Underground coal gasification (UCG) is one of the clean coal technologies being investigated by Eskom. Conceived in the late 1800s, it is a process where coal is gasified in situ, and has been developed in various countries across the world. A matrix of wells is drilled into the coal bed, the coal is ignited and air/oxygen and water are pumped into the injection wells. Fire is essentially used to "mine" the coal and produce syngas which can be used directly as a fuel for power generation.

UCG was commercially proven on several sites in the former Soviet Union, and a pilot plant successfully operated for four years in Australia [1, 2]. It enables the extraction of coal reserves that would not normally be mined, which increases South Africa’s coal resources dramatically. It is estimated that there is a conservative potential for 350 GW of electricity capacity, based on UCG within South Africa.

Eskom CSD has funded a detailed research, development & demonstration program on the Majuba coalfield, using UCG technology from Ergo Exergy Technologies (Canada), who have applied their knowledge gained from the former Soviet Union and Australian operations. The pilot plant was commissioned on 20 January 2007.

This process avoids the need for coal mining, transportation, preparation, the gasifier equipment, and the transportation and disposal of ash. These all have cost, labour and environmental benefits. UCG technology has been researched over the past 70 years, and has been in commercial operation for more than 50 years in the former Soviet Union. The gas was used there for heating and power generation. Although strictly speaking this technology is commercially mature, it is fair to say that this former Soviet Union technology is only now emerging in the Western World with the first pilot plant having operated for four years in Australia and the Eskom pilot plant having just started up in January 2007. There are many other commercial projects either entering pilot plant phase or still undergoing study, in Australia, New Zealand, USA, India, Pakistan, Canada and Italy. National RD&D programs are also re-emerging in the USA and UK, after their first attempts failed to reach commercial maturity. The Chinese are developing another variant, designed specifically to extract remaining coal reserves from previously worked underground coal mines.

There are many emerging factors that give a new impetus to the commercialisation of the technology, both internationally and locally. These include an increasing need to reduce emissions from coal-fired power plant; a desire to find alternatives to natural gas as a fuel due to high prices and availability; and a reviving interest in synthetic fuels as a result of high and unstable oil prices.

UCG has synergies with conventional mining through the ability to exploit coal reserves that would not normally be mined. This effectively increases South Africa’s coal resources. The Eskom resources and strategy (R&S) and generation divisions have estimated that there is an additional 45-billion tons of coal (excluding coalfields in KwaZulu-Natal, Ermelo and Witbank) suitable for UCG. This amount of coal equates to 350 GW of electrical generating capacity, assuming the use of UCG together with integrated gasification combined cycle (IGCC) technology with 50% efficiency and 25 year plant life.

Eskom corporate services division (CSD) has funded a detailed research, development and demonstration program that considers supplying UCG gas, obtained from the Majuba coalfield, to the existing Majuba power station and a new power station. CSD is collaborating with UCG experts, Ergo Exergy Technologies (Canada), who have applied their knowledge gained from the former Soviet Union and Australian UCG operations.

**Process principles**

UCG involves injecting steam and air into a cavity created in an underground coal seam, to form a synthetic natural gas comprising predominantly carbon monoxide, hydrogen, methane, hydrocarbons (gas, liquid and solid), carbon dioxide and moisture. The latter two constituents are the result of complete combustion, which is required to liberate heat to drive the gasification process. The

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**Fig. 1: UCG Process (picture courtesy of Ergo Exergy).**
underground cavity is created as the coal burns, and the boundaries of the cavern form the walls of an underground reactor. The reactor is able to operate at high pressures (related to its depth) and temperatures. UCG has the potential to extract coal resources previously regarded as either uneconomic or inaccessible due to depth, seam thickness, seam slope, seam fracturing and displacement, or other mining and safety considerations. A simplistic illustration of the underground coal gasification process is given in Fig. 1.

**Resource utilisation efficiency**

The UCG overall chemical efficiency is typically 75%, but the recovery is over 95% as the entire coal seam, including any methane gas and combustible roof, floor and partings, will be consumed in the process. Fig. 2 illustrates relative utilisation efficiencies for the current scenario of an Eskom power station with an associated underground coal mine.

**Suitability of South African coals**

UCG technology has the following coal resource requirements:

- Seam width greater than 0.5 m
- Seam depths greater than 150 m, up to in excess of 1000 m
- Coal calorific value down to 12 MJ/kg, and volatile matter greater than 8%

![Resource utilisation efficiency](image)

*Fig. 2: Resource utilisation efficiency for (a) a current, high efficiency longwall mining operation with a conventional sub-critical pulverised fuel power station; (b) a underground coal gasification (UCG) mining operation integrated with a combined cycle power station; (c) a coal bed methane (CBM) mining operation integrated with a combined cycle power station.*

![Coalfields of South Africa](image)

*Fig. 3: Potential UCG sites that contain coal that is presently not commercially mineable (indicated in the ellipses).*
The technology can tolerate geological faulting or displacement by dykes, by virtue of modularity, mobility, low surface site establishment costs, and re-usability of all components.

These features are generally the opposite of the requirements for conventional underground mining, and hence offer opportunity for expanding South Africa’s mineable coal reserve base by extracting coal previously disregarded as being unminable. To quantify this, almost three quarters of the country’s coal resources are presently regarded as conventionally unminable, but could be extracted with UCG. The geographic availability of UCG-type coal resources is relatively broad, compared to the availability of presently mineable coal reserves. This enables far more strategic positioning of new generating plant, to support demand side needs and stabilise the transmission network.

Eskom’s UCG development plan [5,6,7]

Eskom is developing UCG production to initially co-fire the gas with coal in Majuba power station, and to explore options for supplying gas for a new high efficiency power station. A conceptual and scoping study was completed in November 2002, which showed significant potential of UCG for South Africa. This was followed by a pre-feasibility study of applying the technology in Majuba colliery in December 2003. The Ergo Exergy UCG experts assessed the extensive geological and hydro-geological data available for the site, and concluded that there were no insurmountable technical problems and very good preliminary economics. Subsequently high pressure testing was conducted in July 2005, to prove the suitability of the chosen pilot site.

The positive results from these tests led to the construction of a 5000 Nm3/h pilot plant, which achieved ignition and first flaring of gas on 20 January 2007 (Fig. 6). This is a significant milestone for Eskom.

Environmental performance

Air pollution

The typical environmental performance of current and future fossil-fuel power generating options is described in Fig. 4 [3]. Natural gas combined cycle is taken as the baseline for all fossil fuelled stations. The figure shows how UCG-IGCC is the closest coal fired plant to achieving the emissions of a natural gas plant. The ultra-supercritical pulverized fuel plant is still under development, and could potentially be a cleaner coal option than UCG-IGCC once commercially available.

Water consumption

UCG consumes water in the gasification process, to produce hydrogen. This does entail consumption of the water in the coal seam, and in the immediate surrounding strata. The underground aquifers are closely monitored to ensure no impact on aquifers closer to the surface that may be in use for domestic or agricultural purposes, or may evacuate into surface streams. Apart from the usage aspect, there is also a risk of contamination of aquifers and water bodies with UCG products. This risk is mitigated by maintaining a negative hydraulic gradient into the underground cavity (Fig. 5), thereby forcing removal of UCG products with the water influx [4].

Land usage

The UCG process is analogous to conventional longwall underground mining, and surface subsidence is therefore expected. For this reason monitoring equipment is installed to measure rates and extents of subsidence, and furthermore surface infrastructure and natural features (such as rivers) are deliberately not undermined. It is noted firstly that UCG direction and extent can be accurately controlled underground by air injection; and secondly that UCG leaves the ash associated with the coal behind in the UCG cavity, where it partly fills the mining void and reduces subsidence. This contrasts to conventional mining, where the ash is removed and transported with the coal to the surface.
and Africa – being the first implementation of this technology for the continent.

The process is presently being optimized and expanded, as part of the demonstration phase. The gas has already been used to successfully generate a modest 100 kWe of electricity, with the use of a converted diesel generator set. This marks the first new generation of electricity with UCG gas, since the former Soviet Union UCG plants in the 1950’s.

The technology is being developed by Eskom in a phased research, development and demonstration (RD&D) manner, with milestones and hold-points. The design and construction of the demonstration plant is already underway, with plans to produce 70 000 Nm3/h by the end of 2008. Following approvals, production will proceed to 125 000 Nm3/h by end-2009, and with approvals again to 625 000 Nm3/h by the end of 2010. This gas will be co-fired with coal in the existing Majuba power station, until approvals are received for a new 350 MWe UCG-Integrated gasification combined Cycle (IGCC) ultra-high efficiency power station. This could potentially be commissioned in the 2012 timeframe.

In parallel with the RD&D phases, a motivation is being compiled for a new 2400 MWe commercial power station, which will be proposed to Eskom and stakeholders. An EIA has also been commissioned for this new concept. It is proposed that the new power station shares gas with the existing Majuba power station, so as to maintain UCG gas production flexibility.

Conclusions

UCG is ideally suited for complete extraction of both the solid and gaseous fuels, from coal resources that are not destined for conventional mining to extract solid fuel.

Eskom has determined that UCG technology offers the following merits:

- UCG technology, in combination with a combined cycle power station, significantly reduces the emissions footprint of a coal-fired power station.
- The overall resource utilisation efficiency is very high, especially when the gas is used for power generation in a combined cycle power station. UCG as a mining technology also effectively extends South Africa’s coal reserves, by allowing extraction of coal previously disregarded as being unminable.
- The focus on “unminable” resources suggests minimal overlap with existing conventionally mining houses, although conflict is possible with CBM developers.
- The broader geographic availability of coal suitable for UCG enables Eskom to position new coal generating plant far more strategically, to support demand side needs and stabilise the transmission network.
- The technology will increase Eskom operational flexibility and efficiency, by allowing the coal mine and power station to effectively integrate.
- The technology, on a large scale, offers the opportunity to reduce the cost of electricity from new coal-based power stations. It achieves this through an inherently simpler mining process, and a shorter resource-to-electricity production supply chain.
- The UCG technology is modular, and Eskom has already pioneered the basis of the first module. The modularity, availability and relative simplicity of major plant components enables faster lead times than for conventional coal plant.

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