A cleaner, cheaper, indigenous fuel for combined cycle plants

What role can underground coal gasification play in a modern power system, considering the UK in particular?

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Even as recently as ten years ago, the concept of underground coal gasification (UCG) was known only to a small circle in the coal and energy industries. It had been around for a long time – more than a century, in fact – and had been tried and applied at various times and in a number of places. But in the latter part of the 20th century, cheap and abundant natural gas had undermined the case for extensive commercial development of UCG and, through the 1980s and 1990s, only one site, in the former Soviet Union, was still operating and just a handful of trial applications were under consideration, for example in Europe, Australia and China. Yet UCG adherents were convinced that its day was about to come.

In the last five years, the situation has altered dramatically. There is now a huge upsurge in UCG activity and expenditure around the world, to bring the process to commercial reality. This has been driven by the recognition of the three problems of global warming, volatility of international fossil fuel prices and the existence of massive quantities of unmineable coal in the main energy-hungry nations. To this can be added the serious doubts that renewables are capable of meeting, in the next few decades at least, the expectations being placed on them by energy policy makers, not least (or maybe especially) in the UK.

The default option in the UK is always to build more combined cycle plants, with the facilities required to import LNG into the national distribution system now becoming operational thanks to the huge investments of recent years. My message is: "Carry on! One day, UCG can offer a cleaner, cheaper, indigenous source of substitute fuel for these stations!"

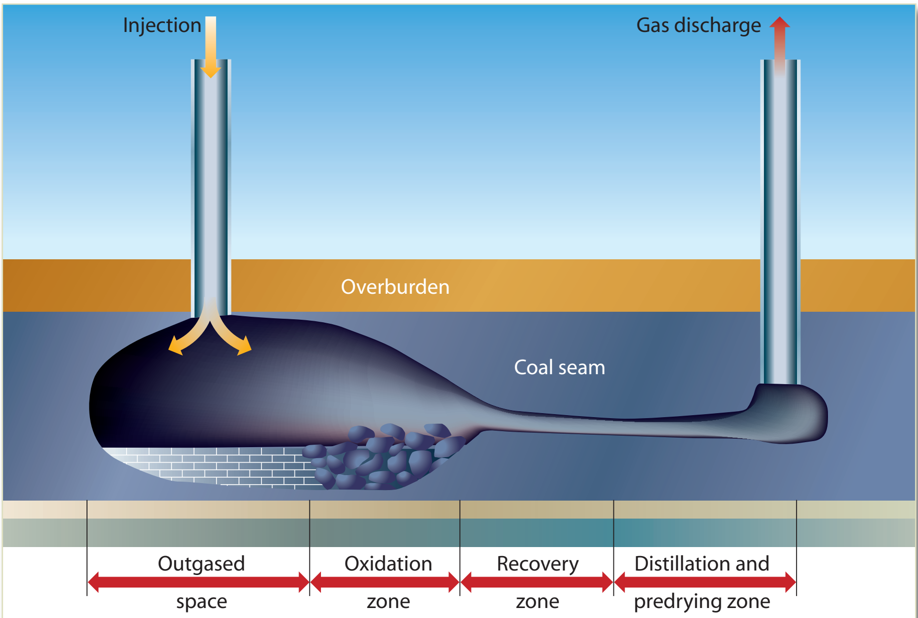


Figure 1. Underground coal gasification: the basic process (diagram courtesy Promgaz)

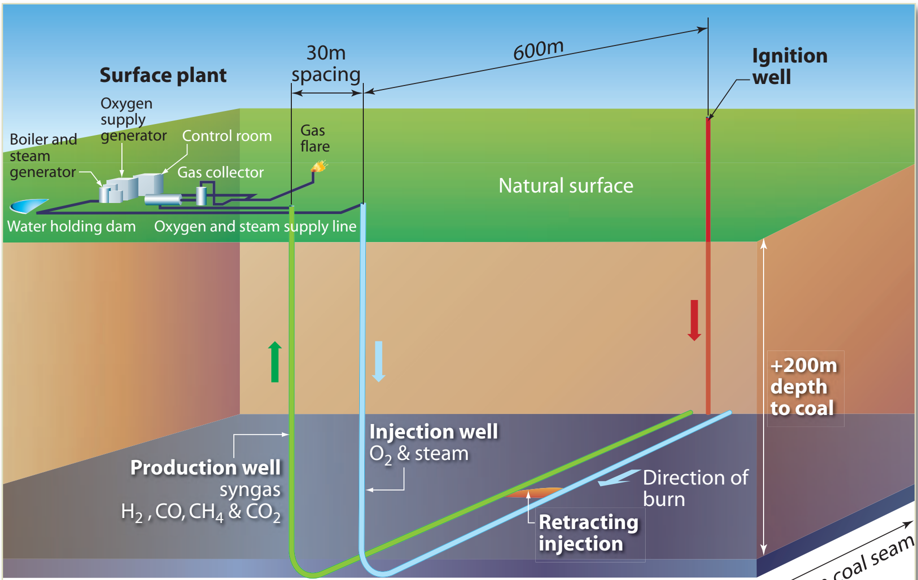


Figure 2. Bloodwood Creek UCG facility, as used for the 100 day trial (diagram courtesy Carbon Energy)

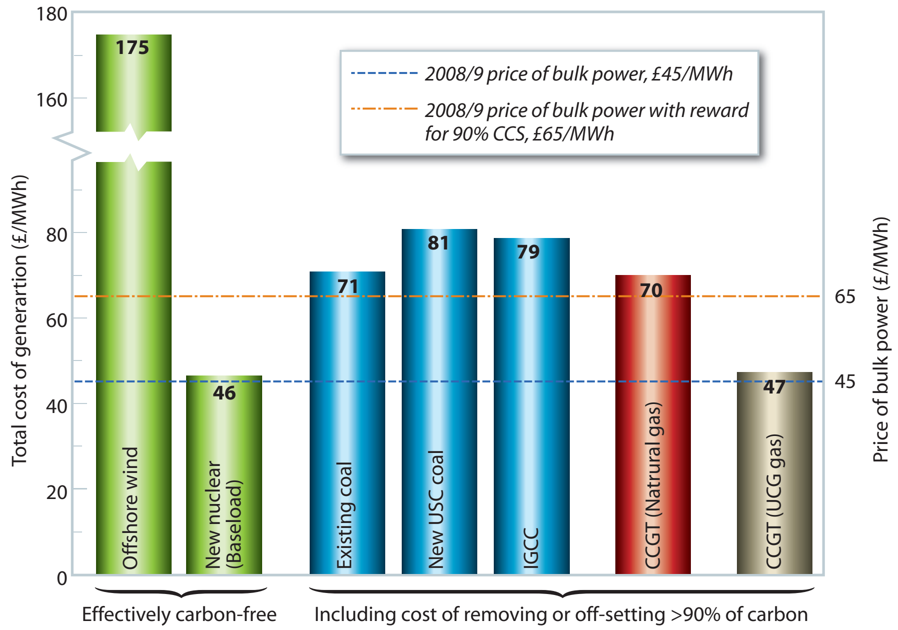
The UCG process

What is it? Basically, an unworked seam of coal in the ground is accessed by two drilled wells, into one of which an oxidant is fed, the coal is ignited and part-combusted, and a product gas flows from the other well (Figure 1). The key variables are seam depth, coal grade, groundwater conditions and seam inclination, while the oxidant can be either air or oxygen, with or without steam. The combustible component of the product gas is a mixture of methane, hydrogen and carbon monoxide. The rest is mainly carbon dioxide, together with trace amounts of compounds of sulphur and nitrogen from impurities in the coal, plus nitrogen, if the oxidant was air.

Shallower seams, say 100-200 m deep, are amenable to gasification with air and produce a lower-calorific value gas, typically 3-5 MJ/m^3, which has historically been used for co-firing in coal-burning boilers. Such a scheme operated for decades in the Soviet Union and is still working at a site in Uzbekistan. In South Africa, Eskom is evaluating this method for the Majuba power station. Recent trials at Chinchilla in Queensland have been successfully feeding gas produced by air gasification to a Fischer-Tropsch plant to produce clean diesel fuel. For deeper seams, say below 500 m, because of the increased cost of drilling access wells, the economics move in favour of gasification with oxygen, to produce a gas with a higher CV, in the range 10-12 MJ/m^3, where the range of typical analysis could be: CH_4, 10-20%; H_2, 10-35%; CO, 10-20%; and CO_2, 25-40%.

The most advanced trial of this technology is at Bloodwood Creek, Queensland, in a project being conducted by Carbon Energy, a partnership between the public and private sectors. The plan at Bloodwood Creek is to progress stage-by-stage to long-term commercial operation. A first continuous 100-day burn has been successfully completed, Figure 2.

Figure 3. Costs of low-carbon power generation (diagram compiled by K J Fergusson, UCG Partnership)



UK potential

Although it is at a depth of just 200 m, Bloodwood Creek is the closest analogy to the types of site where UCG is first likely to be applied in UK, and is being closely watched here.

In the UK, applications have been made to the Coal Authority for a number of UCG licences and the first was granted in February to Thornton New Energy, for a site in the Firth of Forth.

In contrast to the limited reserves of mineable coal in Britain, reported by the Coal Authority as less than 200 million tons, and being extracted at a rate of about 20 million tons per year, a study by DTI in 2004[1] estimated that there was about 17 billion tons of potentially gasifiable coal onshore in Britain, with a parallel estimate giving a figure at least double that offshore, suggesting a total of over 50 billion tons.

Expressed as life of the resource, this is centuries at the UK total national energy consumption, and at least a millennium of CCGT output at projected rates. Even with uncertainties about the recoverability of the coal in place, the size of the resource for UCG is not likely to be a constraint for a very, very long time.

Controlling emissions

There is now a readily-accessible body of published information on the basic UCG process and its variants for different applications.[1,2,3]

Broadly, sulphur and nitrogen in the coal will report to surface with the gas, while ash (and most heavy metals) will remain in the cavity. Conventional sour gas cleaning technologies will remove the sulphur compounds.

The UCG cavity is controlled to a pressure just below the hydrostatic pressure surrounding the seam. At 500 m, for example, this would be around 50 bar and the product gas would reach the surface for processing at upwards of 40 bar.

Under these conditions, the process and product gas are analogous to those of a coal gasifier, such as the Shell design (selected for the Hatfield IGCC in the UK), or GE (formerly Texaco), or Lurgi (further developed by SASOL), except that the product gas has a somewhat lower CV. The technology for removal of CO_2 from such a gas is relatively common. Physical solvents, with simple regeneration by pressure reduction, can be used. (This contrasts with post-combustion capture from flue gas at atmospheric pressure. Even if that is perfected, the basic rules of physics, chemistry and economics will leave it a poor second to pre-combustion capture in terms of cost-effectiveness.)

For UCG in the UK, seams deeper than 800 m are the likely targets, which will produce gas at correspondingly higher pressures than 40 bar, making the penalty for CO_2 removal even less. For the typical gas referred to above, removal of the CO_2 from the raw gas will increase the CV to above 50% of that of natural gas. This will still leave the methane and carbon monoxide content to be burnt with the gas, if it is to be used as fuel for power generation, but the carbon dioxide emission per unit of output will be slightly less than a CCGT.

However, if the reward for carbon capture is sufficiently high, the CO_2 capture can be readily increased, first by shift reaction with steam to convert the CO to $H_2 + CO_2$, and second, at greater cost, by reforming the methane to $H_2 + CO_2$. The energy content of the gas will then be hydrogen, basically carbon-free, if all the CO_2 is captured. This gas could be a potential feed for fuel cells (the subject of a recent MoU between Thornton New Energy and Waste2Tricity), but, for bulk power generation, the main application must be seen as gas turbines.

UCG as gas turbine fuel

A decade ago, the manufacture of large gas turbines running on natural gas was well established, and such turbines had successfully equipped the first generation of CCGTs in Britain. However, gas containing a significant amount of hydrogen (such as in an IGCC) was seen to present problems for the turbines of the time. Since then this problem has been addressed.

In a paper presented recently to the UK Coal Research Forum in Leeds, Grant Budge of Powerfuel described the plans for starting up and operating the power generation capacity of the Hatfield IGCC project. The station will first be built and operated as a natural gas fed CCGT. The coal gasifier will be commissioned possibly a couple of years later. The gas turbine is warranted to operate on either natural gas or syngas from the gasifier and this flexibility is part of the business plan, where, depending on the relative prices for coal, carbon dioxide and gas, the adjacent mine output will either be sold or gasified.

If operating experience at Hatfield bears out this capability for a new turbine to run on either fuel, it has significant implications for using UCG gas as a substitute for natural gas in CCGTs. It will demonstrate that gas turbine technology is becoming flexible enough to operate a unit over a wide range of gas conditions.

In his recent budget, the UK Chancellor placed obligations on new coal-fired stations that will require the partial implementation of carbon capture. Compared to coal, natural gas produces about a third of the CO_2 per unit of output, so an efficient CCGT should still be just capable of meeting the carbon limits for fossil-fuelled power plants. But any further tightening of permitted CO_2 emission limits for fossil-fuelled stations – which will be inevitable as Britain predictably fails to meet its renewable targets – will require CCGTs also to reduce carbon emissions. This can only be done either by steam reforming some or all of the methane in the fuel gas, with pre-combustion carbon capture, or by post-combustion carbon capture. Because of the ease of removing the carbon in UCG gas, to whatever extent is required, as explained above, the eventuality of having to equip a combined cycle plant with carbon capture will offer another opportunity to substitute UCG gas as the fuel.

Load following

Nuclear power is fundamentally operated as baseload. Wind power, on the other hand, is generally operated to the limit of the available wind, but is accordingly highly variable and has to be balanced by a spinning reserve of other generating capacity (although the stated cost of wind power never seems to allow any reward for the under-utilisation of the spinning reserve). In the UK, load following with CCGT is principally achieved by adjusting the number of units on line. The generating flexibility of last resort is currently provided by the PF coal-fired stations, where units are taken on and off line over a 24-hour cycle, and their output throttled, in a way that was never envisaged when they were built in the 1970s and 80s.

If the role of UCG in power generation is seen as substituting for natural gas feed to CCGTs, how will it cope with that pattern of load-following? Variations in natural gas demand, both down and up, are basically a contractual matter between the generator and the pipeline operator. Because UCG gas will not meet grid specifications, it will be individually piped from source to consumer. It is predicted that the UCG process in an individual cavity will have a turn-down capability, possibly about 25%, and the complete cavity can be put on standby by stopping the injection of oxidants, for a period of many hours, resuming operation by re-starting the injection, perhaps with use of an igniter. The gas cleaning and carbon capture plants may be more problematic. Sulphur extraction, water–gas shift and CO_2 capture are flexible processes, but steam reforming of methane may require some adaptation of the typical steam reformer to cater for load-following requirements. As a first approximation, however, a UCG-fed CCGT should be at least as flexible as a plant fuelled with natural gas.

Comparing the costs

The list of variables to be taken into account in making cost predictions for the main generating methods is daunting, and includes: future contract prices for fossil fuels; volatility of spot prices; exchange rates; extent of subsidies for renewables; value of traded/allocated CO_2 emission permits; practicality and cost of large-scale energy storage; value placed on energy security and diversity; construction costs; and state of the economy.

For the purposes of comparison, the uncertainty of many, but not all, of these can be minimised by using forecast data published by the appropriate industry sectors, so the level of optimism should be common. The outcome is perhaps accurate to about plus/minus 15-20%, at best.

Selecting figures in these circumstances reminds me of an incident in my early years at ICI Heysham Works, where pressure steam reforming of naphtha was being developed. It would have been helpful to the operators in some circumstances to have an indication of secondary air flow to part of the plant, which had not been provided, and which could not easily be added due to the design of the ducting. The resourceful instrument manager proposed, as a rough indication, to measure the pressure drop across the secondary air heater and display it in the control room, calibrated as flow, based on the calculated pressure drop from the design of the finned heater. Regrettably, he installed an instrument with a high-grade dial which could be read to three significant figures, and the operating logs were filled in to this level of precision. Around small changes to this reading, intense debate often flared in the control room, even though the instrument manager reminded them that the reading was only accurate to about 30% and he threatened to put frosted glass in the dial so it could only be read to the same accuracy as the signal! So please read the cost comparisons shown in Figure 3 through frosted glass! The figure endeavours to compare the costs of generating power in 2009 terms, but including the cost of CCS (carbon capture and storage) for the fossil fuel options, either by full or partial operation of the process, and with purchase of the necessary EU-ETS certificates to achieve an overall 90% carbon capture.

Notwithstanding the difficulty of finding or estimating several of the costs used to compile Figure 3, and their imprecision, some clear messages can be taken from this chart:

- Without the generous subsidies available to it – and even with them – wind power is not competitive compared with nuclear or fossil fuels (as the least cost of the renewables, only wind has been included in the comparison).
- New nuclear stations should be able to operate competitively if (a) the fossil stations have to carry carbon capture costs and (b) nuclear stations are permitted to benefit as the predominant baseload generation.
- Even with the purchase, at current prices, of emission trading certificates, the present PF coal-fired stations are likely to be able to operate economically for the rest of their lives.
- New coal-fired USC stations, partly equipped with carbon capture as mandated in the recent UK budget, will have difficulty matching the costs of the written-down existing PF stations.
- So long as they do not have to install carbon capture, CCGTs are claimed to be the lowest-cost generators, although vulnerable to volatile gas prices. But if they too have to meet an eventual 90% carbon capture requirement, their advantage will be eroded.
- IGCC should be able to compete with new USC, more so as the required level of carbon capture increases.
- UCG should be competitive against them all; no value is attributed to the coal, giving scope for revenue to the exchequer from royalties on it.

Back on the radar

UK energy policy has evolved over the last eight years or so, first with great emphasis on renewables, then recognition of the role nuclear and carbon abatement technologies could offer, and finally support for "clean coal" in the form of ultra-supercritical PF with post-combustion capture. UCG, for the last five years, has been off the government's radar, but that is now changing.

In the context of power generation, recognition must come of the huge role UCG can and will play as a clean, competitive, indigenous source of fuel.

References

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