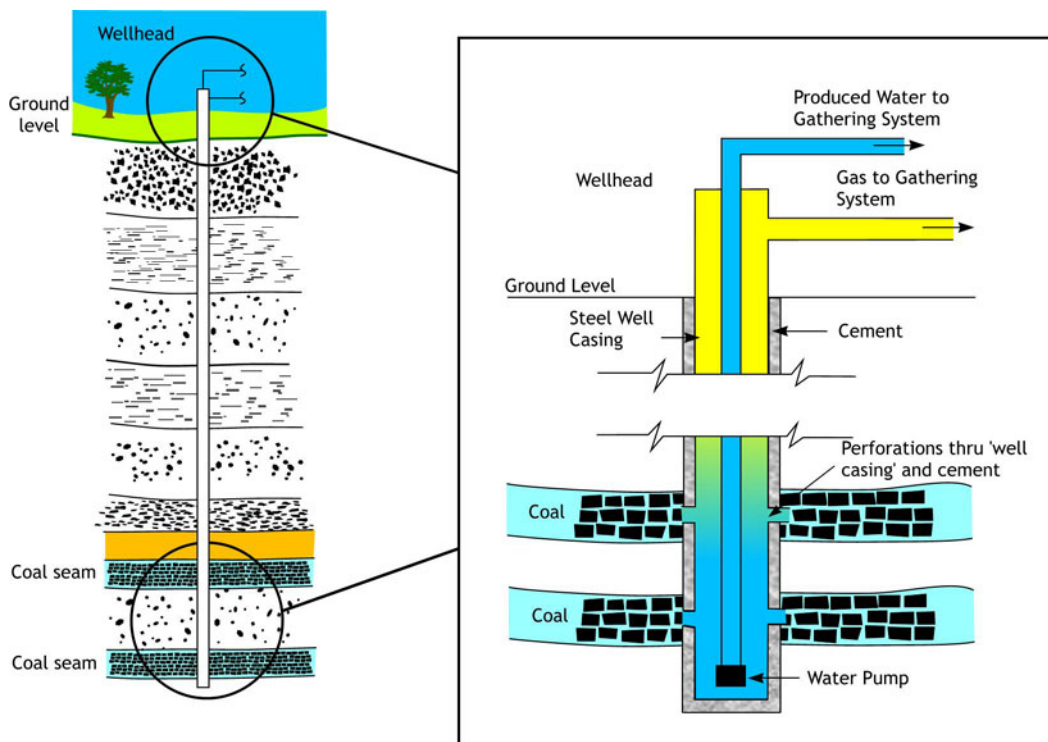


Figure 4. CSG Production Well Schematic

Another factor which may impact on the selection of initial CSG / LNG production scale is the presence of ground water in the coal seams. Not only must a substantial quantity of water be pumped from each well before CSG production can become established (and this may take several months, or longer, per well) but, once CSG production is underway, it is necessary to avoid interruptions to gas extraction in order to hold the groundwater at bay. If gas extraction ceases, water can quickly re-saturate the coal seam and subsequent dewatering may take weeks or months to complete before gas production becomes fully re-established, which would be an intolerable situation for an LNG exporter operating under contract. Various design and operation strategies can be considered to mitigate this risk factor (and these are discussed later in this paper) but one important option is to design the LNG plant for very high reliability and availability in order to minimize the risk of unplanned shutdowns requiring CSG wells to be shut-in. This will encourage operators to select robust, well-proven technology, as represented by a medium-size LNG train, and perhaps consider other LNG plant design enhancements (again discussed later) in order to further reduce risk of total shutdown. It is expected that the significance of the risk posed by groundwater will reduce over time, partly because older CSG wells are thought less likely to suffer catastrophic flooding (so much groundwater having been already removed) and partly because older LNG plants are likely to have been expanded by the addition of more trains, which should mean less risk of a total complex shutdown.

Aside from the large number of wells required and the risks of water flooding, some of the other 'extraction' challenges which need to be recognized are:

Production variability. The characteristics of coal seams vary from well to well in terms of CSG content (reserves), permeability to gas flow (production rate), wellhead pressure and the tendency of ground water to interfere with gas production. These factors mean that each coal seam has to be evaluated by sampling and testing over a wide area. Fortunately, the large number of wells means that the impact of local variability can be effectively handled by the effects of 'averaging' from multiple wells: some may be less productive than expected but others will be above average.

Disposal of produced water. Significant quantities of 'produced water' (ground water from the coal seam) will probably need to be removed before CSG production can start. This water may be fresh or brackish water suitable for direct use for irrigation (for example) but other produced waters may be salty and require purification (e.g. by reverse osmosis) prior to use or discharge to an existing water course. An additional complication may arise if there is risk of any communication between ground waters held within regular aquifers and those present in the coal seam, since depletion of aquifer water is likely to meet with strong local opposition.

Low gas pressure. The CSG produced at the wellhead is most likely to be at low pressure (e.g. around 1.0 barg), meaning that local compression cost for transport by pipeline will be higher.

On the plus side, factors which will play in favour of the use of CSG for LNG production are:

Security of supply. LNG produced from Australian sources of CSG (for example) will be coming from a politically stable area of the world which is conveniently situated for export to prospective markets in Japan and Korea. This should be an attractive proposition to LNG buyers who place security of supply high on their wish-list.

Reserves. The indications are that worldwide CSG reserves are going to be plentiful, so the development of CSG to LNG projects should come to be seen as developing from a niche technology market into a global player which is able to compete with conventional natural gas reserves.

Stable composition. The composition of CSG tends to change very little over the production lifetime of a well, which simplifies the design of downstream facilities. The nitrogen content tends to decline over time, whereas the proportion of carbon dioxide gradually increases. These changes reflect the differing affinities of coal for carbon dioxide, methane and nitrogen as illustrated by the Langmuir isotherm plots shown in Figure 5.

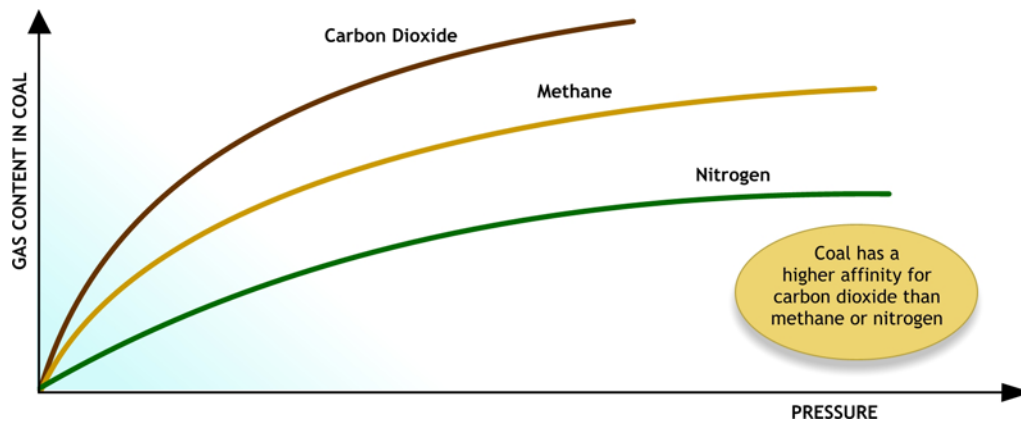


Figure 5. Relative Affinities of Coal for Main CSG Constituents

Proven technology. The commercial extraction of CSG from coal beds, though relatively recent in energy resource terms, is already a proven technology as discussed earlier.

Fresh water resource. Though the produced water may initially be perceived as of 'nuisance value' only, it seems likely that sources of fresh water production will increase in value in the future and, in the case of CSG extraction, its use (after treatment) for irrigation may promote the economic redevelopment of large areas of land for agricultural use.

Sequestration of carbon dioxide. The fact that coal has a higher affinity for carbon dioxide than methane - as illustrated in Figure 5 above - raises the possibility that carbon dioxide may be used to enhance the production of methane from coal beds, while at the same time allowing CO₂ to be sequestered underground. Programs designed to assess the viability of this 'double-benefit' technology are already underway around the world, including in Canada, the USA and the UK.

Potential reduction of methane emissions to atmosphere. Methane is one of the most potent greenhouse gases, approximately 20 times more powerful than carbon dioxide. Therefore, the deliberate extraction of CSG from shallow coal beds offers at least a possibility that some natural fugitive emissions of methane can be reduced, though the global impact may be small. Methane from abandoned mines is already recovered and used (locally) to minimise fugitive emissions, and prior CSG extraction would enhance mine safety where it is intended to mine the coal at a future date.

COAL SEAM GAS FIELD HANDLING AND TRANSPORTATION

Perhaps the main challenge facing developers of CSG resources is the geographical extent of the facilities required to extract and gather the gas. Given the potentially large number of wells and their dispersion over the countryside as described in the preceding section, the developer will need to operate over an area of several thousand square kilometres of land. This is likely to be a logistical challenge given that field development will probably impact on multiple landowners and be subject to regulation by central and local government agencies. But it's not an impossible task – it has already been done successfully in the USA, Canada and Australia.

On the plus side, though CSG in-field facilities may be numerous and geographically scattered, the majority are small in scale. For example, individual well heads each occupy only a small parcel of land (typically 10 m x 10 m) and comprise a small riser assembly and associated two-phase separator from which separate gas and water flowlines are led off to the nearest of several central treatment and compression stations. Alternatively, the application of angled and/or horizontal wells can enable wellheads to be grouped at the surface into cluster arrangements located within a larger lease area, permitting wellhead separation facilities to be combined and reducing the total number of flowlines running across country to the central treatment and compression station.

The CSG arriving at a central treatment and compression station is dried to pipeline specification (e.g. by TEG) and compressed up to pipeline pressure (typically up to 150 barg) for injection into the main gas trunkline. In most situations it is anticipated that each central station will also be provided with water treatment facilities for conditioning of produced water for local use. The unit operations employed in these central stations are all well-proven in conventional oil and gas field production facilities.

The precise configuration of the gas gathering and conditioning systems, and of the associated produced water treatment and disposal systems, will be subject to design study and optimisation on a project-by-project basis. It is expected that a modular design approach to in-field facilities will be favoured since this offers a possibility of achieving some economy of scale in the design and construction of numerous wellhead facilities and separation and compression stations. It can also facilitate future expansion of production by the addition of appropriate modules to keep pace with an ongoing programme of well-drilling, or by enabling facilities to be relocated to new production zones after early wells become exhausted.

LIQUEFACTION OF COAL SEAM GAS

Liquefaction of CSG can rightly be regarded as a relatively novel application of existing technologies for the liquefaction of natural gas and perhaps the main areas of technical concern arise from two particular issues:

- The lean nature of CSG due to the absence of any significant quantities of hydrocarbon compounds heavier than ethane. This means that CSG produces an LNG with a lower heating value (LHV) which is likely to be close to or beneath the minimum value normally specified by LNG consumers.
- The need to configure the design of the first LNG plant such that CSG feed gas intake interruptions due to both planned and unplanned downtime are reduced to an absolute minimum in order to keep the gas flowing from the CSG wells.

These concerns are addressed as follows:

Feed Gas Composition.

A lean feed gas will produce a lean LNG product, and in the case of CSG the LNG will be essentially pure methane containing up to the maximum permitted level of nitrogen, giving an LNG product with a Gross Heating Value (GHV) of approximately 37.26 MJ/m³ (1,000 Btu/scf).

In pure processing terms, a lean CSG feed gas permits significant simplification of the process scheme (refer to Figure 6). In the first place, LPG extraction facilities (e.g. scrub column), normally found at the front end of a liquefaction unit, can be deleted – since there are no heavy components to remove. Secondly, the absence of these heavier components in the feed means that there is no requirement for condensate stabilisation or LPG fractionation facilities, though one downside is that some refrigerant components used (and consumed) in the cryogenic refrigeration circuits (e.g. ethane and propane) will need to be imported to site because they are not available for extraction on-site from the feed gas.

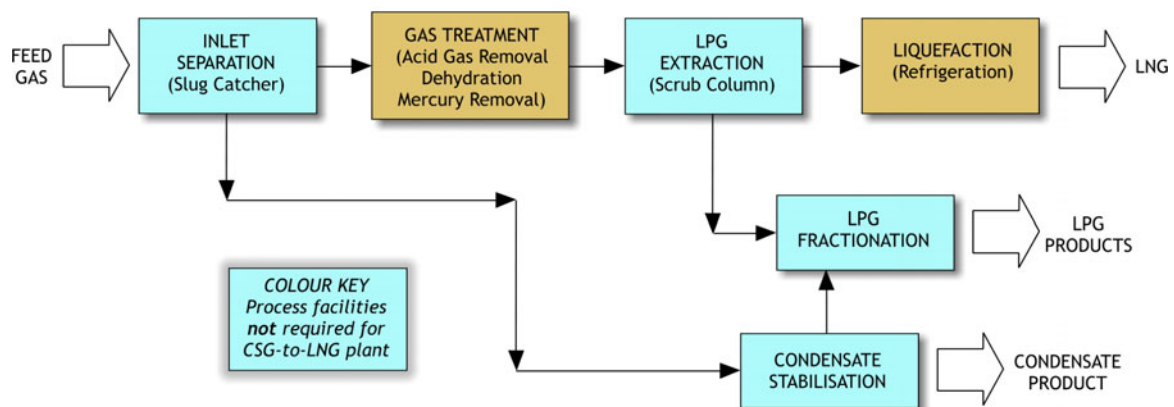


Figure 6. Block Flow Diagram of Typical LNG Production Facility

Another feature of CSG is the virtual absence of hydrogen sulphide (H₂S). This simplifies the design of the Acid Gas Removal section which can then be optimized for carbon dioxide removal alone. Furthermore, the absence of H₂S enables the waste acid gas stream from the regenerator to be vented directly to atmosphere (or re-injected underground) without further treatment, though provision may be included for a final incineration stage if some allowance for trace quantities of H₂S needs to be embodied in the design. Certainly, the complexity and unreliability associated with sulphur recovery plants is avoided altogether.

Considering the LNG product, there are a number of ways of handling the issue of low GHV. The first is to sell the lean LNG at a reduced price: the onus is then on the customer to either adjust the GHV of the re-gassed product by spiking with LPG components at the regassing terminal, or by blending with richer gas sources (if reliably available), or to utilize the lean gas in a specific purpose-designed facility such as a power station. Secondly, the LNG can be spiked with LPG components by the seller at the point of dispatch in order to meet customer end-use specifications; however, this would require the LNG complex to include facilities for the import of LPG components for dosing purposes.

A final point to note in terms of LNG product specifications is the need to meet maximum nitrogen content specifications. If the CSG feed gas is unusually high in nitrogen content, it may

be necessary to introduce a specific nitrogen removal step (beyond customary end-flash) in order to remove sufficient nitrogen, adding to operational complexity. As ever in all cases involving significant levels of nitrogen in feed gas, careful consideration will need to be given to the design of the nitrogen rejection facilities to assess whether the resultant levels (and variability) of nitrogen in fuel gas caused by the rejection strategy are compatible with on-plot fuel gas consumer specifications, particularly gas turbines.

Minimisation of LNG Plant Downtime and Avoidance of Unplanned Shutdowns

In cases where a CSG field is dedicated to feed the first train of a new LNG complex, the risk of an interruption in LNG plant operation causing a shutdown of the CSG production wells is seen as a significant risk to project viability because of the potential difficulty of re-establishing full gas production if the shutdown persists long enough to allow groundwater to re-saturate the coal seams around well sites. Consequently, various strategies may need to be developed to combat the risk.

Some of the strategies employed may rely on finding alternative outlets for the CSG gas in case of LNG plant shutdown, such as:

- Line packing – likely to be a short-term measure only.
- Diversion into a domestic gas user network, perhaps by backing out natural gas – but this assumes flexibility in upstream operations and will probably involve sale of gas at a distressed price.
- Diversion of CSG production for buffer storage in depleted conventional natural gas reservoirs (if available) for later recovery – but this will involve injection and recovery costs and may require additional processing of recovered CSG to overcome potential problems caused by contamination with heavier components and/or water leached from the reservoir.
- Ultimately, flaring of gas may be necessary to prevent flooding, though total quantities should be capable of mitigation by using turndown or shut-in of selected wells based on accrued operating experience.

As a result, it is probable that project teams will place an unusually high emphasis on the availability and reliability of the first phase of the LNG plant development in order to minimise any risk of serious interruption of CSG feed gas intake to the complex. Design strategies which can promote high availability and reliability factors include:

- Use of well-proven liquefaction technologies from licensors such as APCI, Shell and ConocoPhillips plus selection of a plant capacity which has a proven long-term operational record.
- Consideration of enhanced sparing of equipment to maximise uptime.
- Use of 2 x 50% (say) parallel strings of equipment or complete trains; this strategy is particularly beneficial to the reduction of 'unavailability' (i.e. avoidance of a complete shutdown) since a failure in a critical equipment item only has the potential to reduce throughput by (say) 50%, enabling significant CSG production from the wells to be maintained.

- Substitution of industrial gas turbine drivers by higher-reliability drivers such as aero derivative engines or electric motors – and here, a wider choice of drivers is facilitated by the selection of a mid-range LNG plant/train capacity.
- Greater reliance on the use of imported power (as main supply or back-up) from high-availability national grid systems.

Design Optimisation

Process configuration studies can be used to generate and evaluate potential plant configurations and the effectiveness of different designs in minimising downtime can be tested by RAM studies. As ever, the benefits of improved reliability and availability have to be tempered against any negative impacts on project capital cost, operability, etc., and it is inevitable that the final design choice will be a compromise between competing factors. It seems unlikely that a one-size-fits-all solution will emerge across different projects, particularly in the near-term when project developers – and investors – are likely to take a conservative approach to design until actual experience is gained of the operation of the complete supply chain.

CONCLUSIONS

Coal seam gas is already established as a viable and valuable alternative source of natural gas, and the current boom in exploration – and production – is set to underwrite its credentials as a major natural energy resource.

Though much CSG is already produced and consumed locally, nevertheless reserves in some areas of the world – notably Australia and Indonesia – are seen as more than sufficient to support the long-term production of LNG for export. Furthermore, the production of CSG from shallow onshore coal fields should be more economic than the recovery of natural gas from conventional reservoirs located offshore.

The technology to produce LNG from CSG is not only very similar to that employed for the liquefaction of conventional natural gas, but the LNG plant has the cost and operational advantages of requiring fewer processing steps. The resultant LNG product is 'lean' (as it lacks richer LPG components) but this is not expected to present a major obstacle to sales, as witnessed by the recent surge of interest among major players in the established LNG industry to take substantial financial interests in upcoming CSG-to-LNG projects.

The future for CSG looks bright and Foster Wheeler is delighted to be at the forefront of the drive to monetise CSG via LNG.

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