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The Future of Cheap Energy: Underground Coal Gasification

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Between 2000 and 2010 world energy use increased by 2.6 billion metric tons of oil equivalent per year. Of this increase, a little over half came from coal, and 72% of the coal increase came from China. The vast exploitation of Chinese coal, the cheapest source of electricity in the world, enabled western nations to benefit from both cheaper goods and outsourcing environmental issues, and for China to benefit from increasing goods exports and rising domestic consumption. Substantial doubt has risen, however, about the possible duration of this economic miracle since China now produces 48% of global coal and consumes around 3% of its reserves every year. How long will Chinese coal last?

The reserve limits for coal, for China as well as the rest of the world, can be postponed for several generations if the technology to gasify coal underground can be commercialized. Underground Coal Gasification (UCG) enables the access of deeper coal layers hitherto unavailable through conventional mining. Several modern pilot projects have been successfully completed in recent years and commercial projects are underway. This article gives an overview of present developments, the technology of the process, costs to produce electricity and liquid fuels from the syngas, and discusses environmental concerns. The article is informed by the excellent presentation given at the ASPO 9 presentation given by Marc Mostade, Technical Director of Clean Coal, and advisor to the UCG Association. The slides of that presentation can be downloaded here, and the video is available here.

The History and Present Underground Coal Gasification Activities

The technology of UCG is quite old as it was already developed in the 1920s and 1930s in the former Soviet Union. These activities resulted in several pilot plants and five industrial sized UCG plants in the 1960s, but efforts were abandoned as large natural gas discoveries made the process uneconomical. Today of these only the Yerostigaz plant owned by the Australian Linc Energy in Uzbekistan remains. Several trials were also undertaken in this period in Europe, documented in detail at the website of the UCG Association.

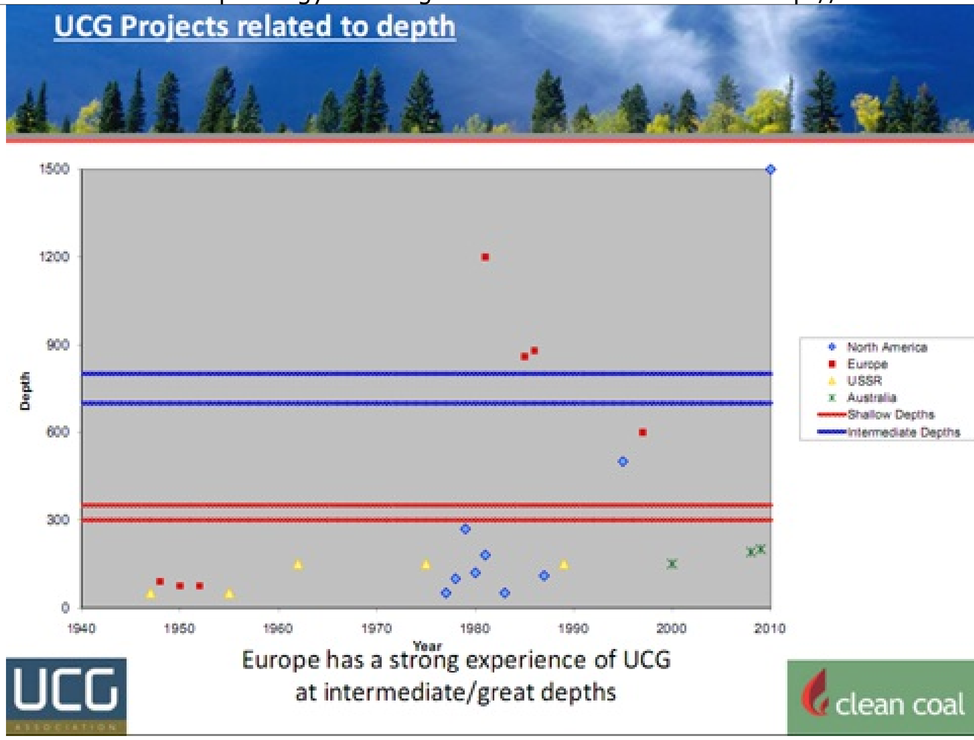

Figure 1 – An overview of UCG trials over time and their depth. Slide from a presentation given at the ASPO 9 Conference by Marc Mostade, [Technical Director of Clean Coal], and advisor to the [UCG Association].

The technology has gained substantial interest in the last ten years as fossil fuel prices increased and concerns over rising fossil fuel imports in Europe have grown. There are now over 30 pilot projects either operating or in the planning stage in more than 25 countries, including the U.K., Australia, the U.S., South Africa, and China. Of special importance are:

• The 1 km deep 5 MW coal pilot [carried out by ENN in China] that ran for 26 months. The Chinese government last month [signed a 1.5 billion USD commercial partnership] with the UK government for commercial development of the technology to be deployed in Inner Mongolia.

• The [Swan Hills project] supported by the government of Alberta in Canada that should start in 2012 and become operational in 2015. The 300 MW syngas electricity plant is intended to be equipped with a carbon capture and storage facility. The commercial project follows a trial project in the region which successfully gasified coal in-situ at 1.4 km's of depth.

• The [Chinchilla project in Australia] operated by Linc Energy which since 2008 was combined with a Gas-to-Liquids plant to produce 20 barrels per day from the UCG syngas. The company is presently finalizing the engineering aspects to begin construction of a 20.000 barrels of oil equivalent per day UCG-GTL plant in 2012. Linc Energy claims it can commercially produce a barrel of oil equivalent at a price of 30 dollars.

The Technology of Underground Coal Gasification

The latest standard of the technology incorporates horizontal directional drilling. To obtain the gas two wells are drilled - an injection well which brings steam and oxygen or air underground to ignite the coal seam and maintain the process, and a production well which pumps out the raw syngas. Previously vertical wells were used which are difficult to connect and limit control over the formation of the underground cavity as they cannot be steered. Today's horizontal wells can be connected using a magnetic target and detector positioned in the tip of the wells. The injection well is retracted along the borehole to gasify the coal which flows to the production well. The process is monitored above ground based on measurements of pressure, temperature, gas flow rates, gas composition at the wells. These are informed by simulations carried out to model the process. The control of the process comes from the injection of the oxidant, as too low or a halting of flows will stop the process.

The produced syngas varies in composition depending on the coal quality and for a standard horizontal two well retractable injection point technique (CRIP) includes hydrogen (11-35%), carbon monoxide (2-16%), methane (1-8%), carbon dioxide (12-28%) and other smaller components. Specific alteration of the gasification system can also result in a variance of the syngas composition. Yang et al. (2008) published about a field test to manufacture hydrogen using a two-stage gasification process with multiple steam injection points to raise the temperature. In the test syngas was succesfully produced with on average 50%+ hydrogen content with a range between 40% to 73%, and both CO and CH4 contents of over 6%.

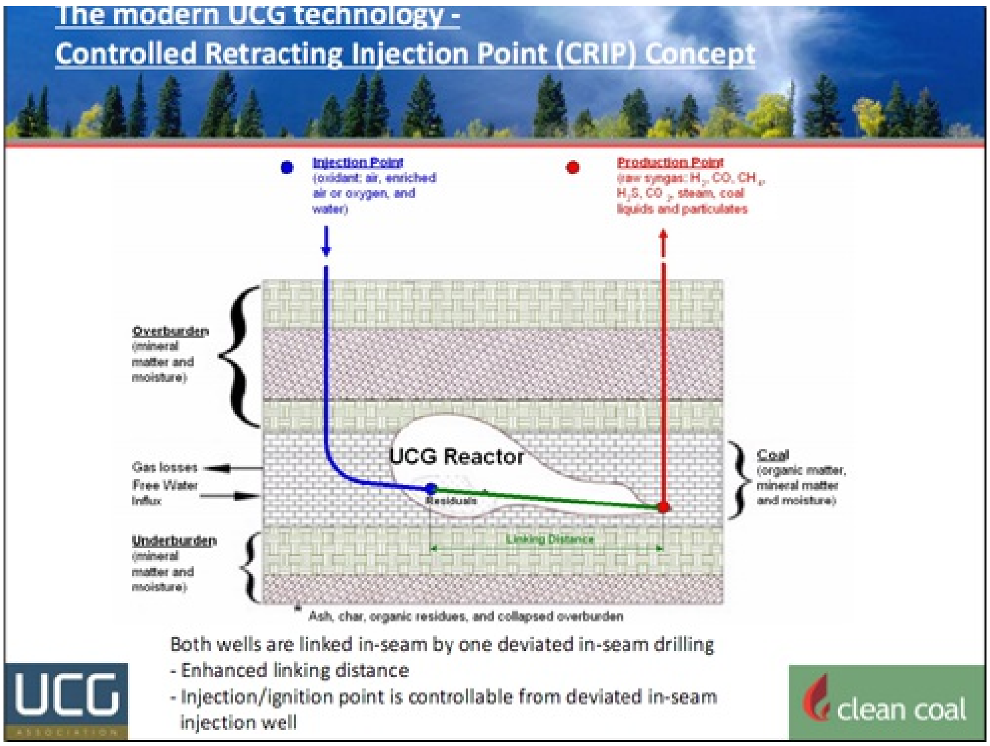

Figure 2 – The Controlled Retracting Injection Point technique. Slide from a presentation given at the ASPO 9 Conference by Marc Mostade, Technical Director of Clean Coal, and advisor to the UCG Association

The process itself takes place in a coal seam normally saturated with water at hydrostatic pressure. There, several processes take place including evaporation, pyrolysis, steam gasification, CO2 gasification, and direct hydrogenation, depicted in figure 3. To prevent the “reactor” from collapsing the process needs to take place in modules at a specified length, width, and depth, shown in figure 3. Thereby sufficient structural support is created both via the rock between the modules and by the under burden and overburden, similar to a large extent as the pillars created in room-and-pillar wall mining. Since the reactor is dynamic and its physical conditions depend on the type of coal and surrounding rocks these determine the possible size of a “module”.

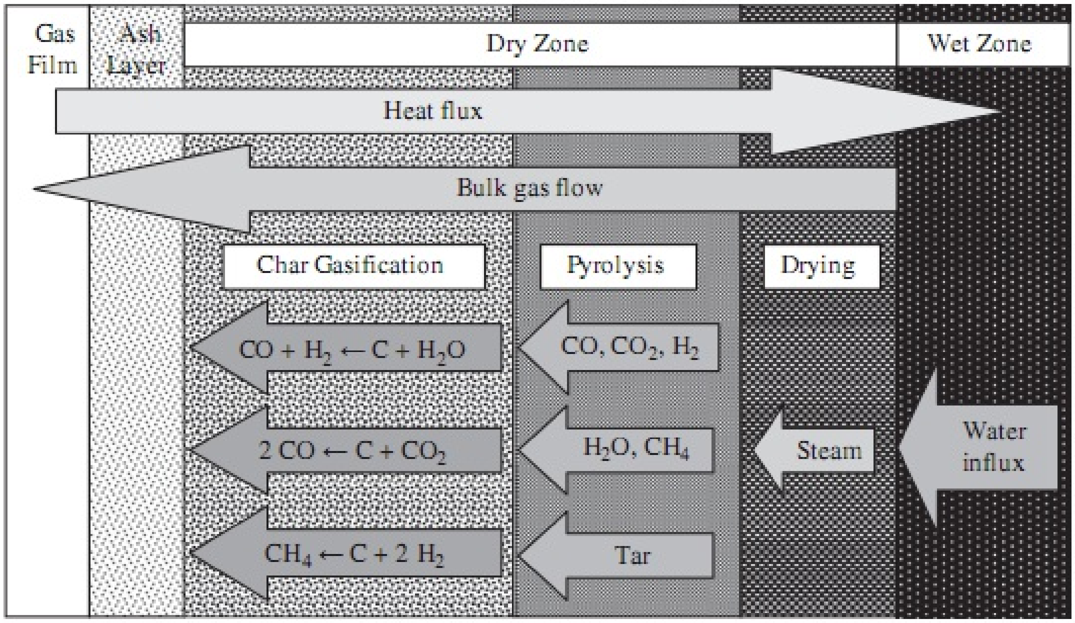

Figure 3 – Qualitative description of phenomena occurring at the UCG cavity wall. Reproduced from Perkins (2005)

More information about the process can be found in a post written early 2010 by Heading Out at The Oil Drum.

The economics of Underground Coal Gasification

Several estimates have been made of the cost of an electricity plant based on UCG syngas. The main physical variables are the quality of the coal, depth and thickness of the coal seam, linking distance of the injection and production well, distance between the cavities, and sweep efficiency. The calculations based on theoretical and actual operations point to a cost range of 1 to 8 USD per GJ of produced syngas. The main cost variation is the usage of air or enriched oxygen for injection, the thickness of the coal seam, and the depth of drilling. The later two factors determine the number of wells that need to be drilled and their required length. Oxygen-blown gasification is preferred in case of adding Carbon Capture and Storage technology.

• The estimate of Marc Mostade of Clean Coal is a production cost of 2.5 to 4.5 USD per GJ of syngas, based on a 800 meter deep 500 MW thermal size UCG plant and a coal seam of 4 to 6 meters thickness at 800 meters of depth. The difference is caused by the usage of air-blown or oxygen-blown syngas. Information about the variables underlying his calculation can be found in his ASPO 9 presentation.

• Based on the Chinese ENN Pilot a total cost of 0.9 to 1.7 USD cents per cubic meters of syngas was documented, which translates into 1 to 1.9 USD per GJ of syngas assuming a higher heating value of 9 MJ/Nm3

• In 2007, GasTech carried out an analysis of costs based on coal in the US Powder River Basin using air-blown and oxygen-blown gasification. These were estimated at a cost of 1.5 to 2.4 USD per GJ of syngas.

• In 2011, the School of Public and Environmental Affairs of Indiana University calculated the production costs for air-fired syngas via UCG in the state of Indiana in the US at 4.6 to 7.7 USD per GJ of syngas for respectively syngas produced via enriched or air, assuming a coal seam thickness of 2 to 3.5 meters at 200 meters of depth or more.

These cost levels are when averaged equal to or below the present day price of natural gas in the US, EU and Asian markets, as shown in figure 4 below. The lower cost range is on par with today's coal price on a GJ energy basis.

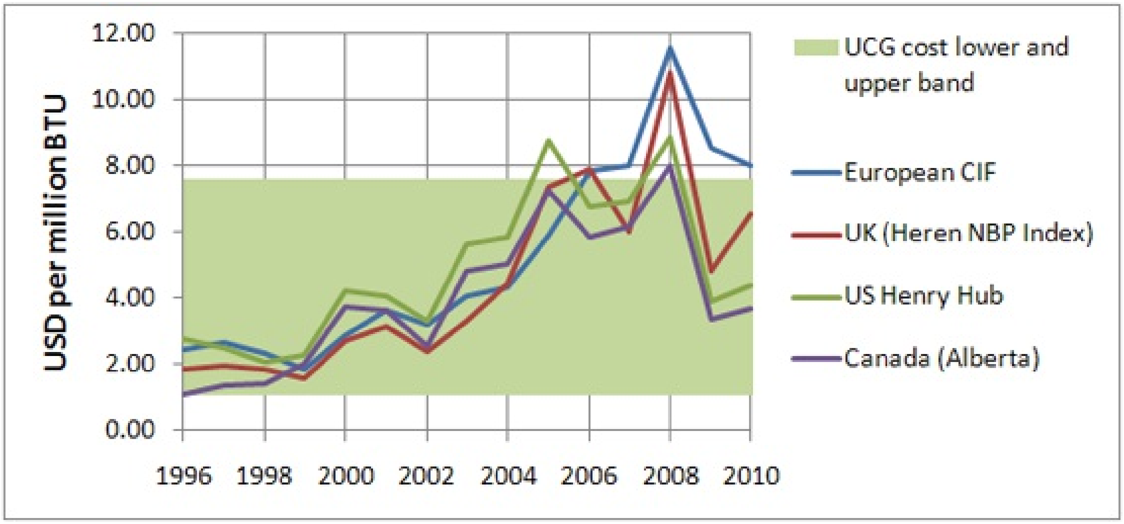

Figure 4 – Natural Gas Prices, European CIF, UK heren NBP Index, US Henry Hub and Canada Alberta from 1996 to 2010 based on figures from the BP Statistical Review of World Energy, viewed against a rough 1 to 8 USD cents minimum and maximum UCG cost per GJ (in the figure translated into BTUs).

The costs of electricity produced with UCG based syngas were estimated in the study of the University of Indiana and shown to be highly sensitive to seam thickness as shown in Table 1 below. The cost for a seam with 5 meters thickness was estimated at 5.2 to 6.4 USD cents per kWh, and a seam with 2.5 meters thickness at 6.4 to 8.6 USD cents per kWh, the lower and higher value caused by air or oxygen enriched injection. The average cost of electricity production in 2010 in the state of Indiana according to the report was 5.7 cents per kWh, which at present makes exploitation of UCG in Indiana economically difficult since only seams up to 3.5 meters thick are available at depths greater than 200 meters.

Table 1 - Sensitivity analysis of UCG based electricity with and without carbon capture and storage for Indiana. Source: [Indiana University]

Zone 7	Base Case, min thickness (2.5 m), 250 m depth		Scenario 1: Base Case with the max thickness (3.5 m), 250 m depth		Scenario 2: Base case with 5m thickness, 250 m depth	
	AF, 8 years	OF, 17 years	AF, 8 years	OF, 17 years	AF, 8years	OF, 17 years
No of production wells	109	51	78	36	55	25
No of injection wells	218	102	156	73	109	51
Annual vertical & horizontal drilling costs, mill $	60.8	28.4	43.5	20.2	30.4	14
Total annual O&M cost for UCG, mill $	68.8	36.9	51.3	28.8	38	22.7
Syngas production cost, $/MMBtu	8.03	4.8	6.4	4.04	5.13	3.42
Electricity cost, $/kWh	0.0863	0.0643	0.0739	0.0579	0.0641	0.0527
Electricity cost with carbon capture, $/kWh	0.1091	0.0815	0.0954	0.0748	0.0846	0.0693

The potential expansion of coal reserves from UCG

There are only preliminary and hence incomplete studies available of how much coal would become available if UCG becomes a commercial technology. The World Energy Council (WEC) estimates that total coal reserves in 2010 amounted to 860 billion including anthracite, bituminous, sub-bituminous and lignite coal. In 2007 the WEC released a coal reserve estimate based on studies from a number of countries including USA, Russia, China, India, South Africa, Australia as well as Europe. These countries and regions combined were estimated to have a potential of 565 billion tonnes of coal accessible by UCG, 52% of today's coal reserves.

These estimates are highly dependent on a number of variables especially the maximum depth of the coal seams extracted using UCG and whether offshore coal is included. For instance, a GasTech study of the Powder River Basin of Wyoming and Montana included only coal reserves at a depth between 152 and 610 meters, and coal seams thicker than 10 meters. In the study it was assumed that deeper extraction below 610 meters and thinner seams would make the process uneconomical. In assuming a 65% recovery factor the study came to 200 billion tons of coal recoverable in the Powder River Basin, a substantially higher figure than the 138 billion estimated for the entire USA by the World Energy Council.

The figures become even more uncertain if also offshore coal comes into the picture which theoretically can be extracted easily with UCG. In the United Kingdom offshore UCG is taking a leap with five conditional licenses granted to Clean Coal Ltd by the UK coal authority in 2009 to investigate the potential for offshore UCG. These could turn into commercial operations by 2014/2015 giving access to 1 billion tons of offshore coal. At this stage the licenses are for relatively shallow offshore sites where the operating plant would be stationed just onshore and directional drilling takes place offshore, but there is no reason for deeper operations not to work unless the cost of the coal becomes too high. If UCG will prove to be economic in a couple of decades a large share of the estimated 3000 billion tons of coal that lie near Norway's coastline could be gasified. After their natural gas reserves are depleted Norway may still remain a gas exporting nation, but then via underground coal gasification.

The problem of carbon dioxide emissions

The major downside to UCG is that by prolonging the age of fossil fuels substantially it would cause human-caused emissions of carbon dioxide in the atmosphere to continue, unless measures are taken to capture greenhouse gasses emitted from UCG syngas combustion. The costs of carbon capture and storage (CCS) from the UCG syngas are expected to be comparable to that of CCS of above ground gasification of coal in an integrated gasification combined cycle or IGCC power plant (Friedmann et al. 2009).

In an earlier post I discussed the IPCC special report on carbon dioxide capture and storage which estimated an additional 0.9 to 2.2 USD cents per kWh of electricity to install CCS at such an IGCC plant. This cost range is similar to an estimate of the University of Indiana that resulted in a cost range of 1.7 to 2.2 USD cents per kWh to add carbon capture and storage to a power plant run with UCG syngas, as shown in table 1 above. The additional costs are plausibly affordable for coal sites with a high seam thickness in comparison to non-CCS based gas power plants, especially in markets with high natural gas electricity costs such as Europe. Therefore, adopting CCS would mean a restriction to use UCG at the most economic sites, reducing but not eliminating the potential adoption of Underground Coal Gasification.

Environmental concerns – groundwater contamination

In contrast to conventional mining, there is no discharge of tailings and sulfur emissions are much reduced as well as the discharge of ash, mercury, and tar because there is no handling of coal involved. There is one important problem that UCG has in comparison to conventional coal mining, which is the hazard of groundwater contamination. Due to a lack of sufficiently high temperatures across the underground cavity, there will be formation of carcinogenic coal tar. In above ground gasification of coal, the temperature can be controlled in the reactor and is kept at high temperatures uniformly to prevent coal tar formation. If the underground cavity pressure is too high it can force some of the syngas and tar into the surrounding formation, thereby contaminating the groundwater. In case of a pilot in Hoe Creek north-eastern Wyoming, groundwater contamination occurred due to the collapse of the cavity roof in which water from a nearby freshwater aquifer mixed with the tar and rock (Bell et al. 2011). Possible suggested solutions are to select coal seams not hydrogeologically connected to surface waters or wells, pumping contaminated water out for surface disposal, re-mediation after gasification, and/or lowering of the gasification pressure were possible:

> “Water contamination issues can be reduced by gasifying at slightly less than the hydrostatic pressure. Water will tend to flow into the gasification cavity, flushing flush coal tars into the gasification zone and towards the production well. This strategy has been successfully demonstrated at the Chinchilla test burn in Australia. A low seep rate will provide steam to help gasify the coal. If the pressure is too low, the water flow rate will be excessive; and the heat required to evaporate this excess water will reduce the thermal efficiency of gasification (Bell et al. 2011, p. 107).”

Unfortunately, such measures cannot fully remove all water contamination because when the process is finished, a cavity will fill up with ground water which mixes with remaining tar. This is not that much of a problem as it is a contained spill according to Bell et al (2011) because the unburned coal can absorb compounds from contaminated water and inorganic rocks will buffer inorganic contamination via ion-exchange. That the problem is taken seriously can be understood from problems with the Cougar Energy project in Australia. The project was permanently suspended by the Department of Environment and Resource Management of Queensland in 2011. In March 2010, a well blocked and ruptured at the Cougar site, resulting in the release of chemicals. By May 2010 elevated benzene and toluene levels were measured in two of the Cougar Energy groundwater measurement holes. Platts reports that this amounted to 2 parts per billion of benzene. In a response Cougar has stated it has since tested over 300 water samples which did not show any detection which exceeded drinking water guidelines. Two other UCG companies with projects in Australia, Carbon Energy and Linc Energy, are also under close inspection of the Queensland State Government. Linc Energy was found to fully comply with environmental regulations but Carbon has been charged for two incidents. One of the Carbon Energy incidents related to the spill of process water to a creek; the other related to unauthorized use of process water for irrigation. Neither relate to direct contamination of groundwater, but illustrate the need for government to scrutinize companies on their environmental standards.

Conclusions

The technology of underground coal gasification has been technically proven to work at numerous locations and different depths ranging from several hundred metres up to 1.4 km of depth. So far the economics look promising with costs competitive to natural gas markets and possibly also coal markets. Furthermore, a combination with gas-to-liquids technology would enable the production of fairly cheap synthetic diesel. These possibilities together with the potential to unlock vast new coal seams unavailable via conventional mining make UCG an important technology that could substantially extend the era of cheap energy. There are justified concerns over groundwater contamination that need continuous attention of both companies and regulators. Finally, the technology does not solve the issue of carbon dioxide emissions as it provides only a marginal improvement over standard coal mining, unless implemented together with carbon capture and storage technologies.

References

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