The development of underground coal gasification

by Mike Rycroft, features editor

Underground coal gasification (UCG) coupled with carbon capture and storage (CCS) offers huge potential as a method of exploiting large coal resources on land and offshore. In addition to numerous projects worldwide, there are several projects both active and being planned in South Africa.

UCG is a method of converting unworked coal, while still in the ground, into a combustible gas suitable for industrial heating, power generation, and the manufacture of hydrogen, diesel fuel or chemical feedstock. The economics are attractive, it offers carbon capture options, and the cost of operating and implementing UCG is lower than many other coal technologies. The technology offers the possibility to exploit coal reserves that are unmineable due to geological reasons and proximity to population centres, in a manner which will cause minimum impact on surface features and minimise the pollution associated with mining.

The development of UCG

According to Julie Lauder, CEO of the Underground Coal Gasification Association (UCGA), UCG has the potential to significantly increase global coal stocks and turn these into a high value synthetic gas, cleanly, safely and cheaply. UCG could increase the world’s economically recoverable coal reserves substantially. There is a steady decline in the quality of the coal produced with exhaustion of reserves of higher grade coals. Many countries are turning increasingly to the use of indigenous reserves of lower quality coals, sometimes the only significant energy resource available. But there are many aspects and challenges in taking a new technology such as UCG to market [1].

Global UCG activity

MoU’s have been signed in Canada, Hungary, India, Indonesia, Poland, South Africa, Turkey, USA, and Vietnam, and research projects are underway in Bulgaria, China, Germany and Japan. There is a huge upturn in interest and potential investment in Australia, which is leading the world. Many coal-rich nations have engaged in dialogue and investigation, with increased commercial activity and potential for the next few years.

Basic regulatory issues

Modern UCG is a new industry and therefore new to everyone, the public, the media and also the regulators. Licensing policies for UCG are now being written in some countries, with mining usually being used as the base reference. UCG somewhat “falls in the cracks” as far as regulatory treatment is concerned. In South Africa, UCG is specified as mining in the proposed Mineral and Petroleum resources development Act (MPRDA) amendments.

There is a constant positioning of UCG in the context of coal mining. Pilot and demonstration plants are an essential part of UCG resource prospecting, but prospecting timelines cater for conventional mining. Pilot and demonstration plants under mining rights have other challenges.

Details required

Regulators may need to deal with competing bids from other users of coal. It is sometimes difficult for a new industry since others are already licensed. In countries such as Australia, there are issues over overlapping tenements CBM/UCG, though both can be done at the same site!

There is no clear definition for UCG nor a standard UCG reserve valuation formula. Investors, bankers and analysts alike would prefer an industry standard, giving one less uncertainty to worry about. The current coal valuation method relates to mining and is not suitable for UCG as it does not reveal the true value. The UCGA is addressing this with the UN expert group on resource classification and all agree that it is better to work together towards a common solution.

The economics of UCG can be very site specific, and depend heavily on the coal seam characteristics.

What is needed for the industry to move forward?

- A level playing field, with other energy sources (nuclear, oil and gas, wind, coal bed methane, coal mining) for the licensing of UCG
- Clear regulatory and environmental frameworks
- A recognised resource valuation standard such as a syngas index
- An industry recognised best practice standard
- Industry recognised training

What is holding back UCG development?

Despite 50 years of trials no commercial UCG project has been demonstrated, according to John Kessels of the IEA [2]. Recent progress with pilot projects show considerable promise, and commercial operations could be possible within ten years, providing greatly increased confidence in the technology.

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Fig. 1: Block diagram of the UCG gas treatment process.
Constraints
There is a lack of understanding of the requirements of a successful UCG project by both investors and regulators, and the topic is poorly covered in the literature. In addition there is an acute shortage of people with appropriate inter-disciplinary academic and management skills and experience as well as a lack of understanding of the geological knowledge needed. UCG is being promoted by different industry groups who do not share knowledge and government support is lacking to underpin deployment of the technology.

The major trials, over the last 50 years or more have been in the USSR, Europe, USA, Australia, South Africa and China, during which other technologies have progressed dramatically (e.g. computer power and use, and directional drilling). Tests rarely "proved" more than one or two aspects of the technology, and many had unwanted side effects. The USSR claimed commercial scale operations, but only some 15 – 20 Mt of coal was gasified and syngas quality was variable. The US DOE programme from 1973 – 1989 addressed engineering concerns and compared methods for enhancing coal permeability. The development of the controlled retreating injection point (CRIP) was a major advance.

Current pilot projects
UCG commercial operations are being assessed in:

- Australia by Carbon Energy at Bloodwood Creek, and Linc Energy at Chinchilla
- South Africa at Eskom's Majuba power plant
- China at the Gonggou mine, Wulanchabu city, Inner Mongolia
- Canada (Alberta) Swan Hills at a depth of 1400 m

Pilots have been successfully carried out with no reported environmental problems. All are planning to expand to demonstration and then commercial scale. Relatively little has been published about the outcomes (or the problems/challenges).

Advantages/opportunities
The process allows exploitation of coal generally considered uneconomic for conventional mining, with minimal surface disturbance as most of the ash remains underground. UCG could provide low-cost syngas in a number of countries with substantial coal resources. Significant trials are now producing encouraging results but these are still on a very small scale (roughly equivalent to 10 – 20 MW output).

Restricting factors
The process takes place underground and out of sight and there are a limited number of parameters which are controllable or measurable. Modelling can help, but few models have been validated. Site selection criteria have not yet been well defined as there is insufficient information and experience. Environmental issues e.g. gas escape through fractured rocks, or water contamination have not been adequately addressed. The process requires a unique multi-disciplinary integration of knowledge from geology and hydrogeology with the thermodynamics of gasification.

Site selection is key to success
The single most important decision that will determine the technical and economic performance of UCG is site selection. A successful test in one location where the geology is favourable does not prove that UCG can be widely applied. It will need a series of successful demonstrations in different geological settings to establish where UCG can be safely carried out on a commercial scale without environmental damage, as coals lie in such a wide variety of geological settings, at different depths, seam thickness and with different permeabilities and properties.

Linking UCG and CCS
The Bloodwood Creek development in Australia is being linked to a practical demonstration of CCS. CCS may add another site selection constraint in that it will be easier to do if there are nearby part-depleted oil wells or gas fields. Use of the cavities formed in the coal seam by UCG has been suggested for CCS but this will require an extensive effort to establish the conditions for long-term containment.

Conclusions
Despite 50 years of trials no commercial UCG project has been demonstrated. The development of new technologies and the increase in the value of energy may change this. There has been a great deal of progress recently with some projects showing considerable promise. The current pilots could result in commercial-scale operations within four or five years providing greatly increased confidence in the technology. Keeping more of the knowledge in the public domain could greatly enhance the chances of UCG becoming an accepted and widely applicable technology.

Power for Africa
The European model of large power plants is not the solution for providing under-developed rural areas with power, says Alan Golding of Analytika Holdings [3]. Current thinking is more inclined to smaller more distributed power generation units which reduce distribution costs. The advantage of UCG is that it can be economical at 60 MW.

There are many areas in Africa that are without power that have coalfields that could be exploited using UCG, such as:

North East Basin
The only information is from drilling undertaken to the east in Zimbabwe. There are indications that there could be thick occurrences at depth of coal but to date no borehole has intersected coal in Botswana.

North West Basin
The most unexplored coal basin in Botswana is mapped as Upper Karoo (an area of sedimentary and volcanic rocks). Any exploration that has been undertaken is solely for water supply. Research into water borehole logs has indicated that this area is not necessarily Upper Karoo and this area may have potential as an exploration target as there are descriptions of black shale and carbonaceous mudstone.

Western Basin
A largely unexplored coal basin in Botswana has known coal intersections. Similar areas exist in Zambia, Tanzania and Malawi. We should consider reversing our exploration philosophy – find the market first! The deeper coalfields of Southern and Eastern Africa might be able to supply power to the more remote areas. Bringing power to these areas will facilitate...
development and therefore UCG can be seen in a positive light.

**UCG projects in South Africa.**

Eskom – Majuba

Typical condensate production volume based on UCG Majuba piloting results to date are:
- Normal operation: 40 – 75 g/Nm³ of synthetic gas.
- Start up/ramp up: 110 – 200 g/Nm³ of synthetic gas.
- Gasifier shutdown: 500 – 2000 g/Nm³ of synthetic gas.
- Typical condensate consists of 90% water and 10% hydrocarbons, ammonia and hydrogen sulphide. The problem lies with the hydrocarbons, which can comprise benzene, toluene, ethyl benzene, and xylenes (BTEX), phenols, coal ash and tars, aromatic hydrocarbons and sulphides, ammonia, boron, cyanide, carbon monoxide and hydrogen sulphide. The removal of hydrocarbons is a complex task.

UCG power generation design challenges centre around the integration of the gas treatment unit because the design is based on a theoretical gas specification, as the pilot plant cannot be operated or optimised to be completely representative of commercial scale plant. Design risks include: undefined waxes, volatile metals, particulates, and wide range gas composition, condensate concentration, temperature and pressure requirements for removal.

Two processes are being looked at for integration, namely the particulate scrubber and hydrogen sulphide removal. In the scrubber there are a variety of design options including dry cold, dry hot, wet hot, and wet cold scrubbing. There is a need to assess boundary feed conditions and effect on downstream processes when making the decision. When considering the hydrogen sulphide removal stage, capital cost and removal efficiencies are not the only criteria for technology selection. It is necessary to look at emissions legislation and other factors such as feed conditions (temperature, pressure, concentration), whether pre- or post combustion is to be used, utility requirements and ease of operation. Other necessary design considerations in the gas handling process include auxiliary power usage, turbine fuel specifications, fuel characterisation, acceptance by various technology providers, and available heating and cooling utilities.

**Research, testing and development of downstream UCG technology options**

According to Megashnee Munsamy of the Sustainability Division of Eskom Holdings, Eskom’s current focus areas downstream from production include treatment and reuse/disposal of UCG condensate and extraction of high value products from UCG syngas [6]. These include:
- Hydrogen extraction from UCG syngas.
- Alternative power generation options to gas turbines such as externally fired gas turbines.
- Treatment and reuse/disposal of UCG condensate has the objectives of identifying the viable technologies to remove hydrocarbons from the UCG condensate and evaluating if the proposed technologies are suitable at demonstration plant scale, while ensuring that the overall integration of these stand-alone technologies provides a satisfactory condensate treatment system.
- Two technologies were adjudicated as feasible and are currently being evaluated.
  - Liquid-liquid extraction
  - Bioremediation

Bioremediation involves the biodegrading of hydrocarbons and the removal of ammonia. The current test involves a sample size of 1000:l of condensate and has run over a period of six months. It was found possible to remove BTEX, PAH, aliphatic hydrocarbons and nitrogen compounds. A system for extracting hydrogen from UCG syngas was developed by the South African Institute of Advanced Materials Chemistry (SAIAMC) at the University of Western Cape. The project was co-funded by Eskom and had the objective of determining if 99,999% purity H₂ can be produced from UCG syngas. The project allowed the simultaneous testing of a hydrogen sulphide adsorbent and a selective hydrogen membrane system.

The externally fired gas turbine (EFGT) project has the goal of determining the feasibility of the use of UCG syngas in an EFGT for power generation, by testing with a modified truck turbo charger to operate as a gas turbine. This approach has the benefits of limited fuel pre-treatment. Application of established post combustion flue gas cleaning technologies allows combustion of all fuel types; solid, liquid and gaseous and provides an alternative path for use of the UCG syngas.

Challenges encountered include the absence of off-the-shelf equipment for the UCG syngas application. Eskom’s recently appointed engineering consultants will now be approached to co-develop a design with its research engineers. The design specification of the furnace and heat exchanger will be the gate keeper for the project moving forward to the demonstration phase. The information gained from these research studies will assist the UCG pilot operation in the development of a basic design for a Majuba UCG open cycle gas turbine (OCGT) power plant and the associated Majuba UCG OCGT business case.

**Sasol’s involvement**

The objective of Sasol in developing UCG is constructive engagement towards optimal UCG development, according to Wessel Bonnet of Sasol New Energy [7]. Sasol recognises concerns about the unconventional nature of UCG, and any potential development will follow prescribed regulatory processes, as well as extensive public participation to ensure an optimal project, following a responsible, step-wise approach to evaluate and demonstrate UCG.

There are many similarities between fixed bed gasification and UCG and Sasol has a rich history in developing and operating surface gasification technology value chains. More than 1-billion t of coal have been processed at Sasol Synfuels and more than 20-million gasifier operating hours, using 84 Mk IV Sasol fixed-bed dry-bottom gasifiers producing > 3-million MN³/h.

Sasol has the experience needed for assessment and characterisation of coal reserves for optimum beneficiation, including geo-hydrology; coal characterisation; mine layout; production scheduling; planning etc. It also has experience in the fields of low temperature and low pressure gasification fundamentals and the handling and treatment of products. There are unique challenges associated with low temperature gasification, which Sasol...
has the experience to overcome. Sasol has signed a general license agreement with Ergo Energy Technology for the use of their UCG technology. The bulk of any UCG project investment will be in the value-chain, including gas treatment and condensates treatment.

**Africary Theunissen Project**

Africary has signed an MoU with an international power company that will build, own and operate a 60 MW CCGT plant. The company plans to buy the UCG produced syngas as a fuel gas from the company, according to Johan Brand, consultant to Africary [9]. This project is expected to transform the face of coal mining and electricity production in South Africa, by independent electricity production utilising domestic coal. The Africary rights include all coal exploration licences previously owned by BHP Billiton. The occurrence of the Theunissen coal deposit is well known, as during the exploration for gold numerous boreholes intersected coal. Trans-Natal Coal Corporation did a large amount of the historic exploration and these boreholes (534 boreholes) have been partially electronically captured to enable the preliminary modelling of the coalfield. Prospecting for coal started in 1980 in the Theunissen coal field and Trans-Natal had completed 240 boreholes by 1981. By February 1982 a drilling programme at a borehole spacing of one borehole per 100 Ha was completed. Malateng Mining conducted a drilling programme on behalf of BHP Billiton during 2008 and 76 boreholes were drilled, logged and sampled on the BHP tenements. Fig. 3 shows details of the Africary project.

**Exxaro’s involvement**

According to a report in the media [7], Exxaro has obtained a licence to deploy underground coal gasification technology from Linc Energy. The technology to be used could reportedly combine power generation and gas-to-liquids (GTL) production. Should it be pursued, the electricity-generating potential of the first plant is reported as not less than 200 MW. Any GTL facility will have a capacity of greater than 10 000 bbl/d.

**IEA CCC report on UCG**

This report, by Gordon Couch of the IEA Clean Coal Centre, was published in July 2009 and covers what UCG involves, the technologies applicable, UCG potential, trials and prospective developments, geological and environmental issues as well as syngas use.

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**References**


