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Underground coalgasification: Moving towards commercialisation

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Abstract. Powering the future is the greatest environmental, economic and social challenge we face today. Despite the current trends towards shifting to renewable energy, fossil fuels and in particular coal, will continue to be a major source of energy for a period of time in the future – a 20% increase in coal demand is predicted between 2008 – 2035 [1]. Underground coal gasification (UCG) is an emerging process which permits access to coal seams which either lie too deep underground, or are otherwise too costly to be exploited using conventional mining technologies (i.e. open cast). The process involves the injection of an oxidation agent (H_2O, O_2, N_2, CO_2, or a mixture of these) into an underground coal seam, ignition and combustion of coal in-situ to produce a synthesis gas that can be used as a fuel for power generation or chemical feedstock. Many studies proved its potential advantages over the conventional mining methods, like increase in coal utilisation efficiency and the improvement of economic performance with simultaneous minimisation of environmental emissions as compared to the currently employed coal utilisation technologies. Although the idea of the underground coal gasification is not new and dates back about 100 years, renewed interest in UCG technology has recently occurred in most coal producing regions of the world. The present study reviews where UCG development has reached around the world and the role it could play in energy supplies, taking into account the current initiative for moving to a low carbon future.

Keywords: Clean Coal Technology, Energy and Sustainability, UCG

1. Introduction

Despite the current trends towards shifting to renewable energy, fossil fuels and in particular coal, will continue to be a major source of energy for a period of time in the future. According to the IEA World Energy Outlook [1], the global demand for coal will increase on average by 1.3% per year for the decades between 2010 and 2040. The tension between the use and the role of coal for power generation in the economic development on the one hand, and the increasing demand for environmental protection on the other, has turned into an issue for which has become critical on the political agenda. The key to accommodate this tension is the development and application of clean coal technologies (CCT). One such technology is the Underground Coal

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Gasification (UCG) that has the potential to contribute to future energy needs in a cleaner and safer way [2, 3, 4, 5, 6]. Although the idea of underground coal gasification has been developed over the last century, the interest in commercial development of UCG projects has significantly revived in the last few years. The aim of this paper is to review the recent developments of UCG around the world and investigate the role which could play in energy supplies, taking into account the current initiative for moving to a low carbon future.

2. UCG technology

UCG is an emerging process which permits access to coal seams which either lie too deep underground, or are otherwise too costly to be exploited using conventional mining technologies (i.e. open cast). The process involves the injection of an oxidation agent (i.e.O_2, N_2, H_2O, CO_2, or a mixture of these) into an ignited coal seam and in-situ combustion of the part of coal to initiate and sustain gasification reactions. The main UCG production is a synthesis gas that can be used as a fuel for power generation or as a chemical feedstock. During the UCG process, a cavity is formed into the coal seam where coal is converted to synthesis gas which is mainly composed of CO, CO_2, CH_4, H_2. Such cavity can be used for CO_2 storage involving the benefit of sorptive linkage between CO_2 and coal increasing storage capacities and safety [7, 8, 9]. Thus, by combining UCG with CCS, a cost effective [10], low carbon emission energy source can be implemented. A schematic representation of the UCG-CCS process is shown in Figure 1.

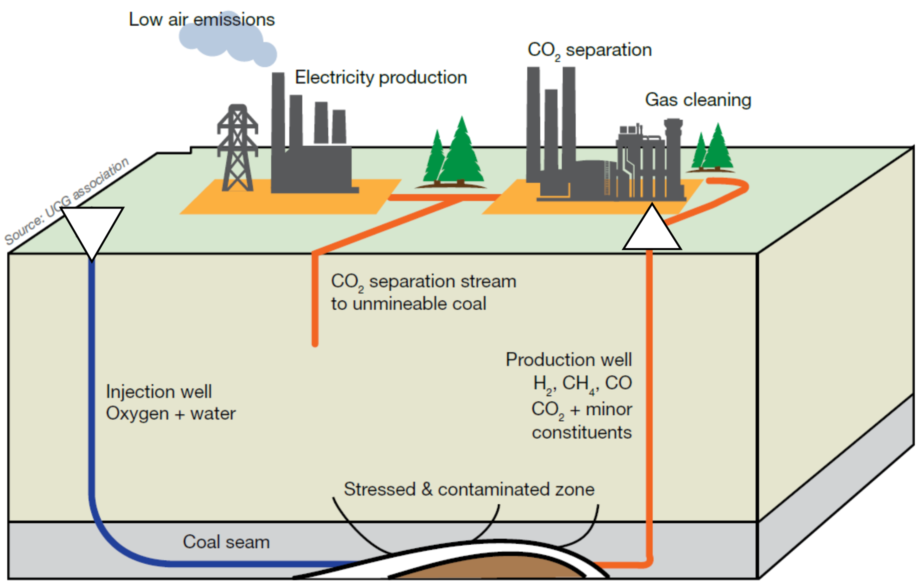

Figure 1. UCG-CCS process (courtesy of the UCG Association).

3. Review of UCG projects and developments worldwide

3.1. Africa

The majority of Africa's coal resources are located in southern and western part. The major deposits are found in Botswana, the Democratic Republic of Congo, Mozambique, Nigeria, South Africa, and Zimbabwe. Environmental concerns pose the main challenge to coal as an energy source. South Africa is among the top 20 emitters of GHGs in the world and the largest emitter in Africa [1]. The Department of Minerals and Energy, and coal-mining industry are fostering the introduction of clean coal technologies in the country and their vast reserve of unamiable coal has led to an interest in UCG technology. The South African energy company Eskom was the first to initiate the investigation of UCG in the country. Eskom has successfully commissioned a UCG Pilot Plant (3MW) next to Majuba Power Station in Mpumalanga [11]. Further plans of Eskom supported by the Ministry of Coal and the Ministry of Energy include construction of a commercial UCG-CCGT plant with the capacity of 40MW run entirely on UCG syngas [12].

3.2. Asia and Australia

China and Australia have seen both research and development activities supported by a number of UCG pilots. Also, there are a few companies which are claiming commercial readiness of the technology. Several research centers are also located in India and Japan. Other Asian States (incl. Vietnam, Pakistan, Bangladesh and Mongolia) are adapting the known technologies and improving them on their own terms. So far, China has run about 15 UCG trials to date, aided by the UCG Research Center of China University of Mining & Technology in Beijing (CUMTB) which has carried out both theoretical research and field tests [13]. In addition, the CUMTB and in collaboration with the coal industry has brought forward the so called "long-tunnel, large-section, two-stage" UCG technology. The considerable interest in development of UCG in China is also provoked by the measures taken by the Chinese Government to reduce pollution from small coal-fired power plants. According to the World Coal Association, there are several UCG projects in various stages of preparation which demonstrates that there is considerable potential of the technology for the future.

Australia virtually led UCG development and demonstration from 2000 until recently. The work was initiated by the private company Linc Energy, which built a demonstration plant for UCG in Chinchilla, Queensland in 1999. A total of five UCG reactors were tested, and the work was accompanied by the construction of a gas to liquid plant for liquid fuels. Linc Energy also owns the world's only commercial UCG facility, Yerostigaz located in Angren, Uzbekistan, which has been producing syngas for power generation since 1961 [14]. Other Australian companies, such as Cougar Ltd have attempted to pursue their own UCG projects, but the Queensland Government has placed a temporary halt to further developments, until a report on the environment and other permitting regulations for UCG have been established.

3.3. America and Canada

America is the continent where active work on UCG as a technology have been carried out for decades by both industry and research establishments, especially in the USA and Canada. Demonstration projects and studies are also currently under way in South American countries like Brazil and Chile. The USA was the principal driver of UCG throughout the 1980's and early 1990's but work virtually stopped in the mid 1990's when natural gas prices fell to record low levels. A revival of interest in UCG occurred about 10 years later (2005), mainly by Lawrence Livermore National Laboratories (LLNL) who secured funding from US DOE to undertake a review of Best Practice in UCG. LLNL have continued research in UCG to the present day with the emphasis on developing integrated 3D THCM multi-physics simulations of the UCG process [15, 16]. Another study in 2008 specific to Indiana, was conducted by the Energy Center, Purdue University Indiana, aimed at identifying specific sites for UCG within the State [17]. The commercial development of UCG in US has been undertaken by three Australian Companies (Linc Energy, Carbon Energy [18] and the now defunct Clean Coal Energy).

Canadian National Laboratories have been experimenting with underground coal gasification since the 1970's, most notably the Alberta Research Council's underground coal gasification field test in 1976 at Forestburg, Alberta [18]. This was followed by excavation of the burn, to obtain data from the coal zone affected by the test. Most of the experiments and projects have served to identify various risks and problems: groundwater contamination, leaking byproducts like benzene, seismic instability, and other issues. Currently, the most advanced Canadian UCG development is a project launched by Swan Hills Synfuels with Synergia Polygen Ltd with support from the Alberta Energy Research Institute (AERI). This project is linked with CO_2 captured at high pressure [20].

3.4. Europe

Significant achievements in the areas of UCG have also been undertaken in Europe. UCG has a long theoretical and field-based history in Russia. The activities have been carried out for more than 50 years in the former USSR and later in Russia. Scientific and engineering knowledge on UCG have been constantly developed, and has led to several UCG operations. Since 1996, when field work stopped, Russia has been improving the basic structural components and operational parameters of UCG technology. The new designs and technological know-how that have recently emerged are protected by a series of Russian patents. The new UCG technology is able to provide stable commercial production of syngas volumes (several billion m^3 of syngas per year), and has better controllability, reduced number of production wells, and higher process stability. Such UCG units offer significant cost benefits to the coal sector. In terms of equivalent heating value, the UCG-derived gas appears to be 25 - 30% cheaper than conventional coal.

Over the last few years, significant funding has been allocated by the Research Fund for Coal and Steel (RFCS) to support further research in the UCG area [7, 10, 21, 22]. An example of such projects is the Hydrogen Oriented Underground Coal Gasification for Europe project (HUGE, 2007-2010) which has been coordinated by Central Mining Institute in Poland [21]. The project was undertaken together with other eleven partners from seven European countries. Its main focus was the theoretical and experimental development of in-situ production of hydrogen-rich gas from coal using underground gasification. The study demonstrated in ex-situ tests that high hydrogen production can be achieved by pulsing air and steam and obtained further experience of UCG operations through a short underground pilot trial at the Barbara experimental mine [21]. Further work on the safety and environmental impact of UCG, including the possible use of reactive barriers was conducted under the HUGE2 study (2011-2014). Poland also has a nationally funded UCG project (with a budget of €7M), which took place at a depth of 465 m in Silesia, Poland. The gasification trial lasted for about 60 days and was completed within 2014. Maximum designed thermal power of installation was 3 MWth. A novelty of the project was the use of CO_2 as gasification agent. A new initiative on UCG led by the UK Coal Authority, and supported by the UK Department of Trade and Industry, took the results of the Spanish trial and investigated the feasibility of UCG in the UK, in a study which included a review of onshore coal resources, environmental impact studies, advances in directional drilling, regulation and public perception issues. The main conclusion was that UCG should be located as a near shore and estuary technology and a site was identified in the Firth of Forth as a possible field trial location. The four-year study led to detailed work by the Coal Authority, Environment Agency and the HSE on the licensing and permitting of UCG. Since 2008, 17 licenses have been issued for UCG blocks in offshore locations. CCS in the UK is also very active. Research programs are underway to reduce the cost of CCS. Now, the focus is on full scale demonstration project which in order to prove a full scale installation of CCS with power generation.

4. Can UCG development reach its commercial potential?

Meeting the challenges of energy supply safety and competitive energy costs is more important than ever. Combine these two vital objectives with maintain carbon emissions low is vital towards the reduction of climate change. There are many countries around the globe which need to import energy from abroad to meet their countries' energy demand. For example, in EU, many member states are heavily reliant on a single supplier including six who are entirely dependent on Russian natural gas imports. In response to the winter gas shortages in 2006 and 2009, and the recent Ukraine crisis, the need for diversified, resilient and low carbon domestic energy routes is of extreme importance for Europe and not only. Therefore, there is a strategic need for any nation to put in place emergency response systems in case of major energy disruptions. To achieve this, the inclusion of UCG and therefore of syngas development into the energy market will depend on overcoming a set of multi-tiered barriers several of which have been tackled over the recent years. Figure 2 shows the five different aspects of development potential for the UCG industry. These are: a) market, b) economic, c) soci-economic, d) technological and e) physical potentials. Through the use of the current technological advances (e.g. directional drilling), government incentives (e.g. carbon credit), multi-lateral agreements and sound practices, development of UCG has achieved significant potential for growth in most countries. However, to achieve market or economic potential (meaning using the technically recoverable resources), UCG development must still overcome many hurdles. Figure 3 shows the path that full resource development took place in the CBM industry in the USA [23]. The UCG industry could take a similar path with the aid to full commercial development in many coal producing countries along the globe.

UCG is evolving as a strategic technology of growing interest ready for a large scale syngas production in a more environmentally friendly way. The technology unlocks utilization of huge unmineable coal resources and increased global stocks offered by its syngas products (e.g. power generation, coal to liquids, hydrogen, fertilizers). UCG also gives opportunities for a range of options for lower cost CO_2 capture and storage. Other benefits of the UGC include reduced surface disturbance and land use conflicts, avoidance of greenhouse gas production associated with coal mining and a relatively small physical footprint for large amounts of energy extraction. However, UCG is a new industry to the public, the media and also to regulators. Though licensing policies for UCG are already being formed in some countries (e.g. Australia, UK, Canada, New Zealand, the U.S.), the lack of regulations is holding UCG back from its commercial development. The challenge to ensure the commercial viability of UCG technology is certainly big, but these hurdles could overcome by deploying the right policies and using the right arguments to convince public opinion. While government support of the technology is needed to produce a reliable base of technical knowledge and expertise, the implementation of more research and pilot projects are required to test possible UCG approaches. Additionally, some commercial field projects could serve as possible locations to develop and test novel monitoring, simulation, drilling, or environmental protection technologies, tools and approaches.

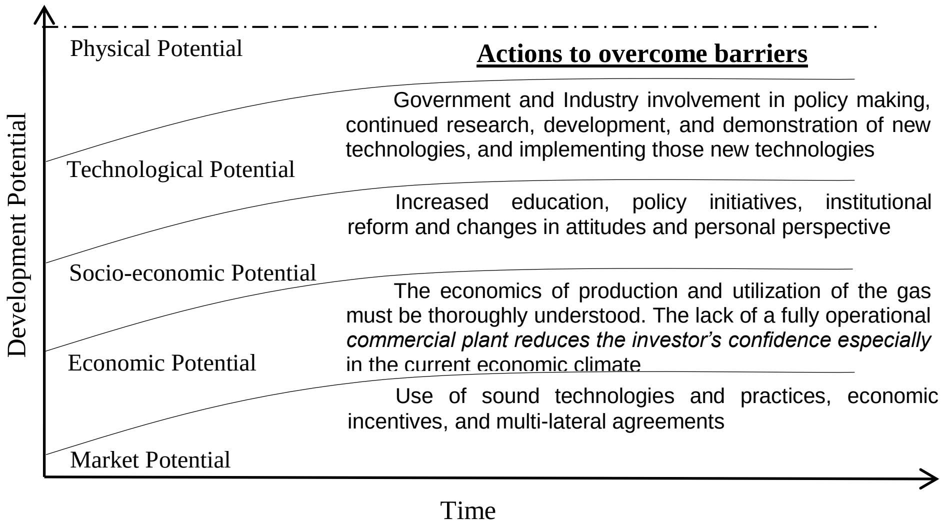

Figure 2. Steps towards the development for the UCG industry.

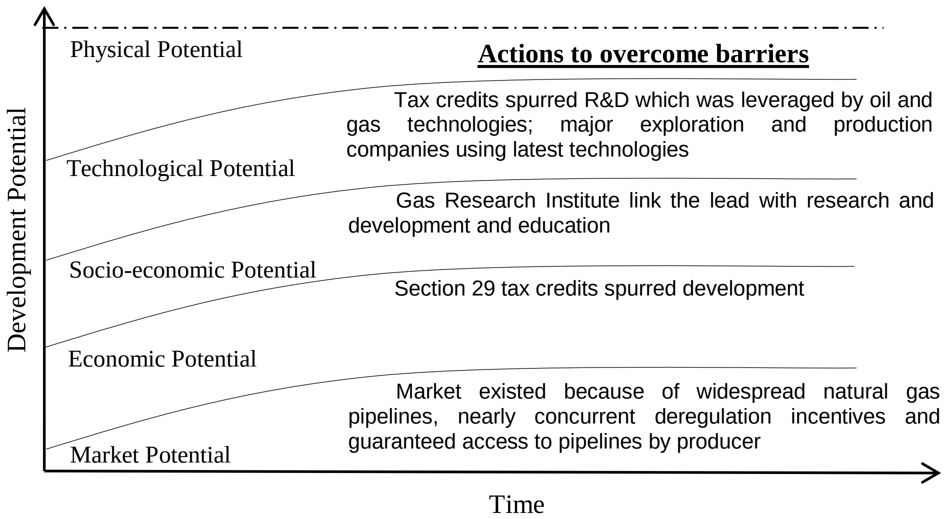

Figure 3. CBM development in the USA [23].

5. Conclusions

Although the idea of underground coal gasification is not new and dates back about 100 years, renewed interest in UCG technology has recently occurred in most coal producing regions of the world. The application of UCG requires a multi-disciplinary practice since it involves a wide range of engineering and related disciplines including chemistry, geology, geo-hydrology, geotechnical engineering, drilling engineering and chemical engineering. Worldwide development potential for UCG can be realized to its fullest extent in the near term, but many formidable barriers remain. It also becomes clear that the UCG technology itself still requires some effort to implement. This effort should be directed towards the analysis of the risks of this technology. The most common barrier to development is the lack of comprehensive policies that not only encourage the development of UCG using the technology that is available today, but policy (incl. environmental) and funding that cause new approaches to be taken and new technologies to be developed and used. The key to the commercialization and growth of UCG industry is collaboration and sharing expertise and knowledge between projects and governments with experience in UCG. EU-funded projects are one such opportunity that sets the basis for EU.

The countries with the greatest interest and most active R&D programs in UCG are China, India, South Africa, United States, Canada, Australian and certain Member States of the EU (incl. Poland, Hungary and the UK). China and South Africa and North America are the countries probably closest to commercialization outside of the EU.Africa is currently leading towards the commercialisation of the UCG, with over US$100 million committed to three major power projects in South Africa. The commercial development of UCG in South Africa is driven largely by the shortage of power and the widespread availability of coal. Finally, the absence, so far, of a fully operational commercial plant using up-to date UCG technology anywhere in the world, is a contributing factor to the lack of investor confidence.

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