Global Development of Commercial Underground Coal Gasification

M S Blinderman
Ergo Exergy Technologies Inc.
Montréal, Québec, H2Y2R6 CANADA
michael.blinderman@ergoexergy.com

Abstract. Global development of Underground Coal Gasification (UCG) is considered here in light of latest trends of energy markets and environmental regulations in the countries that have been traditional proponents of UCG. The latest period of UCG development triggered by initial success of the Chinchilla UCG project (1997-2006) has been characterized by preponderance of privately and share-market funded developments. The deceleration of UCG commercialization has been in part caused by recent significant decrease of world oil, gas and coal prices. Another substantial factor was lack of necessary regulations governing extraction and conversion of coal by UCG method in the jurisdictions where the UCG projects were proposed and developed. Along with these objective causes there seem to have been more subjective and technical reasons for a slowdown or cancelation of several significant UCG projects, including low efficiency, poor environmental performance, and inability to demonstrate technology at a sufficient scale and/or at a competitive cost. Latest proposals for UCG projects are briefly reviewed.

1. Modern stage of UCG development (1997-2017)

A long period of global UCG development spawned by the energy crisis that started in 1973 was completed by the Rocky Mountain 1 trial in the US in 1988 and the European UCG trial in Spain in 1992. Following several years of lull and uncertainty, the Chinchilla UCG project in Australia marked the beginning of new era of UCG development in Australia, New Zealand, South Africa, Europe, Canada and the US. Spanning almost 20 years, this latest stage of UCG development was distinguished by a preponderance of privately funded projects with a significant share of the capital raised from stock markets.

It appears that this latest stage of UCG development has suffered considerably from the drop in fossil fuel prices in the world markets, and from the global commodity market slowdown. Whereas the reduced oil and natural gas prices seem to have affected new and existing UCG projects by decreasing projected sale prices of UCG products, the corresponding precipitous drop in coal price robbed many UCG proponents of the revenue that was intended for investment into new UCG projects.

An example of the latter was the shutdown of the Huntly West UCG plant in New Zealand. The commodity market slowdown led to the slower development the Majuba UCG project in South Africa. Reduced economic performance and the suppressed energy prices in, for instance, North American markets seem to have led to closure of the Swan Hills ISCG Project and deterred start-up of the Parkland County UCG project in Canada.

The other factor in limiting UCG activity in the world is the lack of preparedness of environmental regulations and a gross misunderstanding and misinformation on UCG within environmentally
concerned communities, caused no doubt by scarcity of factual information on UCG. This regrettable state of public awareness has led to reluctance of local authorities to approve new UCG projects in several jurisdictions, in particular, in Queensland, Australia and Scotland, United Kingdom.

Along with these objective reasons for a slow-down in the global UCG development, there have been other, possibly more subjective technical grounds for a slowdown or demise of several widely anticipated UCG commercialization projects. In order to commercialize a UCG technology, its performance must usually be proven and demonstrated at a pilot scale. The pilot plants are supposed to demonstrate technical parameters of the technology, such as syngas yield per a unit of coal mass, syngas yield per a unit of injection agent flow rate, coal gas efficiency, carbon conversion efficiency, and the overall thermal efficiency of the process. Besides, pilot plant should prove environmental performance of the technology by demonstrating controlled and limited environmental impacts and the operator’s ability to control and mitigate environmental risks. Pilot plant is also relied upon to show competitiveness of capital and operational costs and provide cost data for financial modeling of a full-scale, commercial plant. This presumes that the pilot plant in its design, scale and duration is representative of the process to be used at commercial scale and is capable to demonstrate the key salient features of the full-scale process in terms of its technical, environmental and financial parameters.

All UCG projects initiated since 1997 have operated as pilot plants. Four of them used the εUCG™ technology supplied by Ergo Exergy Technologies Inc and will be reviewed elsewhere. Several UCG pilot projects that have used other UCG technologies so far have not led to attaining commercialization.

2. Recent UCG pilot operations

The Swan Hills UCG trial has been conducted in Alberta, Canada in 2009-2011. It targeted a 7m thick seam of sub-bituminous coal at the depth of 1,450m. The UCG technology employed was described as linear CRIP. The underground system has been constructed by drilling directional hole with a 1,400m long in-seam section and a vertical production well [1].

The information reported by the project operators is scarce. There is no data on the quantity, quality, temperature, pressure, flow rate, liquid components, mechanical impurities of the syngas produced. Equally no data is provided for duration of gas production or parameters of injected agent such as oxygen-water ratio, flow rate and pressure. No mention has been made of the process efficiency, extraction rates, and total amount of consumed coal. Environmental performance has not been considered in the report, and no mention of environmental monitoring system has been made except for a microseismic monitoring well that seems to have been used for process monitoring.

It appears that no detailed site characterization has been undertaken prior to commencement of gasification and no obligation of monitoring the potential underground impacts has been required by the plant permit conditions. As we understand from the report, the gasification process lasted not more than several days in the row and it is unclear how many gasification attempts have been made. Some operational information can be drawn from a government regulator’s incident investigation report [2]. On the sixth day of an apparent resumption of the process there was a blowout, explosion and fire in the directional injection well resulting in the loss of wellhead, release of gas and liquids into atmosphere, and fires in the nearby woods. The plant has been shut down and abandoned.

Linear CRIP system attempted in this trial, in our view, has the following inherent limitations:

1. Despite CRIP maneuvers, efficiency of gasification and quality of the syngas inevitably deteriorate with each subsequent maneuver, primarily due to the detrimental influence of multiple previously depleted CRIP reactors, downstream from the active reactor, through which the syngas must flow to reach production well.

2. One linear CRIP module trialed in Swan Hills is too small to support a commercial use of the syngas. Multiple modules would be required to feed a standard size power or chemical plant. These modules must be separated by barrier pillars to ensure independent operation.
of the modules and prevent cross-flow of injection agent and produced syngas. Extraction efficiency within one linear CRIP module has been recently estimated at approximately 28% [3]. Taking into account the necessary width of the barrier pillars, the overall extraction efficiency of a mine plan consisting of multiple CRIP modules with barrier pillars would be less than 10% - far below the coal mining industry average.

3. Combined effect of syngas quality deterioration and very low extraction efficiency is a low reliability and poor use of natural resource, which in our view renders the method of linear CRIP unacceptable as a commercial coal extraction and conversion technology.

Although the project proponents seem to claim that the results of Swan Hills pilot operation may be useful in commercializing UCG at a great depth, given what is known about operational results and in absence of any news on the project for the last four years, we believe that commercialization of the process trialed at Swan Hills is unlikely.

The Chinchilla II project operated from 2007 till 2013. Unlike the Chinchilla I UCG project that was developed and operated using the εUCG™ technology, between 1997 and 2006 at the same coal lease [4], the Chinchilla II was designed, constructed, operated and managed with absolutely no involvement of Ergo Exergy Technologies Inc.

The Chinchilla II pilot plant is located near town of Chinchilla in southeastern Queensland, Australia. It targeted a 135m deep, 10m thick seam of sub-bituminous coal. Although technical information about the operations is very limited, it seems that the project utilized mostly linear CRIP method. There were four consecutive attempts at UCG at four different locations within the same property. Details of the process at any of these trials have not been made public, so there is no information on composition of injection agent (air/oxygen flow rates and pressure) nor there is any clear information on flow rates, pressures, temperatures, composition, impurities or stability of syngas production, which would not give us a chance to appraise the process efficiency. Total coal resource converted by four trials combined has not exceeded 8,000t. Starting from 2013, Queensland government announced a major investigation into environmental performance of the Chinchilla II plant. Department of Environmental and Heritage protection (QEHP) reported that in the course of this investigation

- over 230 boreholes were drilled, water and soil samples were collected from 13 surrounding farms;
- laboratory tests confirmed presence of carbon monoxide, hydrogen, hydrogen sulphide, BTEX and other chemicals in the collected samples;
- there was “scientific evidence of operation above hydrostatic pressure, fracturing the landform, and excursion of contaminants”.

QEHP also alleged that plant owner failed to report numerous plant incidents, including several listed below:
- Fire that caused site evacuation in 2007
- Persistent leaks of toxic gas into air and groundwater from 2007 till 2011
- Worker’s claims about their ill health as result of “uncontrolled releases” of gas at site in 2007-2013.

As a result of this investigation QEHP charged the company with irreversible damage “to more than one environmental receptor (the atmosphere, vegetation, water and soil)” and laid five criminal charges against the plant owner. A 320 km² exclusion zone around 1 km² plant was established restricting farming activities there (reportedly to be extended further). According to recent reports, five officers of the company are also on trial for similar charges [5]. In the meantime, the company that owns and operates the plant has declared bankruptcy and is in the process of liquidation.

In light of all the above we tend to believe that commercialization of the UCG process trialed in the Chinchilla II project is unlikely.

Bloodwood Creek is the name of another UCG pilot project conducted in Queensland, Australia in 2008 through 2012 [6]. It targeted a 200m deep, 9m thick sub-bituminous coal seam. Method of
parallel CRIP has been employed with 500m long in-seam panel. Two trials of gasification have been made with the first panel abandoned early in operations, apparently due to irreversible problems with injection wells, caused by explosion and blockage. Second trial reportedly produced gas of stable quality. There has been one reported instance of GW contamination in operations. Following the panels shutdown, residual contaminants reported to remain in the cavity.

Serious concerns with material balance in demonstration of parallel CRIP technology have been expressed based on CFD modeling of the gas flow within a parallel CRIP panel [7]. The modeling shows that in the conditions described above the oxygen of injected air will not react with the coal seam near injection point but rather proceed into the volume of created cavity to be consumed in parasitic reactions with syngas created previously, thereby causing deterioration of produced gas quality. This means that raison d'être of CRIP method – to improve stability of the process while increasing size of underground cavity – does seem unattainable in either linear or parallel CRIP configurations. Besides, all the issues with extraction efficiency discussed above for linear CRIP are equally valid for its parallel incarnation. Uncontrollable variability of gas quality and quantity together with low extraction efficiency appear to be the technical barriers that the proponents are still to overcome on the path to commercializing the CRIP-based UCG methods.

Several UCG plants, operated in the past 20 years, have been based on eUCG™ technology and are considered in a separate paper.

3. Current developments

In many parts of the world where there is no sign of pending energy abundance (including that of shale oil and gas), UCG development remains the only and imperative option for supplying affordable energy and hydrocarbon feedstock for local industrial and retail markets. Examples of such locations include South Africa, India, Pakistan, Bangladesh, and Indonesia.

It is clear that a new stage of UCG development must be based on a solid foundation of specific and comprehensive UCG regulation covering environmental protection, potential conflicts of ownership of mineral and petroleum rights, royalty regimes etc.

Many countries with large coal resources and lack of conventional oil and gas are now focusing on proposing and developing a detailed UCG regulatory framework. Among them are China, India and South Africa. These efforts are spearheaded by appropriate governmental offices, and there are indications that the regulations in these jurisdictions may become functional within the next 2-3 years.

There are a number of UCG projects that are now being prepared in anticipation of the pending regulations.

In China, there are reportedly four proposed UCG projects targeting power generation, and supply of syngas to a Fischer-Tropsch facility and a synthetic methane plant. Only scarce information has been made available by the developers.

In India, the Central Government has specified a pathway for government-owned corporations to develop UCG plants at a pilot scale. The coal and lignite blocks that would be allocated to these companies for UCG development have been identified; and the work should start in earnest once the pending regulations are available.

In South Africa, there are at least three projects that are now anticipating new UCG regulation including that of groundwater licensing. They include the Majuba UCG project development by Eskom Holdings Limited, the 50-MWe Theunissen UCG project owned by African Carbon Energy, and the Sterkfontein project developed by Oxeye Energy.

In the meantime, it appears that in several locations existing regulations could be sufficient to support a UCG project much sooner than that.

The following is a short list of the UCG projects that are currently being developed. This is not a comprehensive list, as it is rapidly evolving.

There are at least three UCG projects currently proposed in South and Central Australia, including Leigh Creek UCG project. This project is targeting a large power plant, taking advantage of the
current lack of power generation capacity in the area. The target coal deposit has been considered for UCG starting from pioneering work by Dr. Ian Stuart and Dr. Len Walker in 1982.

In Indonesia, there have been discussions of three UCG projects for which the government intends to grant operational licenses. These include a project developed by Phoenix Energy Ltd, which would produce electricity in two locations, starting from a small power plant and leading on to a larger IGCC facility with a 100-200 MW capacity.

In Alaska, a joint venture between Laurus Energy and CIRI is developing a power and synthetic methane project with ultimate capacity of 150MW and 70PJ/a, respectively. The project is in the stage of site characterization.

The Parkland project in Alberta, Canada, also owned by Laurus Energy and mothballed earlier due to low energy prices in the province, is now planned to re-start targeting a new chemical product that seems to offer better market competitiveness.

UCG projects in the UK, developed by Cluff Natural Resources and targeting offshore coal deposits have been recently put on hold in Scotland but appear to have a chance to still continue in England.

Apart from UCG projects pursuing clear commercial outcomes, there are a number of UCG projects that are conducted primarily for R & D purposes. These include the recently concluded European TOPS research project [8] that considered technology options for coupled UCG and CO₂ capture and storage; and HUGE - Hydrogen Oriented Underground Coal Gasification for Europe, development largely by Polish researchers in Główny Instytut Górnictwa. The HUGE demonstration installation was built on the premises of CCTW Mikołów in the Underground Testing Range [9].

A number of the above projects are relying on the CRIP UCG technique developed in 1975 by Lawrence Livermore National Laboratory in the USA. However, a majority of UCG projects, both the ones operated in the last 20 years and those currently under development, have been using the εUCG™ technology provided by Ergo Exergy Technologies Inc. (Canada). The latter technology also supports several new UCG projects under consideration in Turkey, India, Canada, Argentina, Pakistan and other locations.

References
[1] Swan Hills Synfuels LP 2012 *Swan Hills In-Situ Coal Gasification Technology Development – Final Outcomes Report* (Alberta, Canada)
[2] Alberta Energy Regulator 2014 *AER Investigation Report: Swan Hills Synfuels Ltd., Well Blowout, October 10, 2011* (Calgary: Alberta Energy Regulator)
[3] McVey T 2011 Final Report: Technoeconomic Evaluation of Underground Coal Gasification (UCG) for Power Generation and Synthetic Natural Gas (Livermore: Lawrence Livermore National Laboratory)
[4] Walker L, Blinderman M and Brun K 2001 *Proc. 2001 Gasification Technologies Conference*, (San Francisco, Gasification Technology Counsil).
[5] Queensland Department of Heritage and Environment Protection *http://www.ehp.qld.gov.au/management/linc-energy* (accessed April 20, 2017)
[6] Mallett C and Hains J 2015 *Proc. The Seventh Int. Conference on Clean Coal Technologies*, (Krakow, IEA)
[7] Blinderman M, Dvornikova E V, Orlov G V, Sundaram B and Klimenko A 2016 *Proc. 8th Int. Freiberg Conference on IGCC & XTL Technologies* (Cologne: Bergakademie Freiberg) p 64
[8] Durucan S, Korre A et al. 2014 *Energy Procedia* 63 5827
[9] Mocek P, Pieszczek M, Świądrowski J, Kapusta K, Wiatowski M and Stańczyk K 2016 *Energy* 111 313