

Review of the Feasibility  
Of Underground Coal Gasification  
In the UK

DTI Report  
September 2004

## **Abstract**

Underground coal gasification (UCG) involves the gasification of coal in the coal seam so that the gas can be utilised for power generation. The concept is simple, but the development of a controllable process has proved difficult with the available technologies up to the early 1990s. Generally UCG was restricted to shallow coal seams, which lead to environmental concerns, however, its prospects have benefited from new underground exploration and production technologies, developed for oil and gas exploration, which now makes possible reliable process which can be used in deep coal seams, 600 metres or more.

A recent European field trial between 1992 and 1998 demonstrated that deep UCG could be undertaken successfully and in 1999 the Coal Authority initiated an investigation into UCG as a potential long-term energy exploitation option for the UK. This work was later taken up by the DTI. A series of studies were performed within this investigation covering resource, technical, environmental, planning, public perception and economic aspects of the technology. It also looked at relevant work overseas and more recently, the process and cost implications of CO<sub>2</sub> capture from UCG product gas.

This report concludes that UCG, in conjunction with carbon dioxide capture and storage (UCG-CCS) to reduce carbon dioxide emissions, has the potential to contribute to the UK's energy requirements. However, there are hurdles that need to be overcome: key is economic viability of this technology compared to other cleaner fossil fuel (CFF) technologies and the environmental concerns with implications for planning permission. For any project to be able to get started these challenging issues will have to be tackled beforehand. Major concerns cover the uncontrolled combustion, the escape of pollutants, groundwater contamination and subsidence. Technical solutions do exist in these areas although they will need to be effectively demonstrated to satisfy the planning/consents regime.

The economic case for UCG-CCS based on the initial assessment in this report holds promise when compared to other CFF technologies. Further, the available coal resource in the UK for UCG is significant and potential target areas with adjacent industrial sites for the processing and power plant have been identified. In particular there are major coal seams beneath the southern sector of the North Sea that could only be exploited with a technology such as UCG in the longer term.

If planning and environmental issues can be dealt with, UCG, in conjunction with carbon capture and storage, increases diversity of supply and hence contributes to security within the context of a low carbon economy.

# Review of the Feasibility of UCG in the UK

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# Review of the Feasibility of UCG in the UK

## Executive Summary

### Introduction and Background

Underground Coal Gasification (UCG) has a history of development around the world in countries as diverse as the United States, France, Belgium, UK and in particular the former Soviet Union. However, as natural gas became abundant in the 1980s and evidence emerged in the US that there could be environmental issues around this technology, in particular, the contamination of surface water by the gasification process, interest waned in the technology. Nevertheless, in Europe studies and an initial trial in Spain suggested that deep seam UCG, using new oil and gas technologies, appeared to offer an alternative to conventional mining.

The Spanish trial (1992-1998) confirmed that it was feasible to construct and operate wells in coal seams at depths of 550m and greater. The two key technologies to enable this were directional drilling and the use of a moveable injection points along the borehole providing control over the oxidants required for gasification. Meanwhile, renewed interest in UCG was developing in China, where twelve pilot trials have been undertaken and in Queensland, Australia, which was the base for the Chinchilla UCG trial. These use simple vertical boreholes, shallow coal seams and an air-blown system (instead of oxygen) for gasification, which are rather different technologies to those required for deeper seam gasification.

In the light of the trials and the growing overseas interest in UCG, the UK embarked on an investigation to assess the long-term viability of UCG as a future method of coal exploitation. It examined the suitability of UK coal resources, the environmental risks and the economic viability of this technology compared to other energy sources. Further, given the Energy White Paper's emphasis on low to zero energy technologies, the gas from UCG could only be seen as a fuel compatible with a sustainable future if the carbon extracted with it was separated and sequestered. The Coal Authority, the DTI, and more recently Scottish Executive and a major power supplier sponsored the investigation. Specialist consultants carried out the studies feeding into this Report.

### Status of the Technology

#### Drilling and Borehole Technologies

UCG requires boreholes to access the coal, and three methods have been developed to connect between them, namely:

- a. Air pressurisation between vertical holes. (Chinchilla, Australia, and the former Soviet Union (FSU) sites).
- b. Man-built galleries in the coal. (Chinese trials).
- c. Directional drilling in the coal seam with controlled injection (US and the European Field trial).

The above methods have been demonstrated in single channel configurations but only method (a) has been operated at large scale (>200MWe). A recent pilot project (1999-2003) at Chinchilla was successful and an international company now offers it as a

commercial process. Method (b), from China, is dismissed for as being inappropriate for UK coal seams on commercial and technical grounds.

Method (c) using directional drilling is more costly to construct but has the advantage that the basic drilling and completion technology is available from the oil and gas industry, and the adaptations for drilling in coal have been tested in the European UCG trial. Furthermore, directional drilling in coal has advanced considerably since these trial wells were drilled, and it appears very likely that UCG process wells can be constructed successfully in UK coal seams.

The issue of shallow versus deep UCG will be determined by the environmental, economic and utilisation issues summarised below. If deeper UCG is required to satisfy UK environmental regulations, then method (c), based on directional drilling is likely to be the way forward. This however, does not rule out shallow UCG for specific sites in the UK, where the appropriate hydrogeological conditions prevail.

The key unknowns for method (c) are sustainable gasification over long in-seam wells (>200m in length), the branch drilling of borehole networks for commercial scale operations, and the control of a large gasification process, using moveable injection in simultaneous channels (see CRIP, Appendix 1). At least one pilot trial extending to semi-commercial operation would be required to obtain the necessary operational and environmental data, before a full-scale project, could be considered for construction. Test work to date indicates that the technical and engineering risks of failure from scaling-up the underground process are relatively small.

Coal seam characteristics to a resolution of at least coal seam thickness are a pre-requirement of the design and construction of UCG process wells. A detailed seismic survey and the drilling of exploratory boreholes would need to be undertaken. It is also important to have good knowledge of the adjacent strata to ensure well bore and environmental integrity, and provide the necessary information for the environmental impact assessment (EIA) which would be mandatory for a UK planning application. Site evaluation will be a significant part of the initial costs, and sites may fail as a result of detailed investigation.

## **UK Coal Resources**

UK coal resources suitable for deep seam UCG on land are estimated at 17 billion tonnes (300 years supply at current consumption) and this excludes at least a similar tonnage where the coal is unverifiable for UCG. The largest areas are in Yorkshire, the Dee area and Warwickshire, with smaller deposits in Central Scotland and South Wales. Most of the coal seams with potential for UCG are located in rural areas, but important and useful exceptions exist under rivers and brown field areas. Opportunities are likely to occur in the Firth of Forth, the Dee Estuary and around the River Humber.

## **Environmental Issues**

### **Groundwater, surface water and subsidence issues**

The gasification cavity is a source of both gaseous and liquid pollutants and can pose an environmental risk to groundwater in adjacent strata, depending on whether the contaminants can migrate beyond the immediate reactor zone. US tests in shallow coal seams produced significant groundwater contamination, but the deeper European trial showed no detectable effect on groundwater concentrations in surrounding boreholes.

A UCG project site with the appropriate operational controls should present a very low risk to groundwater, but a robust assessment will be required. The UK Groundwater Regulations are likely to be met when the target coal seam lies in an area of “permanently unsuitable” water without communication to existing aquifers. This would have to be proven through environmental investigation. A full analysis of the groundwater risks, hydrogeological modelling of the site, a network for monitor groundwater during and after operations, and a suitable mitigation response to pollution breakout will be required.

The surface plant will have a significant requirement for temporary storage of various process and contaminated water streams. Control of spillages and the use of best practice in the processing of effluent waters will be an important part of site management.

Surface subsidence will have to be evaluated as part of the Environmental Impact Assessment. The gasifier would be designed to minimise any adverse effects of subsidence. Significant subsidence will be unlikely as cavities will be narrow, compared with long wall mining, and separated by pillars of coal.

### **Air Emissions and CO<sub>2</sub> capture**

The traditional emissions of concern are the oxides of sulphur and nitrogen, particulates and heavy metals like mercury. Air emissions controls are already stringent for these materials and the technology of mitigation is well developed. UCG should have no special difficulties in meeting current and future Regulations.

The framework for approval of a UCG project is a permit under the Integrated Pollution Prevention and Control (IPPC) Regulations. The utilisation of UCG product gas at surface will have to conform to the Large Combustion Plant Directive (LCPD), the UK air quality requirements and any future further conditions that might be imposed on gasification plant through European IPPC guidance notes (known as BREF and currently in draft form).

A UCG power plant produces CO<sub>2</sub> post-combustion emissions, comparable with the surface gasification of coal (~0.8tonnes/MWe). An Australian study has shown that the emissions are lower, on a life cycle basis, than power generation using supercritical pulverised fuel.

Capture and sequestration of all the CO<sub>2</sub> from the UCG process will be required for UCG with Carbon Capture and Storage (CCS) and the options considered were:

1. Shifting and reforming of the carbon containing gases (CO and methane) in the UCG product gas to hydrogen and CO<sub>2</sub> and capture by physical absorption (Selexol).
2. Post-combustion capture after power generation using a chemical separation process (amine based).
3. Oxy-firing of the product gas in a boiler or gas turbine producing only CO<sub>2</sub> and water in the flue gas.

The study suggests that the most likely and cost effective option in the near term, is total pre-combustion capture using method 1, which has the additional advantage that the

product is mostly hydrogen which could be distributed for transport or used in large stationary fuel cells.

### **Planning and Licensing Regulations**

A UCG project in the UK would require approval under the planning and environmental laws and a license from the Coal Authority would be needed to access the coal. Development of a UCG trial or production facility would be considered as a mining operation, but any associated electricity generation facilities above 50MWe would be viewed as industrial development requiring the consent of the Secretary of State for Trade and Industry.

Under Town and Country Planning provisions, there is a presumption in favour of permitting application for mineral projects, but UCG, initially, will represent a departure from the Mineral Development Plan and may require special approval. It is reasonable to assume that the first UCG commercial project would be subjected to review under the appeal procedures.

### **Public Perception**

A study of public perceptions indicates that concerns would be raised about uncontrolled combustion, escape of pollutants, ground water contamination and subsidence. Planning and public perception could impose significant restraints on the exploitation of UCG in rural areas. UCG under estuaries and in near-shore waters with the power and processing island located on a brown field onshore site is seen as the best prospects for early project entry in the UK.

## **Economic and Commercialisation of UCG**

### **Economic evaluation**

The main findings of an initial economic assessment were:

- Large scale UCG with power generation (300 MWe) undertaken remote from the gasification site has a generation cost comparable to, and possibly less than, Integrated Gasification Combined Cycle (IGCC) technologies. However, small-scale developments (~50MWe) are not likely to be economically viable as stand-alone projects.
- UCG with CCS has a power generation and capture cost which lies between the two estimates for IGCC with CCS and is comparable with gas turbine combined cycle (GTCC) with CCS.
- The above assessment assumes post-gasification capture and has not examined the case of pre-combustion methane reforming and CO shifting prior to CO<sub>2</sub> capture. This would yield similar abatement levels to the post combustion separation of Case 3 but may have advantages regarding energy efficiency and costs.

### **Onshore and Offshore Opportunities**

A preliminary exercise based on conservative assumptions for power plant location and coal seam access suggests that large UCG power projects could be located in at least five brown field areas around the UK. If these sites had access to temporary satellite UCG stations within 25 km of the generating plant, they could service an estimated 27GWe of installed power generation capacity for at least 20 years. This is greater than the current generating capacity from coal in the UK.

The offshore coalfields in the lower North Sea hold considerable promise for large-scale UCG. Potentially redundant offshore platforms could be used for the production of UCG gas, which would be brought ashore, possibly in existing pipelines, for processing and power production. Potential CO<sub>2</sub> storage sites, like aquifers, EOR opportunities and unmineable coal could be in close proximity.

### **Overseas Potential for UCG**

UCG feasibility studies are underway in Asia (Australia, Japan, and India), Europe (UK, Slovenia, Poland, Portugal and Slovenia) and there is some interest in UCG for hydrogen production in the US. There are growing opportunities for international collaboration.

In the technologies of UCG, UK has a lead in the underground process, the geological selection of sites, environmental issues and the processing of UCG product gas. Offshore UCG, if successfully developed, would use much of the expertise in platform design and servicing that already exists in the UK to support the oil and gas industry. The market potential for offshore technology would be very significant; for example, Japan, has large offshore coal deposits. A co-ordinated policy on the export of UCG technology could result in a demand for UK equipment and services.

### **Conclusions and Recommendations**

This report has established that UCG-CCS is a potential future technology for the exploitation of UK coal resources, particularly for coal resources under river estuaries, near-shore and eventually offshore coal. Concerns remain about the environmental impact of UCG with approval under the Groundwater Regulations and public perception issues being key factors. In addition, the economics of UCG-CCS need refinement and offshore UCG (from platforms) requires further investigation. In short, UCG-CCS is a promising technology for the UK, although it has to be a commercial decision whether to deploy it taking into account the planning hurdles that would need to be overcome before any project can go ahead.

The feasibility study for the Firth of Forth has the potential to become a “lighthouse” project for taking this technology forward and by investigating a specific site area, the study has the potential to clarify and potentially resolve many of the outstanding environmental, planning and hydrogeological issues identified in this report.

UCG-CCS has reached the stage where ideally an industry consortium should lead the future development of the technology, and there is probably a range of service providers (drilling, process design, mineral and hydrocarbon extraction), equipment manufacturers (plant, power generation), which would benefit from a successful development of UCG. The Firth of Forth study is currently the leading opportunity to develop a UCG demonstrator in the UK.

Other important aspects of UCG-CCS are its potential for hydrogen production for transportation or stationary fuel cells, its flexibility for load following as a complement to renewable energy and its export potential for UK industry. If planning and environmental issues can be resolved, UCG-CCS increases diversity of supply and could add to the security of energy supply in a low carbon economy.

The DTI is currently developing a Carbon Abatement Technology Strategy that will consider all forms of sustainable uses of fossil fuels for power generation. In this

Strategy, UCG will be considered along side other fossil fuel technologies, such as IGCC, but at the end of the day it has to be commercial viability that determines which technologies prevail in a sustainable world.

# Review of the Feasibility of UCG in the UK

## 1. Introduction and Background

### Introduction

Underground Coal Gasification (UCG) is the conversion of coal in the seam into a combustible gas. The UCG gas can be used for electricity generation as well as hydrogen production or conversion into liquid fuel and chemical feedstock. The energy is recovered directly from coal seams, avoiding mining related hazards and the handling of surface coal and post-combustion ash. The main technical challenges arise from issues such as the need to protect underground aquifers requiring the assessment of environmental risk and the planning. In this respect legislative and public perception issues are likely to arise in any planning application.

This report assesses the feasibility of UCG in the UK based on the findings of the Coal Authority's and the DTI's UCG investigations. As part of this review, a series of studies have been performed covering resource, technical, environmental, planning, public perception and the economic viability of this technology. This report presents the key findings and makes recommendations on the future treatment of UCG.

During the period of this study, the Government published the Energy White Paper, February 2003 "Our energy future - creating a low carbon economy" which attached importance to the use of CO<sub>2</sub> capture and storage (CCS) technologies with fossil fuel combustion. This changed significantly the context in which UCG can be considered as a future energy option.

### History of UCG

There is a long history of UCG development in the UK. Experiments were undertaken in Durham in the 1920s. In the 1950s trials were done at Newman Spinney, in Derbyshire and Bayton in Worcestershire. These trials succeeded in the gasification of significant tonnages of coal and enabled valuable operating experience to be gained. The decision to abandon UCG by the National Coal Board was taken on economic grounds in the late 1950s with the ready availability of cheap oil. Elsewhere UCG was also being pursued, particularly in the former Soviet Union, where several large-scale schemes were developed. In addition, an extensive US field trial programme was undertaken in the 1980s. Interest however began to wane with the availability of low cost natural gas and the environmental concerns associated with operating UCG at shallow depth.

In the 1990s the European Union supported a project proposed by Belgium, Spain and the UK on the gasification of deeper coal seams. The work constituted a UCG trial carried out at a depth of 550m in the El Tremedal coalfield of eastern Spain (1992-8) and clearly demonstrated that, using the latest drilling and injection control technology, UCG in deeper coal seams would be technically feasible. As the results of the Spanish trial were promising, UK opportunities for UCG featured in DTI Energy Paper 67 (1999) which encouraged this review. The extensive overseas activities that have taken place during the period of this study in Australia, China and elsewhere have been taken into account in the development of this report.



*Figure 1.1 UCG, Test Site at Newman Spinney (~1955)*

## **Environmental Perspective**

It is now acknowledged that climate change is occurring, and that the natural “greenhouse effect” is enhanced by a build up of greenhouse gases, mainly CO<sub>2</sub> from combustion of fossil fuels. Assessments by the Intergovernmental Panel on Climate Change (IPCC) suggests that the global average surface temperature increased by about 0.6°C over the 20th century and are projected to rise further. To prevent the most damaging effects of climate change the EU suggested in 1997 that we should aim for a temperature increase of no more than 2°C above the pre-industrial level, equivalent to keeping the concentration below about 550 ppm, or about twice the pre-industrial level. The present level is about 375ppm. To stabilise CO<sub>2</sub> at or below this level over the next 100 years would require a global emissions reduction relative to the “business as usual” trend of 50 to 60% by 2050 and 70 to 90% by 2100. The UK Government in its recent Energy White Paper<sup>1</sup> supports this view and has committed itself to a 60% reduction in CO<sub>2</sub> emissions by 2050.

These are challenging targets as global energy demand is increasing and fossil fuels will be a major component of the energy mix for decades to come. It is essential therefore that ways are found to increase the efficiency of fossil fuel use and to move towards low and eventually zero emission supply technologies. The latter goals will necessitate, amongst other measures, the successful development and implementation of low to zero carbon abatement technologies.

## **The potential of UCG**

UCG provides a route to achieve the goal of reduced CO<sub>2</sub> emissions as the technology easily lends itself to CO<sub>2</sub> capture both from the raw UCG gas and from subsequent downstream processing/utilisation. UCG therefore has the potential to be a relatively low carbon emission technology, provided that the CO<sub>2</sub> captured in the processing can be satisfactorily transported and sequestered. This raises issues about safety and environmental impact with the associated need for monitoring and verification

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<sup>1</sup> Energy White Paper, Our Energy Future- Creating a Low Energy Economy, DTI, February 2003

procedures are being addressed in other work<sup>2</sup> on CCS by the DTI. It has been assumed that the anticipated developments for fossil fuels (i.e. CO<sub>2</sub> pipeline networks, saline aquifers, enhanced oil recovery (EOR), etc) will be available over the time scale of commercial development of UCG (15years +) and suitable solutions will be available to sequester the CO<sub>2</sub> from UCG large scale processes.

On a global scale, coal will be a component of energy supply for power generation well into the foreseeable future and its use is increasing significantly in many developing countries. Continued use of coal by deploying cleaner coal technologies can help the environmental and security of energy supply issues, and the use of indigenous coal may provide price stability against imported coal. To quote the Energy White Paper, “In a low-carbon economy the future for coal must lie in cleaner coal technologies – which can increase the efficiency of coal-fired power stations and thereby reduce the amount of carbon they produce – or carbon capture and storage”.

UCG is one of a suite of coal technologies, which could provide a combination of high generating efficiency and a potentially satisfactory method for CCS. The evidence to date suggests that UCG compares well with, for example Integrated Gasification Combined Cycle (IGCC) and supercritical thermal plant. UCG however is less advanced than either of these technologies and questions specific to UCG like planning approval, environment impact and operation at commercial scale still needs to be tested in a full scale trial (costing £10-£20M) before commercial decisions can be taken. The costs and developmental risks in evaluating the technology need to be balanced against the benefits.

Some criteria, by which UCG needs to be judged, are as follows:

1. The commercial viability of UCG compared with other sustainable fossil fuels likely to be commercial within the next 15 years.
2. Local and global environmental impact of UCG compared with competing fossil fuel and other technologies.
3. The likely cost and risks of developing UCG-CCS technologies through to commercialisation, and the scope for industrial support and overseas collaboration.
4. Competitive position of UK technology in UCG compared with overseas developments.

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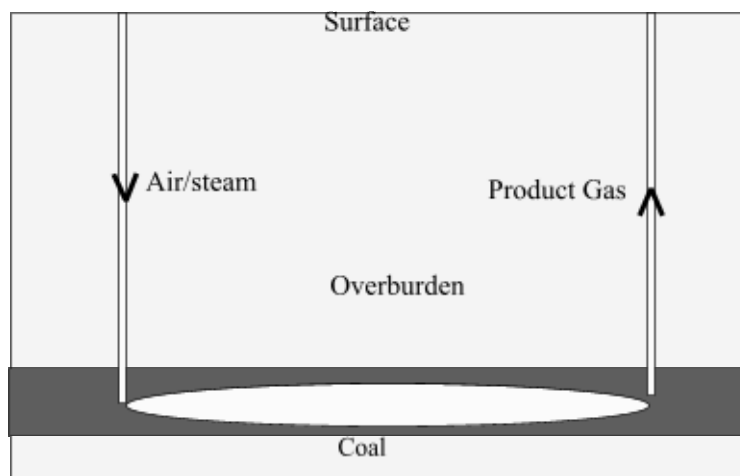
<sup>2</sup> Review of the feasibility of carbon dioxide capture and storage in the UK, DTI Report, DTI/Pub URN 03/1261

## 2. Technology Status of UCG

### Basic Underground Processes

UCG is a process in which an underground coal in the seam reacts with oxygen (or air) and steam to produce a combustible gas of low/medium calorific value. The process is similar, although not identical, to the surface gasification of coal at the heart of the IGCC. UCG is basically a coal to gas conversion process, like IGCC and town gas production.

UCG is conceptually very simple, but controlling the reaction, and producing a consistent gas quality under a variety of geological and coal conditions have been difficult to achieve. The basic concept, figure 2.1, has two boreholes, one for the injection of oxidants and the other for the removal of the product gas. The oxidants react with the coal in a set of gasification and pyrolysis reactions to form carbon monoxide, hydrogen, methane, carbon dioxide and a variety of minor constituents.



*Figure 2.1 - Basic configuration for UCG*

Transport of the gases between inlet and outlet borehole controls the reaction. Coal can vary considerably in its resistance to flow, even in the same coal seam. Younger coal such as lignite may have sufficient permeability to enable a satisfactory connection between wells to be created over short distances (20-50m), but most other coals are too compact or variable to rely on the natural fissures as pathways for UCG.

UCG development has largely been concerned with enhancing the connection between boreholes in coal, controlling the underground process, and scaling up the process to commercial sized operations. These are not trivial problems, and are hampered by the fact that generally, tests can only be made at full-scale in real coal seams, trials are expensive and the results are often difficult to assess at the depths and conditions of UCG.

The mid-nineties onward have seen a resurgence of interest in UCG throughout the coal-producing world, and recent trials have established that viable solutions to the in-seam connection problem can be achieved. In summary, three methods of UCG have now evolved.

The first method, based on technology from the former Soviet Union, relies on vertical wells coupled generally with air pressurisation to open up an internal pathway in the

coal. The process has been tested recently (1999-2003) in the high-ash coals at Chinchilla, Australia. It was reported at the recent DTI Workshop on UCG<sup>3</sup> that commercial feasibility studies are underway in India, Pakistan, Canada and Australia, and there may be also some interest in this method in the UK.

The second (Chinese) method uses man-built galleries in the coal seam as the gasification channels and boreholes are constructed to communicate with the surface. The process operates on alternating air and steam and eleven field trials have been started since 1986; the Chinese UCG programme is the most extensive in the world.

The third method, tested in European and American coal seams, is to create dedicated in-seam boreholes, using drilling and completion technology, adapted from oil and gas production, see figure 2.5 and Appendix 1 for details. It has a moveable injection point known as CRIP (described in the following section) and uses oxygen, rather than air for gasification.

The UK, as one of three participant countries in the recent European trial in Spain (1992-1998), has developed knowledge of in-seam drilling (method 3), whereas data available on Chinchilla and the Chinese trials are limited. Each method involves some proprietary techniques, which have not been disclosed.

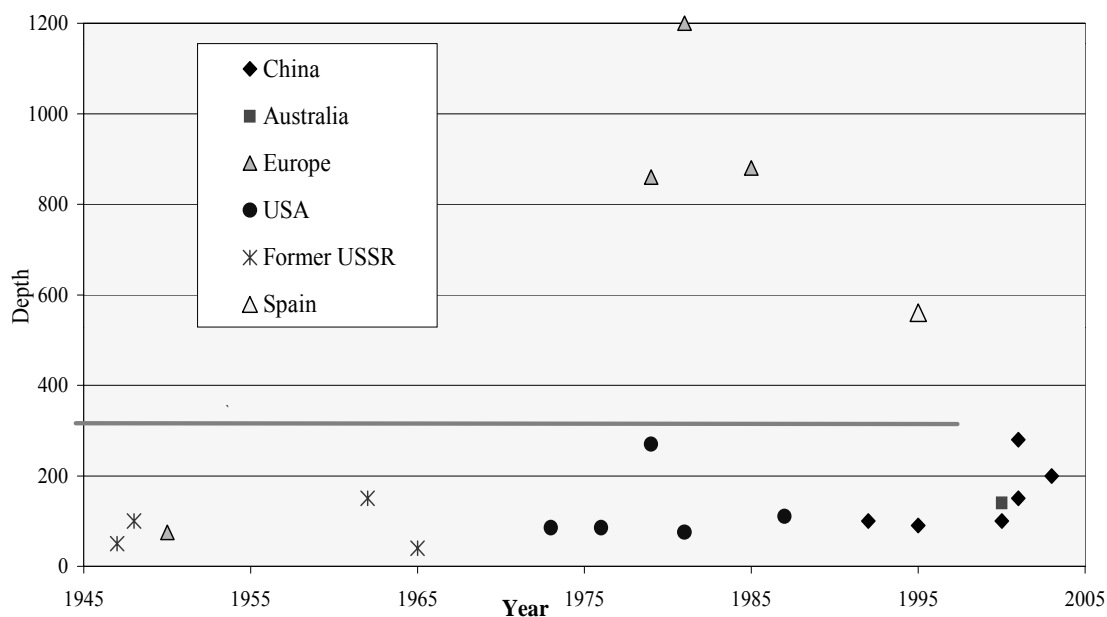


Figure 2.2 UCG trial projects with depth (1947- 2002)

UCG trials and commercial operations outside Europe have all taken place in relatively shallow coal seams, see figure 2.2, whereas recent European trials have generally been deeper. Shallow operations have lower drilling costs but the disadvantage is the potential for environmental pollution. The two recent European trials, in Belgium and Spain at coal seam depths of 840m and 550m respectively, showed that operating at high pressure, >50bar, favours the formation of methane, thereby improving the calorific value of the product gas. There is also evidence that wider cavities are produced as the depth of the coal seam increases.

<sup>3</sup> UCG International Workshop, DTI Conference Centre, October 2003 (presentations available on CD and DTI website)

The current DTI programme on UCG was initiated on the assumption that the in-seam drilling offers the best prospect for accessing and constructing UCG wells in the deeper and relatively impermeable target seams of the UK. The establishment of these criteria do not rule out UCG projects in shallow UK seams, if local site-specific factors support it. - see environmental chapter below

## **Relevant Technical Issues**

The underground part of UCG requires a multi-disciplinary understanding of geology, hydrogeology, mining, drilling and exploration and the chemistry and thermodynamics of the gasification reactions in the cavity. Interaction between disciplines is essential and some of the key technical issues are:

### *Exploration*

Any potential site for UCG operations will need to be explored with a combination of well-spaced boreholes, seismic surveys (preferably three dimensional<sup>4</sup>), and the use of a software package to correlate the exploratory data. The programme will be designed to identify geological structure at coal seam depth to a resolution of at least coal seam thickness, and over an area of coal, sufficient to meet the project lifetime objectives (trial, semi-commercial or large scale operations). Coal reserve margins will need to be built in to allow for geological and planning uncertainties.

A thorough understanding of the coal seam characteristics is a pre-requirement for the design and construction of UCG process wells. It is also important to have good knowledge of the adjacent strata to ensure well bore and environmental integrity, and provide the necessary information for the environmental impact assessment (EIA), almost certainly required for a UK planning application.

Exploration presents no exceptional technical problems for UCG operations, although there is always the risk that sites could be rejected as evaluation unfolds. The cost of exploratory drilling and a 3D seismic survey are high, but generally necessary for successful in-seam drilling operations.

### *Directional Drilling in Coal*

The construction of the wells, the in-seam trajectory and the borehole intersections require considerable accuracy, and would have been beyond the capabilities of drilling technology just a few years ago. Attempts to develop steerable drilling equipment by British Coal and others in the 1980s made slow progress, but more recently, the oil and gas industry has developed steerable long-reach drilling (up to 15km in some cases) to extend reservoir exploration and production. The major service companies responded with a variety of steerable technologies, on-line logging equipment and sophisticated telemetry to communicate with the surface.

Directional drilling in coal, as explained in more detail in Appendix 1, is a lower cost operation, compared with oil and gas. The basic steerable downhole motor has to be adapted for coal and additional sensors are required to track the coal seam boundary, and control the fluid pressure at the bit. A worldwide review of directional drilling in coal has identified a small number of specialist contractors with lateral seam drilling experience, and it is recommended that these be used in any early UCG trial. This technology is now reasonably well proven overseas for coal bed methane (CBM) (in the

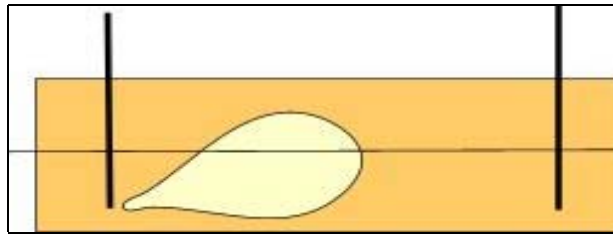
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<sup>4</sup> 3D Seismic surveys use multiple linear arrays of geophones at right angles to the line of seismic sources. Resolutions to 2m are achievable in good conditions, compared with ~5m for conventional 2D seismic.

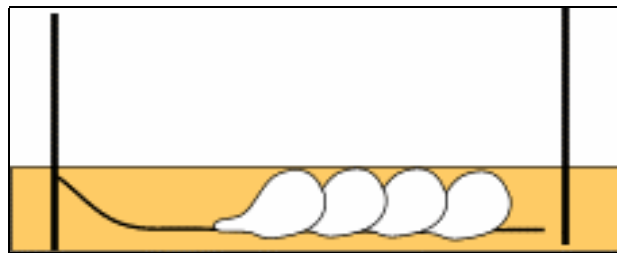
US) and coal exploration (Australia and S Africa). Although in-seam process wells were successfully constructed in the Spanish UCG trial, application of these newer coal-drilling techniques to UCG still has to be fully demonstrated.

*CRIP (Controlled Retractable Injection Procedure)*

Previous UCG trials have shown that a cavity develops and grows with a characteristic shape in the direction of flow, figure 2.3. Eventually, as the cavity becomes large, gas quality decreases, and the channel is no longer effective: therefore, vertical wells, if used without in-seam drilling, have to be close together. This problem was overcome in the later UCG trials by controlling the position at which oxidants are injected into the coal seam, and moving the injection to new coal when required, using a device and manoeuvre known as CRIP, as shown in figure 2.4.



*Figure 2.3 Characteristic cavity shape of UCG*



*Figure 2.4 In-seam gasification with CRIP*

Further details of directional drilling and CRIP are given in Appendix 1.

*Summary of the current status of the underground technology of UCG*

UCG based on in-seam drilling and CRIP has been demonstrated to be technically feasible, and scoping studies have shown that the process would extend to larger scale commercial application. The construction of the in-seam process well circuits has been successfully demonstrated in both US and European trials over the period 1987-1998, and since these trials were undertaken, additional experience and logging equipment for drilling in coal has developed. There is now little doubt that the specialist drillers will be able to construct the intersecting wells with the required accuracy, provided the exploration of the coal seam has been satisfactory, and recent discussions (February 2004) have established that the overseas specialists are able to provide the services required at realistic costs.

The engineering involved in the completion of the wells for injection and hot gas removal at high pressure has also been developed and pilot tested under the conditions of the European UCG trial. Significant know-how has also been developed for the control of the high-pressure process, and the use of the CRIP, which could be applied in any future UK application.

The step-up from pilot operations to larger scale UCG operations has only been achieved in a handful of former Soviet schemes, two of which in Siberia and Uzbekistan are still running, but the technology employed at that time bears little relation to the in-seam drilling approach that would be used in a future commercial UCG scheme. A key development will be the construction of branched wells (see Appendix 1) and the simultaneous operation and management of a number of wells – around 20 wells are required to support a 300MWe UCG power station. Although in-seam circuit design for commercial UCG has been examined in the DTI initiative and designs are available, no testing or detailed simulation has been done to date.

The simpler alternative of air-blown gasification, using vertical wells and former Soviet Union (FSU) know-how, is based on UCG technology already proven at large scale (~200MWe). This gives confidence that scale-up of the higher technology approach would be equally successful. The technological risk associated with the deep UCG process is relatively low.

UCG technology based on in-seam drilling in deep wells has to be proven in a full-scale demonstration project. Developing the technology from pilot stage through to a significant power project is still a major undertaking, involving significant testing and proving work. The test work to date indicates that the technical and engineering risks of failure, associated with the scaling-up the underground process, are relatively small (planning and environment are considered later).

## UK Coal Resources for UCG

The UK coal resource including those offshore is probably the largest in Western Europe and it is estimated that only 1-2% has been mined since the Industrial Revolution. Apart from the lignite deposits in N Ireland, Devon and under the North Sea, most of the coal is bituminous in multi-seam deposits from outcrop to well over 2000m depth. Further exploitation of this vast indigenous resource by conventional mining, beyond the current activity, is very unlikely for economic and social reasons.

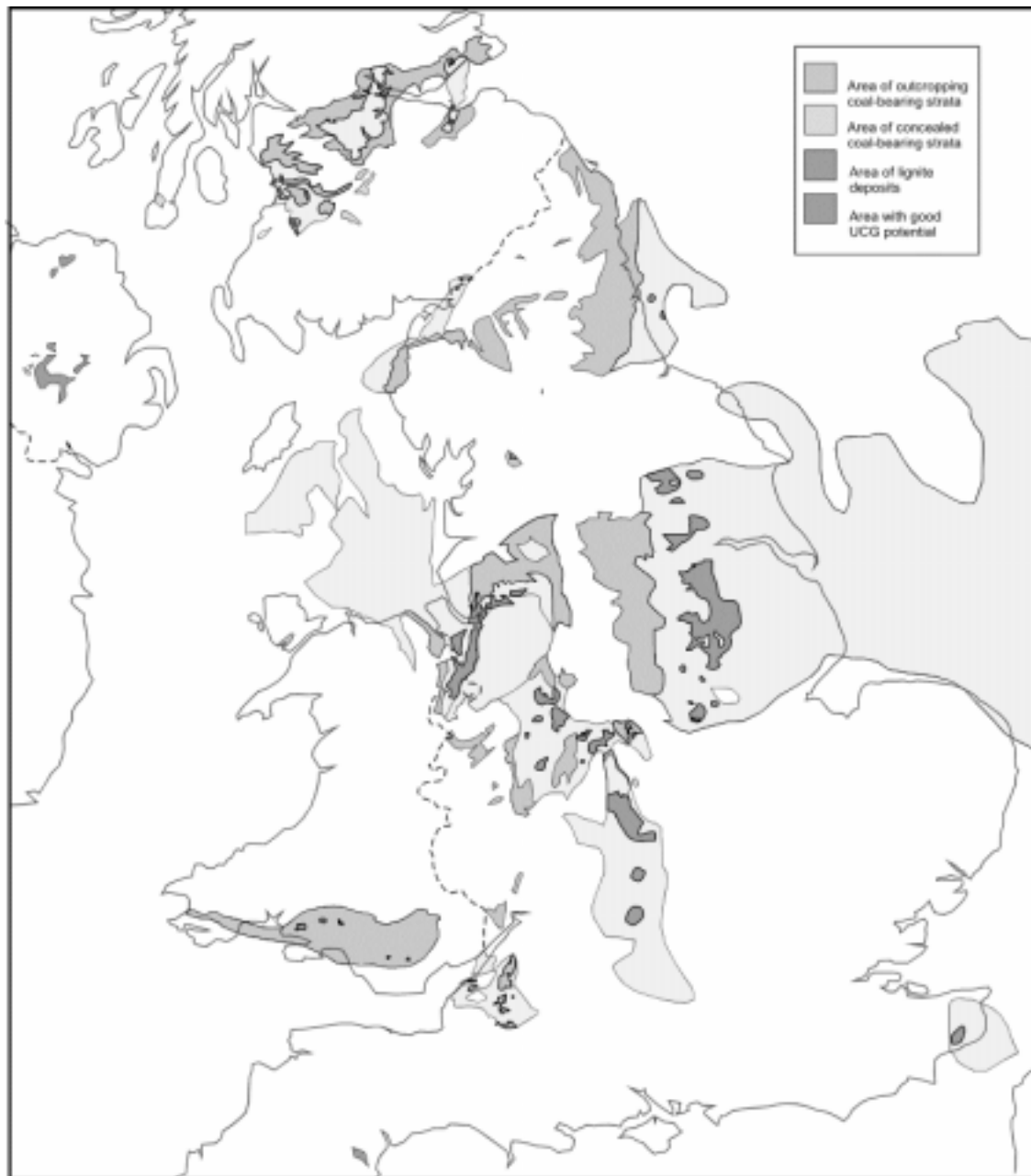
A study was initiated by the DTI (2001) to examine the suitability of onshore UK coals for the new technologies of UCG, CBM and CO<sub>2</sub> sequestration on unmineable coal. It was based on the extensive borehole and other data of UK coalfields, now held in digital form at the British Geological Survey. The selection criteria for a satisfactory UCG area were as follows:

- Coal seam >2m thick
- Depth between 600 and 1200m
- The availability of good density borehole data
- Stand off of >500m from abandoned mine workings, license areas.
- >100m vertical separation from major aquifers.

For this generic study, a minimum depth of 600m has been assumed to lessen the environmental impact at surface in terms of hydrogeology subsidence and gas escape. This does not rule out shallow UCG in the UK for specific sites, where the local strata and hydrogeological conditions can support a shallower operation. The 1200m depth represents the normal limit for mining in the UK, and the same figure was used for UCG on the basis of drilling costs and working pressure at surface. More work might establish that UCG can go deeper, and there are advantages in terms of energy produced in doing so.

These criteria could be refined for specific sites which depends on geological and hydrogeological conditions. Coal characteristics are considered secondary factors for the type of UCG under consideration, i.e. high pressure and oxygen based.

A set of 40 maps of the UK coalfields is now available on CD ROM and the key areas are shown in figure 2.5. Resource calculations indicate that 17 Btonnes of coal, i.e. nearly 300 years supply at 2002 levels of coal consumption, is potentially suitable for UCG. The largest areas are in Lincolnshire, Warwickshire and the Dee area with smaller coals deposits in S Wales and the Clackmannan Coalfield in Scotland. The Firth of Forth and the banks of the Dee Estuary are particularly attractive because of their proximity to existing industrial sites.



*Figure 2.5 Principal UK resource areas for UCG*

The favourable UCG areas identified in this study would need to be followed up with more detailed investigation of the geology, hydrogeology of the target area. The study also needs to take into account of the surface environmental and planning issues, discussed in Chapter 3.

### **Gas Utilisation in Surface Plant**

#### *Gas Processing*

A UCG site will be concerned with handling large volumes of toxic and high-pressure gas, which has to be washed, cooled and filtered before transmission by insulated pipeline to the power-generating site. Purge gas storage will also be required. Locating the equipment at the surface UCG station and protecting the local environment from gas escape, equipment failures emergency procedures, blow offs and spillages will be a significant environmental challenge for the operators.

The essential surface connections, and plant for a commercial UCG power generation scheme, are shown in figure 2.6.

Plant is required to:

- Prepare, compress and inject the gasification agents into the injection well.
- Clean-up the gases for power generation.
- Optionally to steam reform, shift and remove CO<sub>2</sub> from the pre-combustion stream.
- Power generation using Combined Cycle Gas Turbine (or possible boiler and steam turbine).

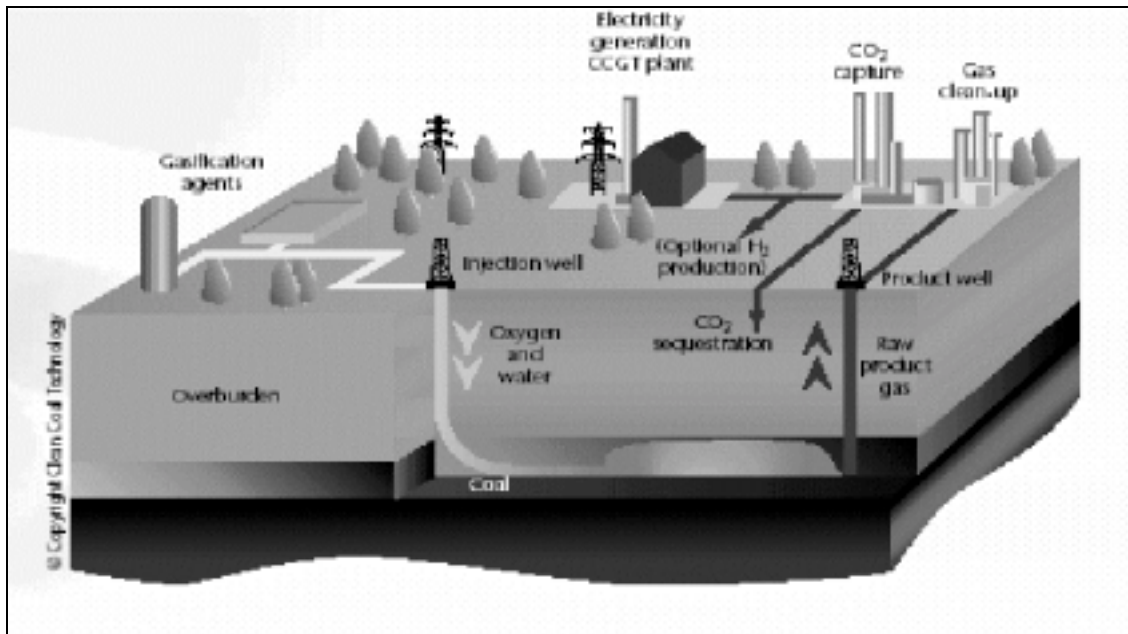


Figure 2.6 Schematic of UCG for power generation

Typical size and output characteristics for two UCG plants of 50MWe and 300MWe capacity are as follows:

UCG Plant Sizes	50MWe	300MWe
Total electricity produced/ year	350GWh	2,100GWh
Number of coal seam panels (500m x 500m) required for 20 years operation	6.6 Panels	24 Panels
Equivalent tonnage of coal in ground required for 20 years operation	5.4M tonnes	19.5M tonnes
Maximum daily oxygen requirements	416 tonnes/day	1,792 tonnes/day
CO <sub>2</sub> captured /year	320,000 tonnes/yr	1,380,000 tonnes/yr

Table 2.1 Size and output characteristics of 50MWe and 300MWe UCG power plants

The production of oxygen, removal of CO<sub>2</sub> and other acid gases, and the utilisation of gas for power generation are mature technologies from the power and chemical industries, which require little or no development. A wide choice of equipment is available for each section of the plant and a design process should consider the options, costs and regulations in detail to arrive at an optimal solution for any particular application. Some general points about the plant are as follows.

#### *Oxygen Supply*

Oxygen for the gasification process can be supplied as air, enriched air or oxygen. The Chinchilla, Australia and Chinese programmes use air to produce a dry gas of calorific value 3-5MJ/m<sup>3</sup> whereas the Spanish trial on pure oxygen at high pressure achieved over 13MJ/m<sup>3</sup> after gas clean up. Oxygen production has a high demand for energy, but the compensations are improved gasification stability, better cavity growth and an 80% reduction in the volume of injection gases that need to be compressed.

Oxygen supply will be required for any high pressure UCG application for reasons of cavity growth and pre-combustion CO<sub>2</sub> capture. The table above indicates that a 300MWe UCG project will need an oxygen supply of 1,800 tonnes/day – this indicates that a dedicated air separation plant (ASU) would be required. For the smaller 50MWe plant, a pipeline supply, the use of road tankers or a membrane separation unit might be considered as alternatives to the ASU.

#### *Clean-up of gases*

The product gas, in addition to the combustible gases carbon monoxide, hydrogen and methane, contains carbon dioxide, water vapour, various minor intermediate products and tars, heavy metals, reduced sulphur, possibly chlorine and nitrogen compounds and some carry-over solids. A typical dry gas composition for oxygen fired product gas (extrapolated from the Spanish UCG trial) after removal of any hydrogen sulphide is shown in figure 2.7.

It should be noted that UCG product gas has a similar calorific value to surface gasification, because of the high methane content. In addition pressure energy is available at the surface from the high operating conditions of the underground process (60-120 bar)

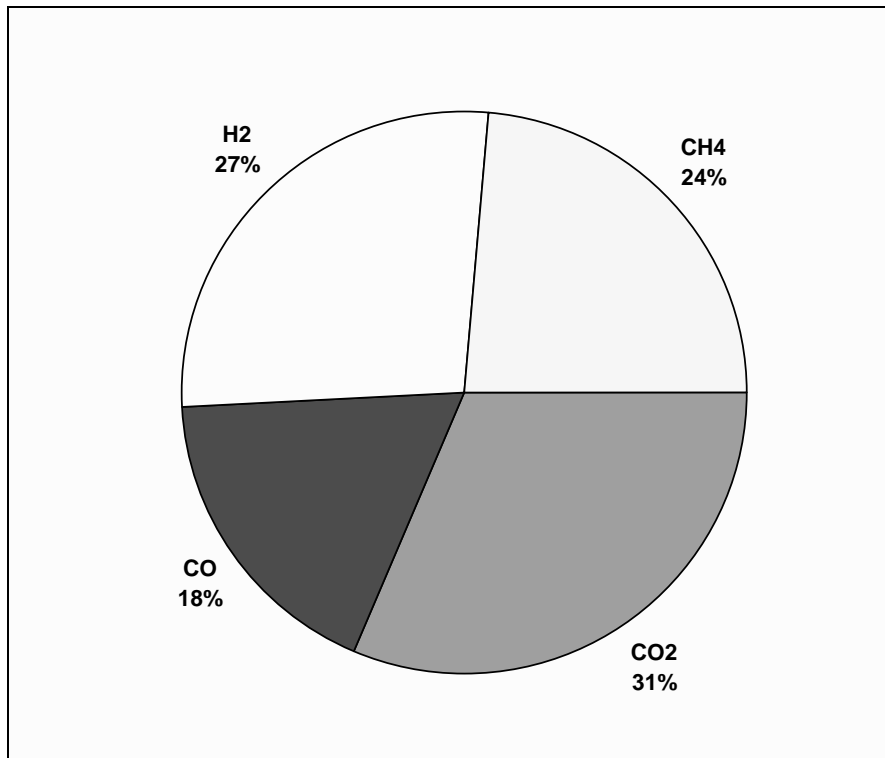


Figure 2.7 Composition of typical dry UCG product (oxygen fired) after gas cleanup (Calorific Value 13.6MJ/Nm<sup>3</sup>)

The dry gas, which emerges from the cleaning process discussed above, can be combusted directly or it can be pre-processed to remove part or all of the carbon gases. CO<sub>2</sub> capture options are discussed in Chapter 3.

The gases leave the wellhead at elevated temperature and pressure, which for UCG on oxygen firing, could be as high as 200<sup>0</sup>C and 100 bar at the production wellhead. A basic scheme for cleanup and treatment, which is similar to surface gasification, is shown in figure 2.8.

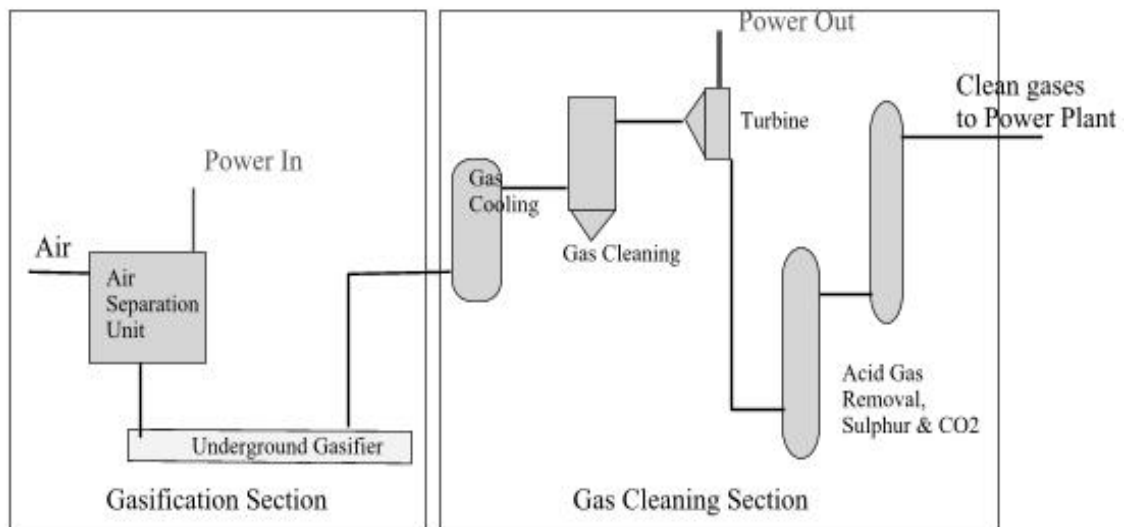


Figure 2.8 Basic flow chart for UCG gas clean up.

The high pressure of the product gas from deep UCG implies lower gas volumes and smaller gas processing plant than conventional IGCC: also the excess pressure can be converted (by turbine expansion) into electrical power for general plant use including providing power for the ASU. The greater the depth that the UCG process takes place, the greater the availability of pressure energy for power at the surface- this is an important advantage of UCG in deep coal seams.

The combination of the washing process and cyclone will remove most of the minor contaminants leaving acid gases such as H<sub>2</sub>S to be extracted by physical or chemical absorption using organic solvent like amine or glycol. An advantage of gasification processes, like UCG and IGCC, is that sulphur (and mercury) can be removed more efficiently and cheaper in the pre-combustion stream compared with post combustion processes.

These clean-up processes themselves produce liquid effluent streams, which need to be regenerated and cleaned before discharge, or transported away for treatment. The Chinchilla UCG project<sup>5</sup> makes a virtue of the waste streams by suggesting that the tars, oils and phenols are separated and sold as a by-product of the UCG process.

#### *Power Generation*

Electrical power can be produced from UCG product gas by turbine, reciprocating gas engine or simply burning the gas in a thermal power plant. The use of UCG product gas in engines and thermal plant has been demonstrated, but the performance of UCG gas on gas turbines is based on the extrapolation data for other low to medium CV gases.

Turbine manufacturers have adapted gas turbines<sup>6</sup> to operate on low to medium CV gases from 2 to 14MJ/m<sup>3</sup>, with quoted cycle efficiencies in the range 44-46%. More specifically, the syngas from the Chinchilla air-blown UCG project in Australia<sup>7</sup> has been evaluated as an acceptable fuel for a 45MWe heavy-duty industrial gas turbine, in advance of the demonstration UCG power project planned for Chinchilla. Further performance evaluations on UCG gas have been undertaken at 400MWe for both the Chinchilla project and the proposed UCG power generation projects in China.

The UCG product gas, after gas clean-up, compression and adjustment, if necessary of the gas composition, (e.g. nitrogen dilution) would be used in a standard combined cycle as shown in figure 2.9.

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<sup>5</sup> See worldwide review of UCG later in this chapter

<sup>6</sup> Presentation on Combined Cycle Power Generation from UCG Gas, G Kelsall & D Abbott, UCG International Workshop, London, October 2003. All workshop presentations are available on CD and the DTI Cleaner Coal Website. <http://www.dti.gov.uk/energy/coal/cfft/index.htm>

<sup>7</sup> UCG and power generation, M Blinderman Ergo energy and R Jones GE Power Systems, Gasification Technologies Conference, San Francisco, October 2002

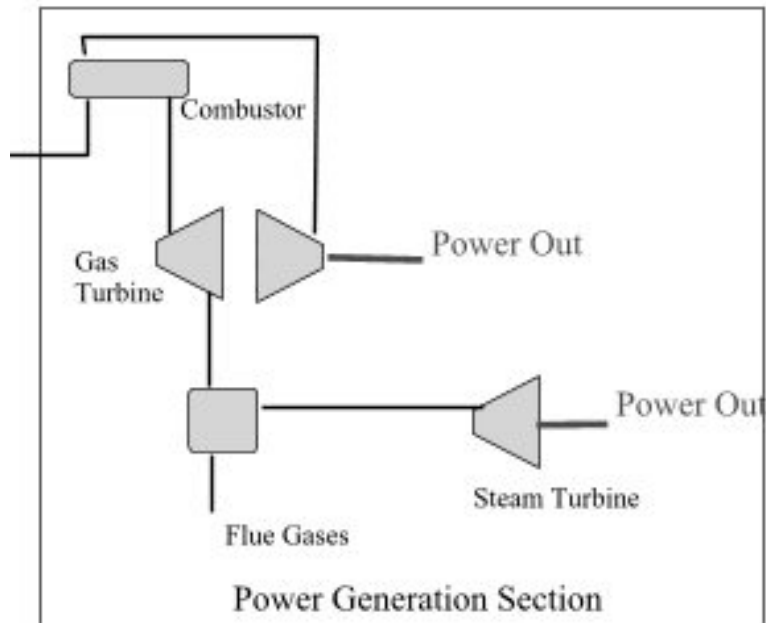


Figure 2.9 Combined cycle gas turbine for UCG

The field trial indicated that the UCG process can be interrupted and re-started over periods of at least one or two days without loss of the underground process. This important feature would allow the UCG operator to gain the value of peak-logging prices, and to provide rapid "swing" gas generation capacity, to balance, for example, the rapid variations in wind generation.

Other possible methods of power generation from UCG gas are to co-fire in a traditional thermal boiler operating on coal or other fuels, or to use a reciprocating gas engine, when only small power loads are involved. Generating efficiencies will be lower, but if existing or redundant plant were to be used, capital costs would be reduced. UCG gas might also be used for re-burn (as in Longannet Power Station, Scotland) to reduce NO<sub>x</sub> emissions from an existing coal plant.

### **Firth of Forth UCG Study**

A study, entitled "The Coalmine of the 21st Century" has been initiated by Heriot-Watt University with support from DTI, Scottish Enterprise and Scottish and Southern Energy Ltd. Its aim is to undertake a feasibility of UCG in the substantial coal resources of the Firth of Forth. This study builds on work already undertaken as part of the initial search for a test site, and will establish whether this area offers prospects for large-scale UCG and power generation. If the one-year study is successful, a prospectus will be produced to attract investment funds in the development of the project.

### **Current Worldwide Activities in UCG**

The recent International Workshop on UCG, undertaken as part of the UK initiative on UCG and held at the DTI Conference Centre in October 2003 has provided an up to date insight into worldwide activities on UCG, currently at a high level. The following is a brief summary.

Interest in underground coal gasification has increased substantially since the mid-1990s and most of it is now looking beyond experimental trials and towards commercialising the process for power generation and liquid fuel production. The motivation has varied from country to country but has been driven by the search for safer alternatives to small-

scale coal mining (China), the desire to exploit unmineable coal (Australia) and as an replacement for diminishing local supplies of natural gas. Coal gasification with CCS, surface or underground, also offers a practical medium-term option for the continuing use of coal and a bridging strategy to eventual energy production with zero emissions, i.e. renewable energy and the hydrogen economy.

### *Europe*

The European trial (1992-1998) and the subsequent UK initiative on UCG (1999 to present), described above, have been the most comprehensive investigation of UCG in deeper coal seams in the world to date. The trial has demonstrated the use of oil and gas technology to achieve high-pressure UCG in deep seams, and has also examined control and site selection for minimum environmental impact: essential stages in the development of an acceptable UCG operation.

A feasibility study has been underway by the Velenje Mining Company in Slovenia, which has identified UCG as a possible future route for the exploitation of a large lignite deposit currently being mined. Areas for a UCG trial, based on geology and hydrogeology considerations have been identified and more detailed investigation and funding options are currently being considered. The thermal power station of 750MWe, adjacent to the mine, is a potential commercial user of the UCG gas, if the project were to be developed.

### *China and Australia*

Chinese mining companies, with support from the Centre for Underground mining Technology (CUMT), Beijing have been working independently to develop their own form of UCG based on abandoned mine shafts. The programme has its roots in the Soviet programme, and a key feature is the use of a two-cycle process (alternate air and steam injection) to produce a high hydrogen product. China has five full-scale UCG trials currently underway, and about six have been completed over the past 10 years. The gas is distributed for local use, mainly for cooking and industrial heating. Plans are underway to build a 400MWe UCG power generation scheme within the next two years. The UK has recently completed a technology transfer programme<sup>8</sup> on UCG with CUMT and the Centre for Economic and Technical Exchanges, (CICETE), Beijing. The laboratory scale rig, figure 2.10, at CUMT could form the basis of a future collaborative programme on UCG.

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<sup>8</sup> Clean energy from UCG in China, report No Coal 250, DTI/Pub URN/03/0611, February 2004-03-2



*Figure 2.10 Model rig of UCG,  
(UCG Centre, Chinese University of Mining & Technology)*

The Chinchilla development in Queensland, Australia is probably the closest UCG project to commercialisation. An independent company using expertise from the former Soviet Union has been operating a trial scheme for 30 months using simple air blown vertical wells. They are in the process of acquiring financial backing to install a 40MWe gas turbine and using the site as a semi-commercial demonstration. It was understood from the International Workshop that there is possible UK interest to exploit the Chinchilla technology in the UK.

The Australian State laboratory, CSIRO, has a well-established programme on UCG involving modelling and process assessment. It is proposing a trial at a site close to Chinchilla. A possible area of growing interest for Australia is the conversion of coal to liquid fuels.

#### *Other Countries*

Other coal producing countries like India, Pakistan and South Africa, Poland and Ukraine are considering the feasibility of importing or developing UCG technology to exploit coal resources. Japan (JCOAL & NEDO) continues to examine UCG for exploiting near shore coal resources and is reconsidering the possibility of undertaking a UCG trial. To this end, the Japanese are providing some support to improve the instrumentation and data collection in one of the Chinese field trials.

Russia still has a small effort on UCG at the Skochinsky Mining Centre, Moscow, and private organisations in the US are undertaking various feasibility studies and initiatives. The US may also be reviving interest in UCG in view of the growing shortage of accessible natural gas in North America.

*Conclusions on the relevance of overseas UCG activities to the UK*

Much of the overseas activity to date has been concerned with shallow UCG, and is of limited interest unless sites can be identified that meet the environmental concerns raised in Chapter 3. There is some UK interest in the Chinchilla approach, assuming it can be adapted to UK conditions, and it is recognised by the developed coal producing countries, (US and Australia) that the protection of groundwater will be paramount

If the UK decides that the economic and environmental advantages of UCG should be further pursued as a long term option, the UK, through its Firth of Forth initiative could be in a position to lead a UCG project. A possible alternative, is to join the proposed Australian deeper UCG trial if it takes place. This is discussed further in Chapter 5.

### **3. Environmental Emissions and Regulatory Position of UCG**

#### **Introduction**

UCG is a potentially large-scale exploitation technology of fossil fuels like natural gas or coal production, in which the delivered product is gas of low to-medium calorific value.

In the past, a new fossil-fuels extraction process would have been considered in terms of its delivered price, convenience of use, reliability of supply, and the environmental issues of extraction, e.g. subsidence, habitat and groundwater contamination. Now, the carbon constrained world of climate change and the recent Energy White paper, requires that the emission of greenhouse gases to air (CO<sub>2</sub>, methane and possibly other minor gases) has to be considered. Furthermore, emissions are likely to bear a future cost under the European Emissions Trading Scheme.

Thus any new technology for fossil fuel energy conversion must be compared and assessed in terms of the ability, ease and cost of CCS as well as the other factors discussed above. A rigorous process of like-for-like comparisons is beyond the current study of UCG, but some evidence is already available.

#### **Comparison with other CO<sub>2</sub> capture and sequestration technologies**

The likely competing fossil fuel technologies for UCG are:

- IGCC
- Supercritical thermal plant
- Ultra-supercritical Thermal Plant
- Oxygen fired combustion
- Natural gas fired GTCC

It is assumed that all UK fossil fuel technologies will require CCS, and that CO<sub>2</sub> sequestration in offshore reservoirs will have been developed over the 20-year time frame required to commercialise UCG. Currently, however, there are considerable uncertainties about the cost effectiveness and regulatory regime for sequestration. Even CO<sub>2</sub> capture processes, which are relatively well developed in the chemical industry, are not well costed on the scale of CO<sub>2</sub> capture from large-scale power generation.

#### *Life Cycle Analysis*

An Australian study<sup>9</sup> compared life cycle emissions (taking into account emissions of construction, operational and disposal of plant) based on the Chinchilla UCG project in Queensland, (see worldwide developments in Chapter 2), against the competing technologies as shown in figure 3.1:

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<sup>9</sup> Australian Coal Association Research Programme (ACARP) study of Coal in a Sustainable Society. Case study B20 electricity production using UCG, 2001.

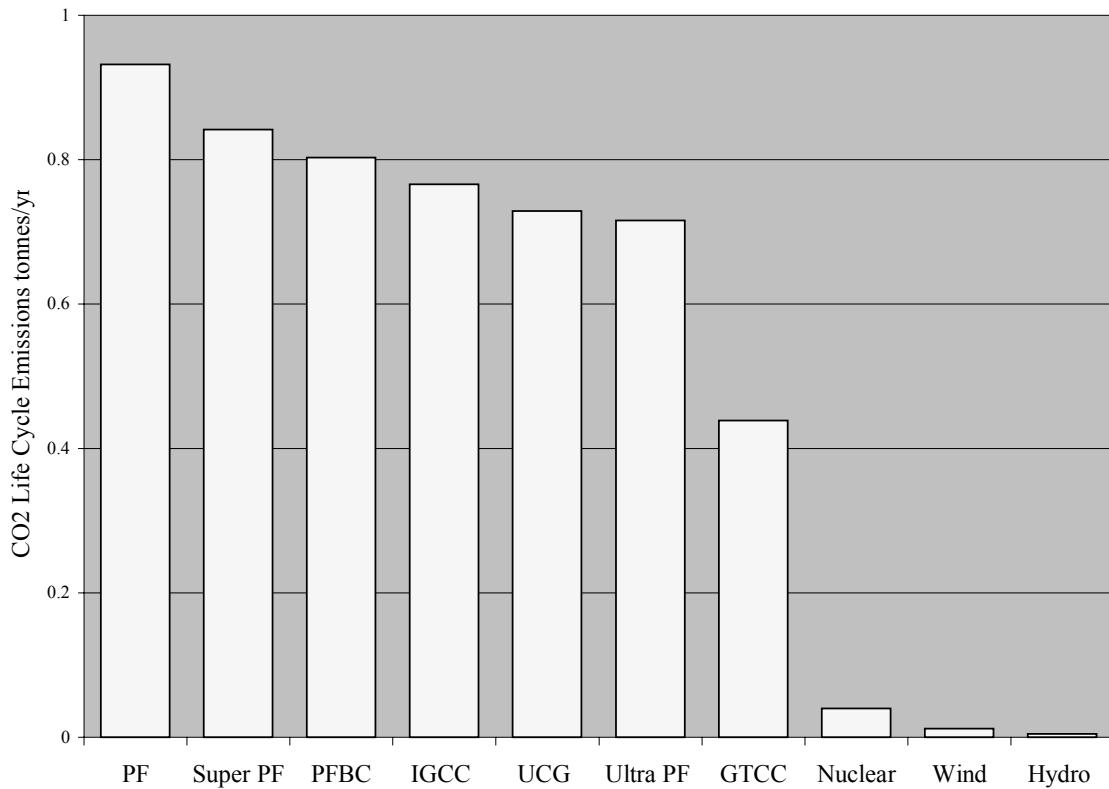


Figure 3.1 Life Cycle Analysis of Competing Fossil Fuel Plant, courtesy of the ACARP study, referenced above.

This analysis indicates that on a life cycle analysis, UCG-GTCC is ahead of all competing fossil fuel technologies with the exception of ultra-supercritical pf and natural gas.

The graph above is similar to the comparison of CO<sub>2</sub> emissions used in the DTI leaflet on UCG (October 2003) as shown in figure 3.2

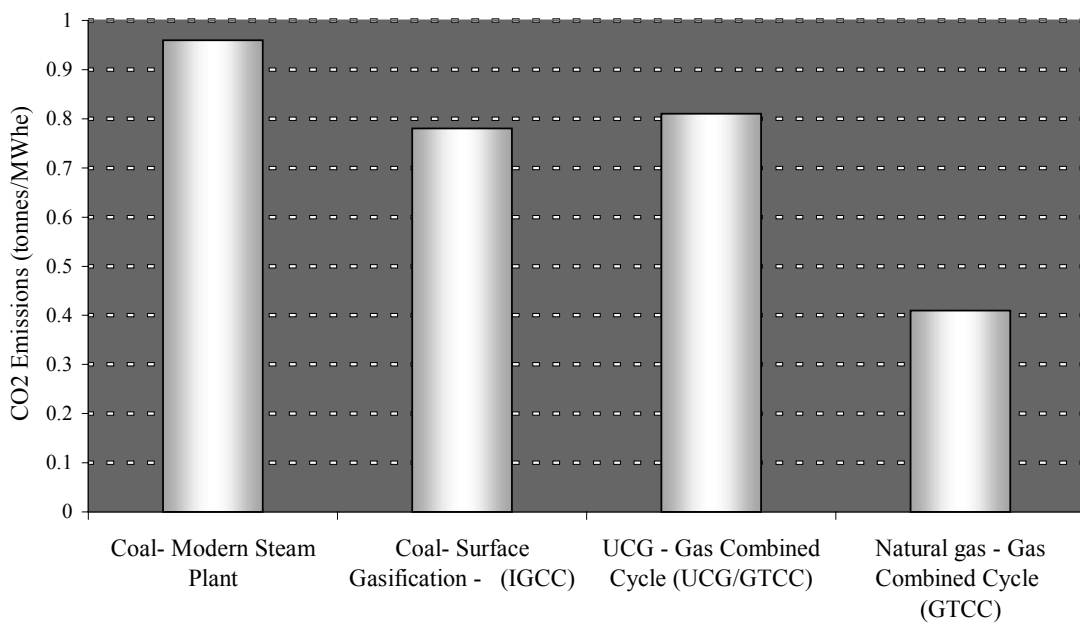


Figure 3.2 Comparison of CO<sub>2</sub> emissions from DTI leaflet October 2003

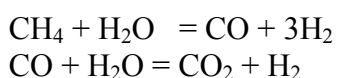
### *CO<sub>2</sub> Capture from UCG gas*

Well-developed processes are available for the capture of CO<sub>2</sub> and the options<sup>10</sup> include physical adsorption, chemical absorption and separation membranes<sup>11</sup>. The pre-combustion processes for the capture of CO<sub>2</sub> are normally preferred for gasification processes like IGCC on the grounds of efficiency and process costs and the same would generally apply to UCG.

CO<sub>2</sub> capture in pre-combustion syngas is far more energy efficient than the post combustion process (one fifth according to one estimate<sup>12</sup>). A similar result should apply to CO<sub>2</sub> capture from UCG product gas, in spite of the additional steam reforming required to convert the methane. Operating pressure is also higher with UCG, which should reduce the energy requirements and plant costs.

Three options for CO<sub>2</sub> capture from UCG product gas are considered:

1. Capture of CO<sub>2</sub> from the product gas, prior to combustion.  
For a high-concentration and high-pressure product gas stream like UCG, the Selexol process, based on physical adsorption into an organic solvent and pressure swing for generation would be used to capture CO<sub>2</sub> in the products stream. The resultant CO<sub>2</sub> would be compressed to pipeline transmission conditions of 80bar for transmission to the sequestration site (see following section): the CO<sub>2</sub> product gas entering the turbine will also need to be compressed.
2. Steam Reforming and Shift Reaction followed by CO<sub>2</sub> capture.  
The mixture of methane and carbon monoxide in the UCG product gas can be converted to hydrogen and CO<sub>2</sub> by the standard process of steam methane reforming (SMR), which involves passing the gases over a nickel catalyst followed by shift conversion to achieve the following reactions:



The resultant hydrogen and CO<sub>2</sub> mixture is passed to a Selexol unit for CO<sub>2</sub> capture and the hydrogen (with nitrogen added from the ASU) is used for power generation. SMR is a well-developed process for hydrogen production in the chemical and oil refining industries. Quoted plant costs are in the range £1800 - £5000 /Nm<sup>3</sup> of methane/h, depending on plant throughput.

The recently published design<sup>13</sup> of an IGCC plant with a CO<sub>2</sub> capture option indicates that the shift process can be undertaken under acid conditions, and that the sulphur and CO<sub>2</sub> removal could be carried out in the same plant, allowing integration of the gas cleaning and CO<sub>2</sub> capture processes, and considerable capital costs savings.

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<sup>10</sup> The options are considered in the four sessions on carbon capture at the GHGT6 conference on Greenhouse Gas Control Technologies, Kyoto, October 2002

<sup>11</sup> Putting Carbon back into the Ground, IEA Greenhouse R&D Programme report, February 2001

<sup>12</sup> Report on the 5<sup>th</sup> Gasification Conference, Amsterdam, April 2002, DTI visit report, K Fergusson

<sup>13</sup> Review of the case for a cleaner coal demonstration plant, Report to DTI by Jacobs Engineering, available on DTI Cleaner Coal Website

### 3. Post combustion capture of the CO<sub>2</sub>.

An alternative is to remove the CO<sub>2</sub> from the exhaust gas of the power plant by post combustion separation, although this is not usually advocated for gasification processes. Dilute CO<sub>2</sub> and nitrogen can be separated using amine solutions<sup>14</sup>.

A better process option, in theory, is to run the power plant at the end of UCG gasifier on an oxygen/CO<sub>2</sub> mixture to produce only water and CO<sub>2</sub> in the resultant flue gas stream. This can then be dried and compressed for transportation to a sequestration site. Modifications are required to the combustion section of boilers and gas turbines, but work is already underway on advanced zero emission power concepts<sup>15</sup>. Since UCG is already using oxygen for the underground process, oxygen fired combustion could be a good match for the UCG power generation section.

Figure 3.3 shows the effect of the three methods of CO<sub>2</sub> capture on both the emission and production rate of CO<sub>2</sub>. The total CO<sub>2</sub> production rate (emissions and capture) increases as a result of the energy required for the capture processes<sup>16</sup>; at the same time emissions to atmosphere decrease as more CO<sub>2</sub> is captured. It is assumed that the efficiency of the capture process using Selexol is a realistic 90% of the CO<sub>2</sub> available. The no-capture case is shown as a base case for comparison - CO<sub>2</sub> “avoided” is the difference between the CO<sub>2</sub> emitted in the capture and no capture cases.

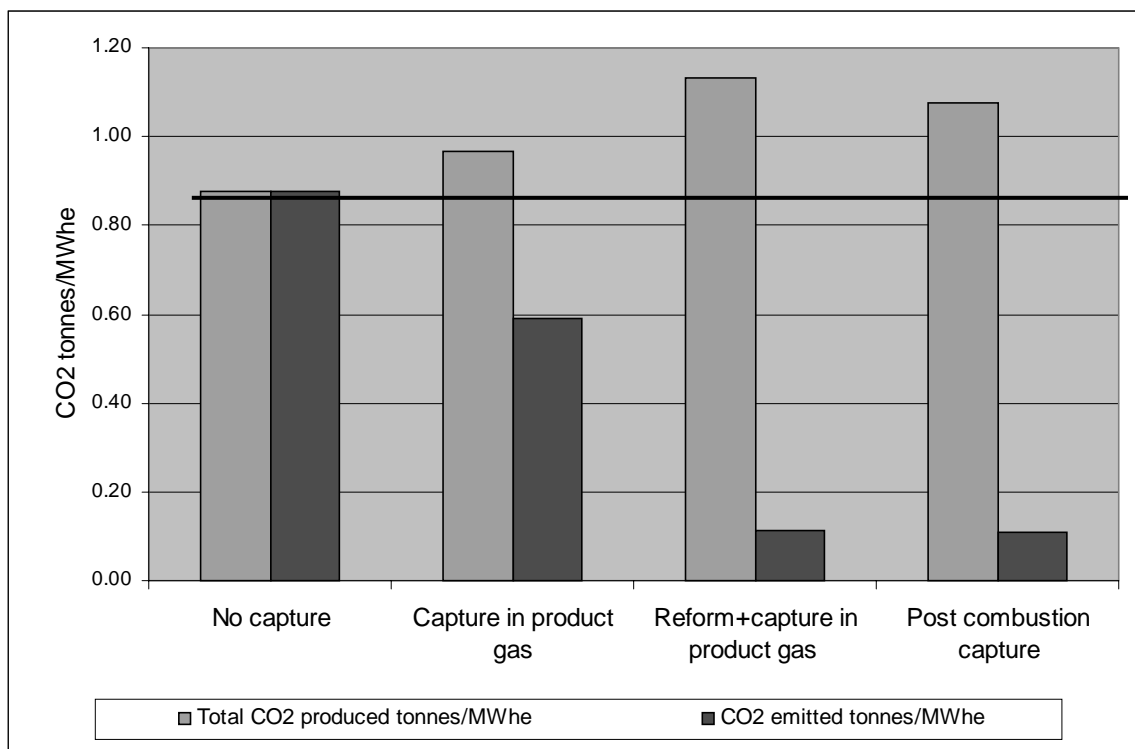


Figure 3.3 Produced and emitted for CO<sub>2</sub> capture from UCG gas (Capture process assumed to be 90% efficient)

<sup>14</sup> The Fluor Danial Econamine System is one such system.

<sup>15</sup> CO<sub>2</sub> control technologies: Alstom Power approach, T Griffin & A Bill, GHGT6 Conference, Kyoto, October 2002.

<sup>16</sup> Efficiency Values extrapolated from DTI publication “Carbon Dioxide Capture and Storage - A Win-Win Option? May 03, AEA Report ED 01806012

The results show that capture of CO<sub>2</sub> in the product gas alone reduces CO<sub>2</sub> emissions by about one third compared with the base “no capture case”. This option is considered further in the economics section, Chapter 4.

The pre-processing of the product gas before combustion increases the CO<sub>2</sub> avoided to 90%, which is about the same as can be achieved with post combustion capture. The difference is that the pre-combustion processing takes place at higher pressure with about one fifth of the volume, and the processing and capture plant can be smaller, and almost certainly less costly. The reformed and capture case is 95% hydrogen, and would be suitable, after further processing, for distribution in a future hydrogen economy.

#### *UCG and CO<sub>2</sub> sequestration*

A UCG plant, like any other power generation plant with capture installed, is a source of relatively pure CO<sub>2</sub>, which could be transported by pipeline and sequestered in a suitable storage location. Parallel projects within the DTI Energy programme<sup>17</sup> examine the options for CO<sub>2</sub> sequestration in the UK (which include enhanced oil recovery, and storage in deep saline aquifers or depleted gas reservoirs) and associated risks and environmental issues, so far as they can be evaluated at present<sup>18</sup>.

One of the possible UK scenarios for large point sources like power stations etc is a pipeline network with access nodes connected to the offshore storage locations. A 300MWe UCG plant would be producing around 1.4 Mtonnes CO<sub>2</sub>/year and this would increase to around 10 Mtonnes/year for the 2GWe offshore plants considered in Chapter 4. Even the lower figure would probably justify pipeline connections (~10km) to the nearest node.

Unmineable coal is a less attractive option for CO<sub>2</sub> disposal in the UK because coal permeability is generally considered to be too low, but directional drilling can improve access to coal seams and may offer limited scope for the future. There is also the possibility of using the abandoned UCG cavity and other stressed strata as a storage area for CO<sub>2</sub>, but this is speculation at this stage.

### **Groundwater Issues**

The only commercial UCG plants ever built were in the former Soviet Union and the last of these was planned and constructed in the 1970s; no reliable environmental information is available on them. The first available environmental data on UCG came from the later U.S. trials, which were extensively monitored for groundwater contamination during and after gasification. UCG at shallow depth can pose a significant risk to groundwater in adjacent strata.

The European UCG trial at a depth of 550m was monitored for water contamination in surrounding boreholes, in the drinking water supply to the local community and in the local river for a period from initial site access to five years after the completed trial. No environmental contamination was detected at any of these monitoring points. The only evidence of contamination was in the water in the cavity itself, which is co-produced with the gas and brought to surface. The main concern of the Regional Authorities was surface spillage and disposal of contaminated water for which special provision was made.

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<sup>17</sup> Feasibility of Carbon Capture and Storage in the UK; Sept 03.  
<http://www.dt.gov.uk/energy/coal/cfft/CO2capture>.

<sup>18</sup> The Intergovernmental Panel on Climate Change is producing a special report on CCS due in June 2005.

The Chinchilla project, Australia, took place under the supervision of the Queensland EPA but detailed results have not, so far been made available. Questions were raised<sup>19</sup> about the post gasification process in the absence of a reliable large water supply.

A UCG project in the UK would require approval under the planning and environmental laws and should be consistent with Government energy policies on a low carbon economy and energy security, as set out in the Energy White Paper. The initial investigation revealed significant uncertainty in how UK and future legislation from Europe will affect UCG. Specialist consultants were contracted to initiate a study with the following objectives:

- Critically review the relevant environmental experience from previous UCG trials.
- Assess the UK environmental legislation applicable to UCG and the identification of issues that would need to be considered in presenting the process for approval by legislators.
- Propose best practice for the key stages of any UCG experimental and semi-commercial programme.

The study also examined the existing UK Regulations that are likely to apply to UCG commercial operations, and any additional requirements that might be imposed by European environmental legislation, such as the Integrated Pollution Prevention and Control Regulations (IPPC) and the new Ground Water Directives. The extent to which the application of existing legislation would deal with wider concerns about controllability of underground coal fires, subsidence, escape of toxic gases and ground water analysis was assessed. Work described later by the Tyndall Centre suggests that there would indeed be widespread concerns for onshore UCG.

#### *Evaluation of Ground Water Risks*

The Groundwater Regulations will require a prior investigation of any proposed UCG site and full consideration of the environmental risks. Most of the risk of wider groundwater pollution is governed by the natural characteristics of the site, namely the permeability of in-situ rocks and geological structures, hydrogeological conditions and the impact on local ground conditions.

A suitable UCG project site with the appropriate operational controls should present a very low risk to groundwater, but a robust assessment will be required. Close liaison with Regulators and conservative approaches to risk assessment will need to be adopted, due to the uncertainties over contaminant generation, persistence, and transport through the geo-sphere. Furthermore, the understanding of the below ground environment from any practical programme of scout drilling from the surface will be limited.

A network to monitor groundwater both during and after operations will be a requirement, the design of which will be site specific and based on knowledge gained from the risk analysis. The mitigation response to pollution breakout, e.g. a rapid shut down and clean up procedure, also will need to be identified.

An important parameter in determining the risk in a UK context is to identify a zone of “permanently unsuitable” (PU) groundwater. This is defined as a block of strata where the water quality and/or yield are so poor that groundwater in that area cannot realistically be regarded as an environmentally or economically significant ‘aquifer’. If a

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<sup>19</sup> Combustion News Feature Article on UCG, Ken Wa, Sept 03

PU zone is established, the assessment of the pollution risk will focus on ensuring that there is no connectivity of the zone with overlying aquifers.

Although relaxations of the ground water regulations using the concept of PU ground water have been applied occasionally for hydrocarbon exploration, the principle needs to be tested, in the context of UCG. Suggestions for an environmental desk study based on a specific target area are proposed in Chapter 5.

#### *Operation of the Cavity and Shut down procedures*

Appendix 2 provides details about how the cavity should be operated and shut down to minimise the spread of pollutants. The basic strategy, tested in the Spanish trial, is to maintain a cone of depression in the groundwater around the reactor, so that flow of contaminants is always towards the cavity. Monitoring the pressure in the strata is required, and shut down must avoid any build up of steam or cavity pressure, which could lead to gas and liquid dispersal.

#### *Surface Issues*

Exploration, drilling, and the process of gas transport, gas treatment and power generation have well defined surface impacts and risks, which can be assessed using conventional methods and these will be outlined in a Best Practice Guide for UCG<sup>20</sup>. Appropriate mitigation will be required for dust, noise, visual impact and emissions to meet the necessary legislative standards (see below).

During operations, contaminated water is produced in the cavity from the gasification reactions, and reaches the surface with the product gas. The washing stage of the gas will also form contaminant solutions, which will have to be treated before discharge to local rivers or recycled as process water for the underground reactions. A UCG site will have a significant requirement for temporary storage of various process and contaminated water streams and will probably need its own small treatment plant nearby to recycle the water for further process operations. Control of spillages and the use of best practice in the processing of effluent waters<sup>21</sup> will be important part of site management.

#### *Surface Subsidence*

Significant surface subsidence is not thought to be likely because the boreholes and resultant UCG cavities from gasification will be narrow, compared for example with long wall mining, but this will have to be evaluated as part of the EIA. A multiple gasifier configuration for a large UCG scheme can be planned to minimise any adverse effects of subsidence.

The potential impact of ground movement on the permeability of strata and structures underground, caused by caving of the reactor, will have to be evaluated for its effect on the groundwater risk. The coal seam will be located well away from abandoned mines and shafts, but boreholes above the cavity for monitoring or production could be at risk and the effect of relaxation (for which there are various models<sup>22</sup>) will need to be addressed.

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<sup>20</sup> To be published: check DTI Website on cleaner coal technologies.

<sup>21</sup> Effluent Treatment Techniques, Environment Agency 1998

<sup>22</sup> See UCG workshop presentations by Smart and Reddish et al, London Oct 03

## **Planning and Regulatory Issues**

### *Planning Requirements*

UCG is covered onshore in the UK by land use, planning and environmental regulation provisions. Land use planning provisions in England and Wales differ in some respects from those in Scotland and significantly from those in Northern Ireland. There is currently no spatial planning system offshore thus each proposal would be considered on its merits. However any gas recovered offshore would be taken to storage and power generation facilities onshore and these would fall within the ambit of planning provisions.

Development of a trial site for UCG, or of a full production facility, would be considered as a mining operation in any planning application<sup>23</sup>. However any associated electricity generation facilities would be regarded as an industrial facility. Therefore policies concerning both mining and industrial operations would need to be taken into account by the relevant local planning authority. In the case of electricity generation facilities exceeding 50MWe in output the responsible authority is the Secretary of State for Trade and Industry.

Under Town and Country Planning provisions, there is a presumption in favour of permitting planning applications, if environmentally acceptable, subject to suitable mitigation measures, where these are in conformity with policies in the minerals development plan. Since UCG is a recent issue in the UK there is an absence of specific policies concerning the extractive element of any proposal in development plans and applications should be considered on their merits. However there will be policies relevant to industrial facilities that are relevant to processing and generation facilities.

Where an application constitutes a Departure from the Development Plan, the planning authority informs the relevant Secretary of State who might either confirm that the planning authority should determine the application, or might recover the application for his own decision. If the local planning authority refuses an application it may be the subject of an appeal to the secretary of State.

In England, revised guidance on Planning and Minerals (Minerals Policy Statement 1 - MPS1) is in preparation to replace earlier guidance in Minerals Planning Guidance Note 1. This is likely to go to public consultation in 2004. While this will not refer to specific minerals, it will set out the general policy context. It is planned to consult on an Annex to MPS1 on "Oil and gas" later in 2004 and this will make some reference to UCG.

Account needs to be taken of the Environmental Impact Assessment(EIA) Regulations that apply to some forms of development. Since there is some uncertainty about the environmental impacts of UCG until a trial has been undertaken, it seems likely that a planning authority would require EIA to be prepared in respect of any planning application. It would be wise to discuss this issue with the appropriate authorities at the earliest opportunity and determine, if appropriate, the scope of any Environmental Statement required. Although extraction beneath the sea would not be within the ambit

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<sup>23</sup> The Planning and Compulsory Purchase Bill is likely to receive Royal Assent in April 2004 and will then be the relevant legislation for England and Wales - the relevant legislation in both Scotland and Northern Ireland is different and further consultation is required

of land use planning, it again seems likely that EIA would be required for similar reasons.

Material information to the determination of a planning application may include, for example, impacts on the local environment, population and habitats. In the case of UCG, many of the issues associated with the storage and processing facilities would be similar to a broad range of industrial facilities. In the case of the extractive operations, drilling and dealing with associated impacts would be broadly similar to other forms of hydrocarbons exploration and extraction. Particular issues associated with UCG would include, however, the extent to which the operation can be controlled, the adequacy of the procedures for closure, and the potential impacts and containment of contaminants especially with regard to underground and surface water. Some of these matters are also the subject of environmental regulation (see below), and the planning conditions should complement, and not conflict with or duplicate, any licence conditions. Therefore close liaison is required between the applicant, the planning authority and the environmental regulator.

Consideration will need to be given by the applicant to whether the extractive operation and any storage/generation should be co-located. The latter would be an industrial operation that might not be appropriate to a rural or greenbelt location but might be more acceptable on land already designated for industrial use in a development plan. The extractive operation would however, even allowing for flexibility provided by directional drilling, need to be essentially within the area in which the mineral occurs. This might raise issues as to the acceptability of provisions for a pipeline between the sites. It might also lead to two separate local planning authorities needing to consider applications if the extraction and processing sites fell into different administrative areas.

#### *Integrated Pollution Prevention and Control and other EU Directives*

The UCG process, for both the trial and semi-commercial operation would be covered under the Pollution Prevention and Control Regulations 2000. UCG, like all gasification processes will need an IPPC permit from the relevant Environment Agency<sup>24</sup>. IPPC requires the application and use of Best Available Technology (BAT) for all emissions and detailed technical guidance<sup>25</sup> is available with revisions in preparation.

The EU IPPC Directive contains a research and development (R&D) exemption clause that was not fully implemented but consultation is currently being undertaken across Europe. If the Regulations were to be modified to implement the R&D exemption, then any trial (but not a commercial UCG project) might be exempt from the full requirements of IPPC.

The gas processing has to ensure that the final emissions from the plant meet current air quality and emission standards for SO<sub>x</sub>, NO<sub>x</sub>, heavy metals and particulates. The revised European Large Combustion Plant Directive (LCPD) (2001/80/EC) aims to reduce acidification, ground level ozone and particulates by controlling emissions of sulphur dioxide, oxides of nitrogen and dust from large combustion plants. The Directive sets emission limit values for large (>50 MWt) combustion plant and is implemented in the UK through the IPPC regulatory regime. The LCPD states that compliance should be regarded as necessary, but not sufficient, to ensure compliance with best available technology (BAT) under the IPPC regime. Sectoral guidance for

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<sup>24</sup> Environment Agency in England and Wales, SEPA in Scotland, or the Northern Ireland Office.

<sup>25</sup> EU Best Available Technology (BAT) Reference Documents (BREFs)

gasification plant under IPPC is not yet available, but could add eventually further conditions.

#### *Ground Water Regulations and the Water Framework Directive*

Approval under the Groundwater Regulations 1998 is part of the IPPC permit process. Normally the release of contaminants to groundwater is prohibited, but the Regulations allow exemptions for pollutants like phenols and heavy metals (List 1 & List II substances) for permanently unsuitable groundwater provided the substances cannot reach other aquatic systems.

The regulatory position at present is that UCG is likely to obtain groundwater consent if it can be established that:

- Adjacent groundwater can be declared permanently unsuitable (see earlier for a definition of PU water).
- Transfer of contaminants to upper aquifers will not place.
- Shallower aquifers are protected (leakage from access boreholes)

However, UCG is viewed as a novel process and risks may emerge as knowledge/thinking develops. Any site-specific applications of UCG will be determined on their merits.

Under the EU Water Framework Directive of October 2000, currently being transferred into UK law, the Commission in September 2003 put forward proposals for a “daughter directive” for consideration initially by the Environmental Committee of the European Parliament, and later by EU Council Working Groups. In the daughter directive, abstractions of drinking water and discharges to ground water will be more tightly regulated but Member States can still authorise exemptions for hydrocarbon extraction, and mineral extraction. A clause<sup>26</sup> similar to the definition of permanently unsuitable water is included in the draft, which suggests that this exclusion will continue.

#### *Other Relevant Legislation*

Separate Air Quality Regulations were produced in England, Wales and Scotland in 2000, in which Local Authorities must review and assess the air quality in their region against set objectives. The emissions to air from the UCG operations could require controls to ensure that they do not cause any significant contribution to the ambient air concentrations and the means of regulating/enforcing these Regulations would be via the Planning and IPPC permitting regimes.

In addition to the above planning and pollution regulations, UCG would have to comply with the “Control of Major Accident Hazards Regulations 1999” (COMAH), The Air Quality Regulations and possibly other EU Directives now enshrined in UK law.

#### *Licensing*

It is anticipated that the drilling and exploration boreholes and the subsequent injection and production wells would require from The Coal Authority:

- Exploration licence.
- Operational licence to work the coal.
- Leasehold interest in the coal.
- Access agreement, where necessary, to pass through other coal seams.

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<sup>26</sup> Clause 31 “In cases where a body of water is so affected by human activity or its natural condition is such that it may be unfeasible or unreasonably expensive to achieve good status, less stringent environmental objectives may be set on the basis of appropriate, evident and transparent criteria”

In addition a surface access agreement would be required from the landowner.

It is currently uncertain as to whether a petroleum exploration and development licence (PEDL) would be required, in addition to any license that the Coal Authority would issue for UCG. An existing PEDL holder may also have to be consulted. These anomalies of the UK licensing systems requires to be addressed, and is an action in this report.

#### *Greenhouse Gas Emissions Trading*

Commercial UCG operations rated at above 20 MWh<sub>t</sub> would come under the remit of the EU Emissions Trading Directive. Any installations established before the end of 2007 (the end of the first phase) would be eligible for allocation of free allowances under the New Entry Reserve, although the rules for allocation are still being discussed within Europe and allocations are not expected before the end of 2004.

Commercial UCG would fall under the second phase of the scheme, i.e. installations after 2007 in which there is considerable uncertainty as to whether CO<sub>2</sub> allowances would be given, although discussions are taking place. UCG linked to CCS would require monitoring provisions to be agreed by the European Commission until a formal protocol can be established.

#### *Safety Issues*

Safety of the plant and below ground installation will be paramount in any future UCG operation, not only to protect people and property, but also to give confidence to the general public that a combustion process underground is fully controllable and safe from explosion and other hazards.

All safety matters related to the drilling and operation of underground boreholes and extraction of hydrocarbon gas from onshore sites are covered by the Offshore Safety Division (OSD) of the Health and Safety Executive and a memorandum of understanding has been drawn up between the Mines Inspectorate and OSD. Notifications are required under;

- The Borehole Site and Operations Regulations 1995.
- The Offshore Installations and Wells (Design and Construction) Regulations 1996).

These Regulations specify the procedures required for the design, planning, operation supervision and abandonment of the process, and require that an independent well examiner oversees the written well examination scheme and the safety documentation.

A two-stage approval process is foreseen in which the project is divided into a construction, and an operational and abandonment phase. Approval of the UCG operations from a safety standpoint will require detailed consideration of the underground ignition, gasification and associated activities; significant effort will be required to develop and agree the necessary documentation with the OSD.

The above-ground plant for oxygen supply, gas clean up and power generation may be located some distance from the wellhead configuration and connected by transmission pipelines. These will be subject to the normal safety regulations for industrial plant; namely, the Health and Safety at Work Act 1974 and COMAH 1999.

## Public Awareness Issues

The general public are largely unaware of UCG, although there have been occasional articles in national newspapers and the popular scientific press. The first site to be considered for a UCG trial was an abandoned colliery at Silverdale, Staffordshire, where planning permission in 2000 was sought to construct the wells for a UCG trial by directional drilling. This provoked significant local reaction, in spite of the public consultation undertaken by The Coal Authority. The issues of concern are summarised<sup>27</sup> in table 3.1.

	Drilling issues	UCG gasification issues	General issues
1	Noise	Fear of uncontrollable coal burn underground	Fear of coal catching fire and burning uncontrollably, the area has a history of 'spontaneous combustion' and this issue was high in the awareness of local people
2	Visual impact of the drilling rigs	Waste from the UCG contaminating aquifers. In particular coal tars which are believed to cause cancer	The area is considered to be cleaner and 'better' since the colliery had closed, particularly dust and air pollution.
3	Increased traffic, one resident estimated the number of vehicle movements at 700 HGV movements over the course of the project.	Danger from underground explosions	The experimental nature of the work was questioned, with people not wishing for a scheme to go ahead when some of their questions could not be answered. A residential area was not seen as suitable for research with many unknowns.
4		Gaseous emissions from UCG could rise to the surface	Regeneration of the local area would be delayed and firms would be 'put off' from locating near the site.
5		Subsidence, the area has a history of subsidence	The scheme did not bring any benefit to Silverdale
6			The value of local property would be reduced.

*Table 3.1 Issues of concern raised by local people at Silverdale Colliery (year 2000)*

A lesson from Silverdale is that local social, cultural and institutional context will have great influence on the manner in which the risks and benefits associated with UCG are perceived. Familiarity of local people with the consequences and legacies of conventional coal mining amplified the perceptions of risk of affected people, and overall, local context will be an important factor in site selection.

<sup>27</sup> Extracted from "The public Perceptions of UCG: A Pilot Study", Report to DTI by the Tyndall Centre UMIST, Dec03

The Tyndall Centre at UMIST<sup>28</sup> undertook a pilot study of the public perception issues of UCG based on desk and a focus group discussion. They found that UCG is likely to be perceived by the public as a potential high-risk project with little to offer local communities.

On the other hand the potential of UCG as a secure source of energy for the UK, and its potential for lower cost CO<sub>2</sub> capture was seen by the focus group as a good safety net for the UK. Suggestions were made for improving public perception of UCG and integrating it more closely within a sustainable energy programme. The focus group felt that there are net economic benefits to be reaped if the UK comes to acquire a technical mastery of the process and can export the technology overseas.

Some of the ways, suggested by this study in which these challenges might be addressed are:

- Develop UCG on a small scale in order to obtain technical of the process and potential innovations in an incremental fashion.
- Include the benefits of CCS from the start of any project and pay particular attention during planning to ensure that the life expectancy of UCG correlates with the bridging policy of CCS prior to full commercialisation of zero emission energy.
- Include UCG within a package of measures aimed at improving the local community's quality of life, economy, environment and employment.
- Ensure all operations, operators and other responsible parties are transparent and open in their dealings with the public and regulators, providing clear and accurate information and also providing local residents with the opportunity to cross-examine the information, developers, technical experts and regulators.
- Include the local public and stakeholder reactions as part of the site selection process, alongside the more tangible issues such as coal geology, hydrogeology and other planning issues.
- Undertake a professional communication strategy, before (and after) any trial site is selected, including setting up of an information web site, and the production of other suitable publications.

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<sup>28</sup> University of Manchester Institute of Science and Technology

## Conclusions on the environmental issues of UCG

As a coal based technology UCG will need to pay particular attention to CO<sub>2</sub> emissions, any large scale development is only likely in the context on carbon capture and storage, which entails solving a particular range of issues. The processes required for CO<sub>2</sub> capture from UCG product gas are available and the higher pressure of the gas may be an advantage. Work is under way on CO<sub>2</sub> sequestration within the UK and internationally via the IPCC and the Carbon Sequestration Leadership Forum.

Ground water contamination is another primary concern with UCG, and will need to be fully evaluated for any proposed UCG project. Factors, which can reduce the risk of contamination, are site selection, deeper coal seams and operating the cavity as a local depression within the strata.

Groundwater Regulations are met when the target coal seam is located in an area of “permanently unsuitable” water, but this has to be proven by environmental investigation and analysis, and the concept still has to be tested in the context of UCG at specific sites. An investigation of a specific site and a probabilistic risk analysis are proposed.

The framework for approval of a UCG project is a permit under the IPPC Regulations. The utilisation of UCG product gas at the surface will have to conform to European Directives for large power plant, the UK Air quality requirements and any future further restrictions that might be imposed on gasification plant. Although air emissions controls are stringent, the technology of mitigation is fully developed and UCG will have to no special difficulties in meeting current and future Regulations.

The Town Country and Planning Acts of England and Wales and the equivalent in other parts of the UK give opportunity for local communities to object to any proposed UCG project, and this could impose significant restraints on the exploitation of UCG in rural areas. On the other hand, planning regulations recognise that minerals have to be extracted where available, including rural areas, and there is a presumption in favour of permitting planning applications if environmentally acceptable. Regional variations can be anticipated and planning applications for real sites, with appeals if necessary will resolve whether UCG is an acceptable method of coal exploitation.

Licensing of UCG operations under the current arrangements through the Coal Authority should present no difficulties, although the position with respect to the licensing of oil and gas operations still needs to be established.

The pilot work on public perceptions suggest possible cautious ways forward, and for UCG in rural coal areas, the power plant will need to be located away from the UCG extraction station in an appropriate industrial area. UCG under estuaries and under water near to shore is seen as the best prospects for early project entry in the UK.

## 4. Economics and Commercialisation of UCG

### Economic Scoping Evaluation of UCG

A preliminary economic evaluation has been made of UCG for a UK onshore situation. Four case studies for UCG have been considered:

- Case 1: 50 MWe Small-scale Integrated UCG Power plants.
- Case 2: 300 MWe Large-scale UCG linked to a remote power plant.
- Case 3: 300 MWe as above with post-combustion CO<sub>2</sub> capture.
- Case 4: 300 MWe as above with partial pre-combustion CO<sub>2</sub> capture in the product gas.

The assumptions and full details used in the economic assessment are available in a separate report<sup>29</sup>. Three options can be considered for capture from UCG product gas, namely:

- Total CO<sub>2</sub> capture in the flue gases,
- Partial pre-combustion capture of the CO<sub>2</sub> in the product gas
- Total pre-combustion capture after converting the product gas H<sub>2</sub> and CO<sub>2</sub> using a steam reforming and shift stage.

The first two have been costed, but plant data was unavailable for the total capture of CO<sub>2</sub> from the pre-combustion gas, even though this is the most likely approach to UCG-CCS. Within the approximations of this scoping study, it is assumed that the costs of total CO<sub>2</sub> capture will be the same for post and pre-combustion processes.

#### *Gas production panels*

It is assumed in the economic assessment that a single UCG channel of the type shown in the early sections of this report will produce around 25MWt on a continuous basis, and these would be grouped into branched modules to feed the production well as shown in figure 4.1.

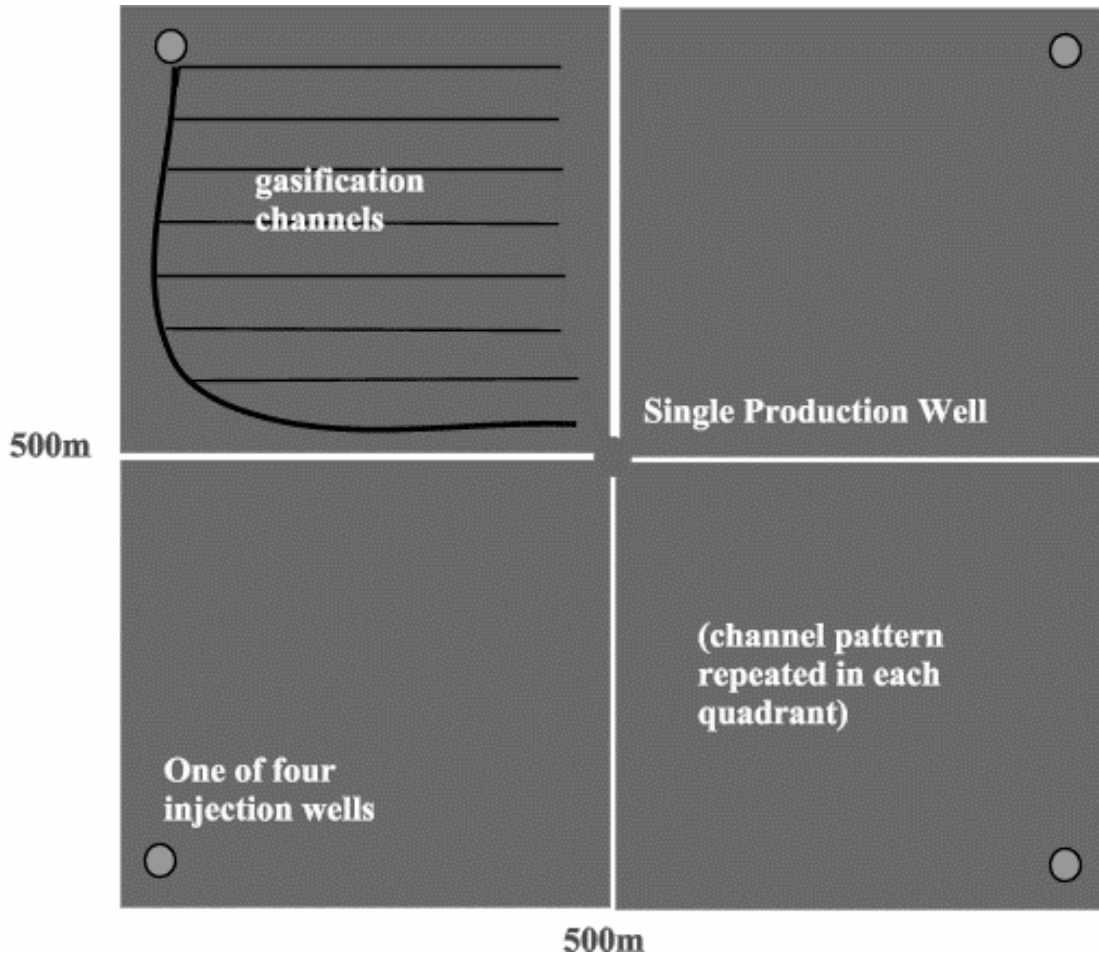
In all the case studies, a UCG panel consists of a coal panel 500m x 500m with four adjacent areas, 250m by 250m, in a coal seam of 2.5m thickness, each accessed by a single injection well. The gas output from the four areas is collected by a single production well located in the centre of the panel. The total thermal output of each panel using assumptions based on field trial data is estimated to be 10,400GWh, which is equivalent to 3.2MWh/tonne of UCG coal resource.

A number of panels working simultaneously would be connected by pipeline to the power and processing island, possibly some distance away. Each panel would typically have a production life of 1 –3 years, depending on the rate of gas production, and once exhausted, and safely shut down, the well would be sealed and the surface returned to its original rural or other state. The pipelines would then be connected to the fresh coal panels, which would have been pre-drilled and prepared in advance. The panels do not need to be adjacent, and multi-seam applications can also be foreseen, which could allow the production wells to be re-used.

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<sup>29</sup> <sup>29</sup> A scoping economic assessment of underground coal gasification, G Marsh Future Energy Solutions, April 2004. Report to be made available on DTI website for the Cleaner fossil fuel programme.

The total development cost of a panel is estimated in Appendix 3 at £9.3M and is equivalent to capital intensities of £15.2 per tonne coal accessed and £2.8 per MWh (£0.79 per GJ) of UCG gas produced. It was assumed that the maximum rate of production from a panel would be about 100MW (thermal) and that the UCG product gas, after drying and cleaning would have a calorific value of about 13MJ/Nm<sup>3</sup> (cf natural gas 38.5MJ/Nm<sup>3</sup>).



*Figure 4.1 Configuration assumed for a UCG production panel (500m x 500m)*

It is anticipated, for cases 2-4 that oxygen would be supplied by pipeline, from the distant power island, and only equipment required for the wellhead operations would be installed at the field production station. The temporary field site at the surface would consist of wellheads, the mechanical equipment for coiled tubing injection, a production platform and a facility to store water for process, initial gas cleaning and emergency quenching. The time period for land use from initial drilling of the panel to land restoration would be about 5-8 years. No appreciable surface movement is expected with the proposed cavity pattern.

#### *Analysis and Results*

All of the economic analysis was carried out in pounds sterling. A capital charge (discount rate) of 10% real was used throughout the assessment to represent the rate of return likely to be required from commercial organisations. All the case studies were assumed to have a 20-year operating life with an average load factor of 80%.

Three sets of results have been developed:

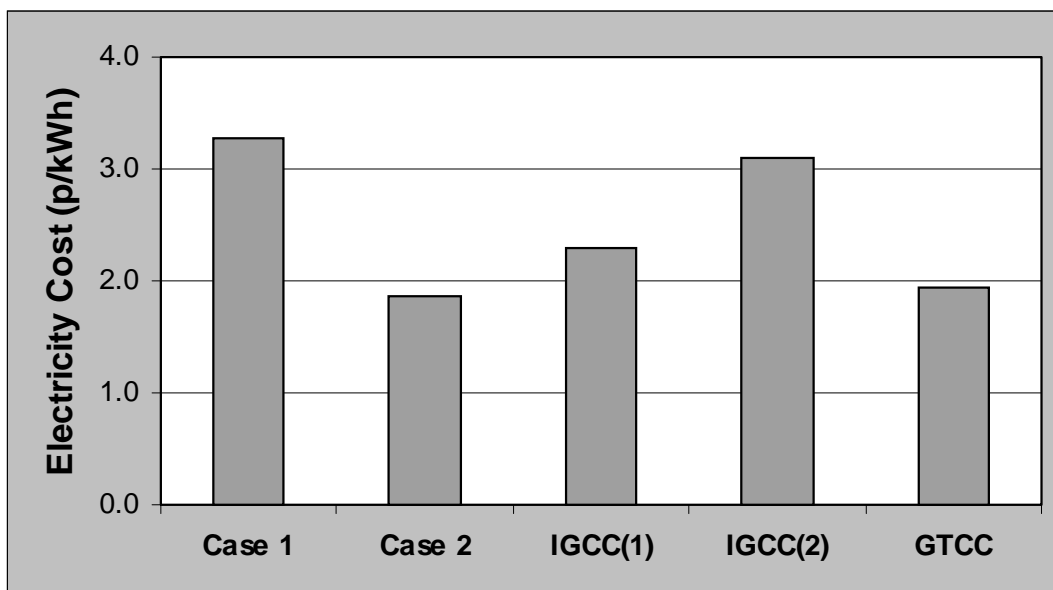
- Cost of electricity
- Cost of electricity with carbon dioxide capture
- Cost of carbon dioxide capture

In each case these results are compared to data for conventional coal and natural gas power plant that were produced as an input to DTI's Review of the Feasibility of Carbon Dioxide Capture and Storage in the UK<sup>30</sup>.

*Cost of electricity*

The cost of electricity generation from UCG without carbon dioxide capture was estimated for Case Studies 1 and 2. These results are compared to the generation costs from standard IGCC and GTCC plant in Figure 2.4<sup>31</sup>. Within the uncertainty of the analysis it appears that large-scale UCG based power generation (Case 2) has a cost comparable to natural gas fired GTCC and somewhat less than modern conventional coal fired IGCC technology.

IGCC (1) is based on data for a capture ready IGCC design from Jacobs Consulting<sup>32</sup> while IGCC (2) is based on data from an IEA GHG Programme report<sup>33</sup>. In contrast the Case 1 scheme has substantially higher costs. Furthermore, UCG can respond to diurnal swings in power demand, thereby increasing its value as a peak supplier.



*Figure 4.2 Comparison of generation costs of UCG schemes with conventional fossil fuel technologies*

*Cost of electricity with carbon dioxide capture*

The cost of electricity generation from UCG with carbon dioxide capture was estimated for Case Studies 3 and 4. These results are compared to the generation costs for

<sup>30</sup> Carbon Dioxide Capture and Storage – A Win-Win Option?, AEA Report ED 018060120', May 2003

<sup>31</sup> Generation costs for IGCC and GTCC plant assumed fuel costs of £30.5/tonne and 23p/therm respectively.

<sup>32</sup> Carbon capture and storage – the case for gasification, a short assessment commissioned by the DTI Cleaner Fossil Fuel Programme, December, 2002.

<sup>33</sup> Leading options for the capture of CO<sub>2</sub> emissions at power stations, IEA GHG Report PH3/14, February, 2000.

standard IGCC and GTCC plant with CO<sub>2</sub> capture in Figure 4.3<sup>34</sup>. UCG based power generation with partial CO<sub>2</sub> capture at the gasification site is only marginally more expensive than generation without capture - Case 2 and its power generation costs are highly competitive to other capture options. However, this technology produces considerably more emissions than the other capture options included in figure 4.3 below).

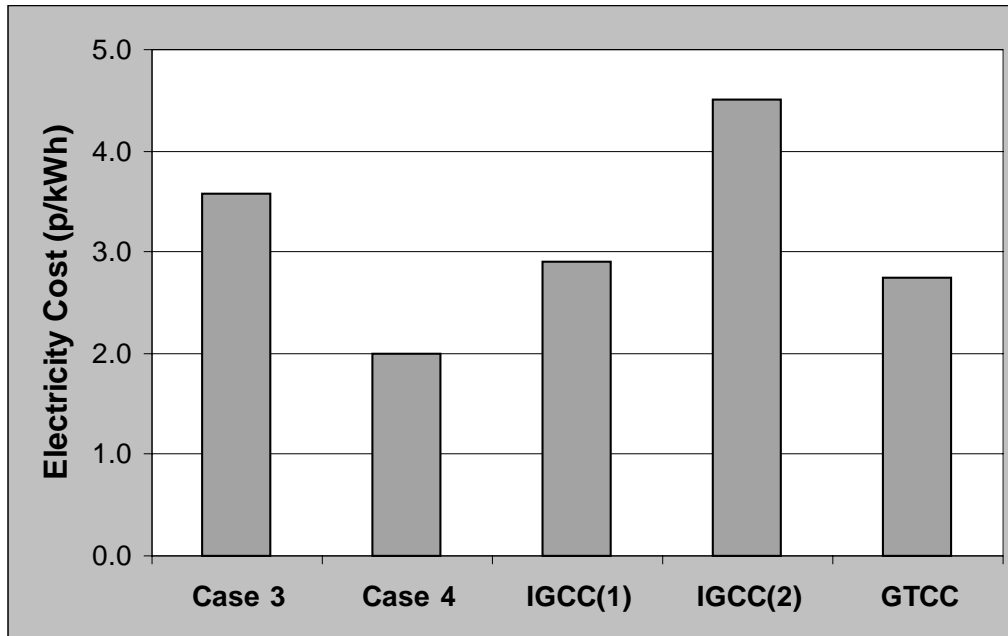


Figure 4.3 Comparison of the generation costs of UCG schemes with conventional fossil fuel technologies all with CO<sub>2</sub> capture

Case 3, which involves 85% capture of the CO<sub>2</sub> in the power plant flue gas, has a generation cost that is competitive with IGCC (2). Both are significantly more expensive than the IGCC (1) design or with capture applied to a natural gas fired GTCC.

In the UK the lowest cost plant at present is GTCC fired with natural gas, and therefore it is reasonable to assume that this technology would be the preferred choice for any new capacity required by the system. If a CO<sub>2</sub> capture plant was built in preference to a GTCC plant, then the cost of CO<sub>2</sub> capture would be the difference between the generation cost of a new GTCC and that of the plant fitted with capture technology.

Using this relationship capture costs for Cases 3 and 4 have been estimated and are compared with a conventional fossil fuel IGCC and GTCC plant in Figure 4.4.

<sup>34</sup> Generation costs for IGCC and GTCC plant assumed fuel costs of £30.5/tonne and 23p/therm respectively.

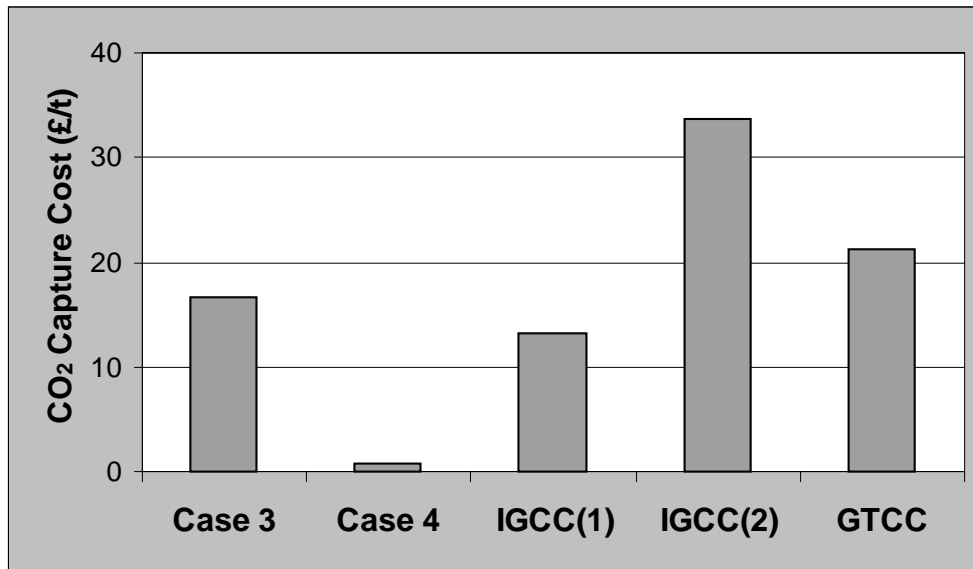


Figure 4.4 Comparison of the CO<sub>2</sub> capture costs of UCG schemes with conventional fossil fuel technologies

The capture of CO<sub>2</sub> from the flue gas of the UCG fuelled combined cycle, Case 3, has cost comparable to conventional power plant. Case 4 has a much lower cost but only limited capture of CO<sub>2</sub> from the medium calorific value gas (see dry gas composition in figure 2.7), and this is likely to be unacceptable in a carbon-constrained world (say 20 years ahead). If comparable levels of CO<sub>2</sub> capture are required (85-90%), then the methane in the product gas will have to be reformed (to CO and H<sub>2</sub>) before the shift and capture stages, but this has not been costed to date, because plant costs are not readily available.

The results are summarised in figure 4.5, as a plot of electricity costs versus emissions for all the cases considered in the economic analysis.

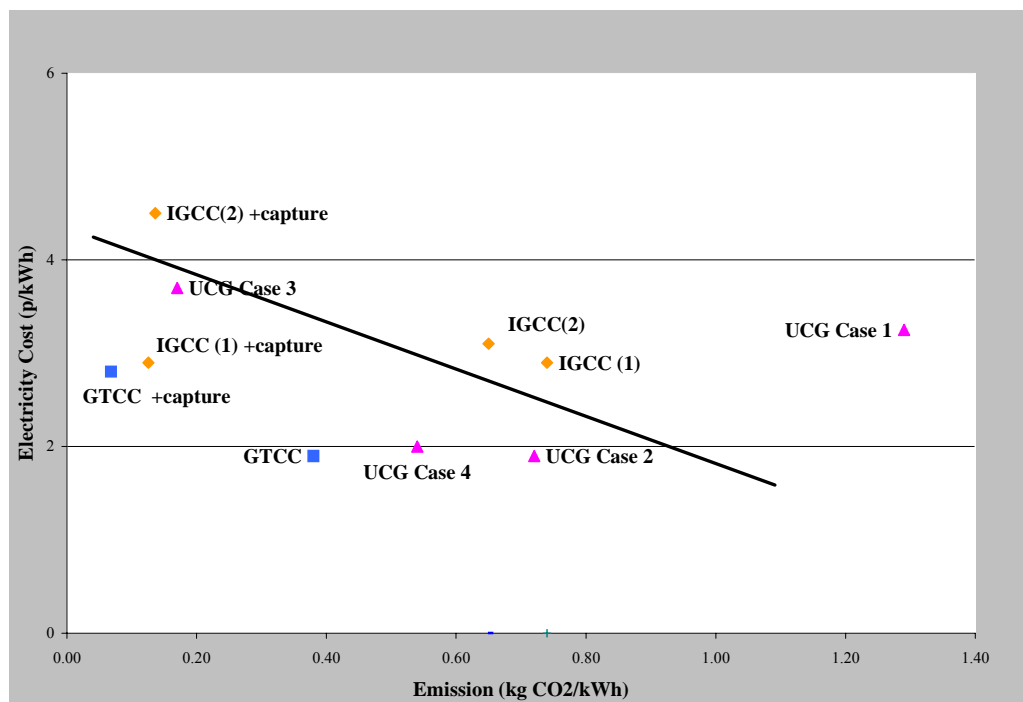


Figure 4.5 Comparison of electricity costs versus emissions for all the fossil fuel options considered.

The results show that that the three competing technologies of GTCC, IGCC and UCG, within the uncertainties of the analysis, follow a trend of increasing cost as emissions are reduced. GTCC provides the lowest costs for both the capture and the no capture cases. The two coal technologies of IGCC and UCG are difficult to differentiate since UCG with capture lies between the two IGCC cases with capture, and on the evidence to date the two are comparable. A more detailed process cost study of UCG compared with IGCC and supercritical PF is clearly required.

#### *Conclusions from the economic scoping analysis*

An initial economic assessment has been made for a range of options for implementing onshore UCG combined with power generation. This has used existing technology data, which, has been interpolated, as necessary, and adapted to fit the cases being considered. Consequently the estimates are likely to involve an uncertainty exceeding +/-30%, and therefore only broad conclusions can be drawn from the results. The main findings are:

1. Large scale UCG with power generation (300 MWe) undertaken remote from the gasification site has a generation cost comparable to, and possibly less than, conventional coal fired IGCC technology. However, small-scale developments (~50MWe) are not likely to be economically viable as stand-alone projects.
2. UCG combined with power generation and CO<sub>2</sub> post-combustion capture has a generation cost which lies between the two estimates for conventional IGCC with CO<sub>2</sub> capture. In practice the CO<sub>2</sub> will be captured in the product gas prior to combustion, but data was not available to cost this option.
3. The cost of CO<sub>2</sub> capture (again post combustion) with UCG and power generation is comparable to the capture cost of CO<sub>2</sub> from natural gas fired GTCC.
4. It is possible to undertake a limited level of CO<sub>2</sub> capture by separating CO<sub>2</sub> present in the medium calorific value gas emerging from the underground gasifier. This has a lower capture cost than other options but only captures about 25% of the CO<sub>2</sub> associated with power generation. This option is unlikely to be attractive in the future carbon constrained world.
5. The option to separate a larger proportion of the CO<sub>2</sub> through pre-combustion capture has not been covered by this assessment. This would involve reforming the methane in the product gas to CO and H<sub>2</sub>, and then shifting the CO to produce additional H<sub>2</sub>. This would yield similar abatement levels to the post combustion separation of Case 3 but may have advantages regarding energy efficiency.

## **Potential UCG Sites in the UK**

### *UCG Small trial sites*

A systematic search by planning and mining consultants was undertaken to find potential UK trial sites for UCG. The initial specification called for a small trial site of 500m x 200m located above a suitable coal seam(s), where directional drilling and single channel UCG tests would be conducted. The target coal seam for the search was bituminous or sub-bituminous coal, greater than 2m thick, depths between 600 and

1200m, separation of at least 500m from abandoned mineral workings and a well-defined reserve of initially 60,000 tonnes.

A detailed examination, covering coal geology, hydrogeology, and environmental issues identified potential areas where a trial might be conducted. One of the better prospects is the Firth of Forth, discussed in Chapter 2. Other possible sites considered included South Wales near Port Talbot and areas previously identified by British Coal as future mining prospects. The latter were mostly located in rural areas, where the Consultants thought that planning permission for the trial would be more difficult, although not impossible.

The new Heriot-Watt study (Chapter 2) will re-examine the whole of the Firth of Forth, where massive areas of coal exist both at Longannet and further along the Fife coast. The outer zone of the estuary has potential CO<sub>2</sub> sequestration sites which will also be investigated.

### Commercial Opportunities in the UK

The total volume of onshore coal in the UK, confirmed as having good UCG potential, is estimated from the resource study, Chapter 2, as 17 Btonnes of coal or 300 years based on current UK consumption of 58Mtonnes/yr. Table 4.1 shows the key resource areas for UCG in order of size.

Area	Average thickness of coal meeting UCG criteria (m)	Area of resource (km <sup>2</sup> )	Volume of coal for UCG Mm <sup>3</sup>	Quantity of Coal Mtonnes
Yorkshire/E. England	3.5	1397	4866	6326
Lancs/Dee	7.6	483	3669	4770
Midlands/Staffs	5.6	445	2506	3258
Warwick/Oxford	3.4	457	1569	2040
Wales	7	24	169	220
Scotland	3.1	43	132	171
<b>TOTAL</b>		<b>2849</b>	<b>12911</b>	<b>16784</b>

*Table 4.1 Summary of UCG Resource in England, Scotland and Wales (UK Resources Study, 2003)*

The detailed maps from the resource study<sup>35</sup> show that the majority (>80%) of this resource lies in rural areas, although important exceptions exist under rivers (Mersey, Forth and Trent) and some of the industrial areas of Lancashire, Yorkshire and the central area of Scotland. In a few cases, the power plant could be placed directly above the coal seam, but most applications in the UK will require the power and processing plant to be separated from the UCG, as considered in the economic analysis above.

#### *UCG Large-Scale Production Sites*

The economic assessment of UCG outlined above suggests that production plants of 300MWe and above, give significantly lower costs of production, which are competitive

<sup>35</sup> CD Rom available on request from Cleaner Coal Technology Programme Helpline [helpline@cleanercoal.org.uk](mailto:helpline@cleanercoal.org.uk)

or lower than other coal processes. Another advantage of larger plant is that CO<sub>2</sub> capture and transmission become more economic.

A preliminary exercise has been undertaken on the key areas for onshore UCG in the UK, to establish the potential size of UCG in the UK. The basis of this investigation was the identification of practical locations for power production and gas processing plants, and the estimation of plant sizes based on the available UCG coal resource within distances of 5 and 25km of the plant, and conservative assumptions about the availability of the coal resource for UCG (see Appendix 3 for more details of the calculation).

Three of the five areas identified have power stations located in the area and two have IGCC planned (S. Yorkshire and Port Talbot). The UCG production plants could replace or augment the existing facilities. The potential for onshore production of UCG, based on this preliminary study is summarised in Table 4.2.

UCG Power Station Site	Power Output based on coal within 5km MWe	Power Output based on coal within 25km MWe
Longannet area, Fife	410	490
Selby/Drax Area, Yorkshire	810	4,800
South Yorkshire	900	7,100
Mersey/Dee area, Lancashire	1,400	14,100
Port Talbot, S Wales*	0	730
Total	3,500	27,200

*Table 4.2 Summary of the potential for onshore UCG power stations in the UK (\* potential for UCG resource in Port Talbot Bay not considered)*

The potential for UCG in these areas depends on how far it is economical and locally acceptable to extend the reach of the power station. The results indicate that the available power generation capacity is increased by a factor of nearly eight if the catchment area is extended from 5 to 25km from the power station location. The largest areas for onshore UCG are around the River Dee, Lancashire and Yorkshire. Central Scotland is smaller but has the advantage that most of the UCG coal is within 5km of the Longannet area. It is worth noting that Teesside is currently considered one of the best areas of CBM exploration, and that UCG and CBM could compete for the same coal in this area. In a multi-seam application, there may be synergies between the two techniques, used on different seams.

The total of 27.2 GWe is larger than the current UK installed coal fired generating capacity of 25 GWe, and UCG has the potential to replace about 60M tonnes/yr of combined mining and coal imports which is the approximately the current annual UK consumption of coal (58M tonnes in 2002).

Other options for UCG production gas could be considered and include:

- Co-fire existing IGCC or GTCC power stations with UCG gas (possibly as re-burn to reduce emissions).
- Smaller scale distributed power plant of 40-100MWe with combined heat and power.
- A supplier of variable load, including peak lopping.

- Conversion of the syngas to hydrogen production (with CO<sub>2</sub> capture) for local distribution, transport or power production in large-scale fuel cells.
- Conversion to SNG to augment reducing supplies of indigenous natural gas.

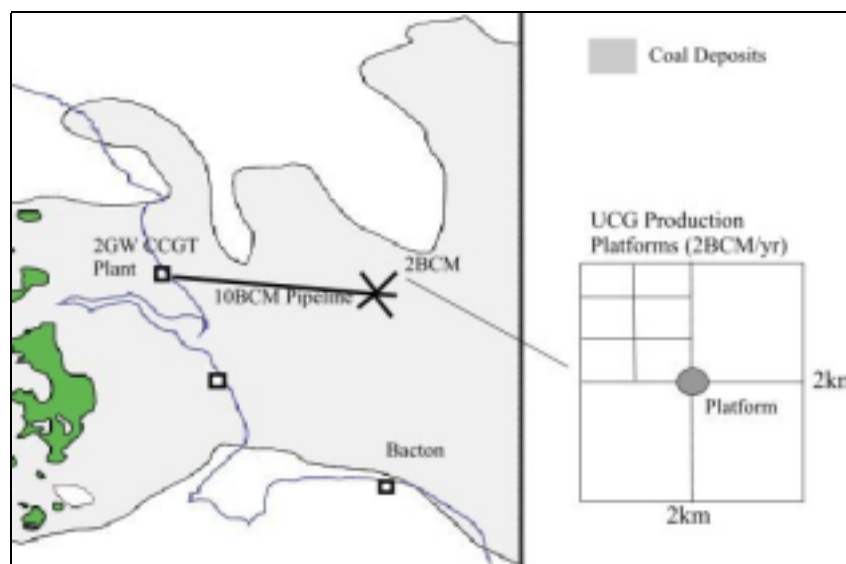
#### *Offshore UCG*

A UCG operation in shallow offshore waters is an attractive option because very thick coal seams are known to exist in large deposits in the North Sea. Furthermore, potentially redundant drilling and production platforms are already in place in the areas of interest and possible CO<sub>2</sub> sequestration sites (aquifers, enhanced oil recovery opportunities, and unmineable coal) could be in close proximity. The UCG product gas could be brought to shore for processing and power generation (possibly using existing pipelines) at suitable industrial locations.

Technically, the 50-100m of sea depth is unlikely to present additional difficulties, which have not already been solved by the oil and gas industry. Environmental constraints, although still important, will be less restrictive for the siting of the wellheads and surface platforms.

The main problem offshore UCG is likely to be safety and cost. The safety issue arises largely from the need to generate and supply oxygen to the injection well and the higher temperatures and ignitability of the product gas, compared with say natural gas. The cost of locating and supporting equipment on offshore platforms is much higher than land based operation (an approximate estimate is three times the cost) and, as far as possible, gas processing, plant control and power production should be kept to a minimum offshore.

The extra cost might also be offset against an increase in the scale of operations, which should be comparable with current gas production platforms, typically 1-20 Mm<sup>3</sup> /day, which is equivalent to between 120 and 2,500MWt of energy available for power generation. Another factor in its favour is the thicker coal seams, which would extend the production life of the coal seam and require a lower accuracy of drilling.



*Figure 4.7 Possible Offshore UCG Configurations*

Figure 4.7 suggests how UCG platforms located on the offshore coal deposits, would be connected by transmission pipeline to an existing gas reception terminal, in this case Easington near Hull, where the production gas would be processed before use in a

GTCC plant. An alternative would be to transfer the gas to an existing nearby power station, like Drax, Yorkshire.

While offshore UCG is an area of promise and future study, the commercial process will need to be developed first on land or very close to shore (e.g. estuaries) before the higher costs and risks of offshore operation are attempted.

#### *Development of UCG*

The route to commercial development of UCG is through trial and semi-commercial demonstration with supporting paper studies.

A development programme for commercial scale would take about 8-10 years to complete, on previous experience. A logical project plan with more details of the estimated study costs and time scales is given in Appendix 4.

#### *Potential for Overseas Collaboration*

Interest in UCG is currently at a high level and the principle activities have been described in Chapter 2. Feasibility studies and trials are underway in many coal-producing countries, including India, Australia, S Africa, China, Japan and Slovenia, and there is some possible renewal of interest in the US. UK is clearly leading the activity on UCG in laterally drilled coal seams, although others are starting to show interest.

The current trials in China and the Chinchilla project in Queensland, Australia are taking place at shallow depth using technology which may need adaptation for use in the impermeable UK coals. Some of the modelling and laboratory back-up work in China may be relevant to future developments in the UK.

The feasibility studies being initiated in Velenje Mine, Slovenia, and by IST, Portugal may be more promising for the UK, but both are at an early stage. Both are seeking and are likely to rely on EC funding.

The three prospects for overseas collaboration, which are relevant to the UK, in order of priority are:

1. Capitalise on the growing US interest (DOE and private interests) on gasification as a method of producing hydrogen and to avoid the previous environmental problems of UCG. The recently signed MOU on fossil fuels between the US and UK Governments may be a future route for collaboration.
2. Investigate the Australian demonstration of UCG, involving Government (CSIRO) and private interests. UCG has been identified and a new company to progress the development has been formed. UK has been invited to participate.
3. Collaborate with the Chinese on UCG. The use of abandoned or manmade galleries is not suitable of the UK, but the Chinese programme is large and some of the basic research work may be relevant. The Chinese would be prepared to host a UCG trial but would expect technology and probably most of the funding to come from outside. The Japanese is already providing technical input on data analysis to the Chinese trials.

## 5. Conclusions and Recommendations

### Conclusions of DTI Initiative on UCG

1. Carbon Abatement Technologies Strategy (CAT).
  - On the assumption that all future fossil fuel technologies will be associated with CCS, the UCG option compares favourably with IGCC, GTCC and super/ultra critical pf.
  - UCG is a process that lends itself to CO<sub>2</sub> capture both from the high-pressure product gas and from subsequent downstream processing, using existing process technology.
  - Scoping estimates of the economics of UCG-CCS suggest that costs of electricity with post combustion CO<sub>2</sub> capture are competitive with the other main coal alternatives, namely IGCC-CCS. Although not costed, pre-combustion processing of the UCG product gas might reduce still further the CO<sub>2</sub> capture costs for UCG-CCS.
  - A comparison of life cycle CO<sub>2</sub> emissions places UCG lower than IGCC, supercritical pf and PFBC, and is only higher than GTCC, renewable sources and ultra-critical pf.
  - Potential CO<sub>2</sub> sequestration sites are located in close proximity to the favoured estuary and near shore sites for UCG exploitation, e.g. Firth of Forth and off the Lincolnshire coast.
2. Security of Supply
  - As conventional mining declines and natural gas supplies in the UK Continental Shelf become exhausted, the UK is becoming a net importer of energy. Half the coal is already imported and in 20 years time, the UK will be reliant on imported sources of energy unless there is a revival in mining or much more natural gas is discovered. There are however still large coal resources both onshore and offshore which could be exploited if commercially viable.
  - UCG offers a potentially practical route to exploitation of the indigenous coal resources provided the initial economic estimates prove correct and the environmental concerns can be overcome.
  - The UCG share of UK energy supply could be as large as the current coal fired component, and would last until renewable energy is fully commercialised.
  - The UCG option for UK energy supply will provide security of supply in the face of increasing supply and cost uncertainties in the energy market.
3. Hydrogen Economy.
  - UCG product gas, like IGCC, can be readily converted into hydrogen and CO<sub>2</sub>, through the shift and capture processes. Large-scale gasification of coal is a practical alternative to natural gas reforming.
  - The hydrogen could be used directly in a stationary fuel cell at high efficiency, or distributed in a hydrogen infrastructure for transport.
  - The high turn down capability of the UCG process adds considerably to its potential as a future option for hydrogen production. Further process investigation is justified in this area.
4. Groundwater Issues.
  - Groundwater contamination is a primary concern with UCG, and will need to be fully evaluated for any proposed UCG project. Factors that can reduce the risk of contamination are site selection, deeper coal seams and operating the cavity as a local depression within the strata.

- Operational failure of borehole, wellheads, etc could lead to environmental contamination, and there is a small risk of subsidence from cavity caving. These risks can be largely minimised by effective exploration techniques (boreholes, logging, seismic surveying)
  - An investigation of a specific site involving environmental testing and modelling and a probabilistic analysis of all the risks is proposed.
5. UK coal resources
- The resource study has shown that UK coal resources suitable for deep seam UCG on land are plentiful and amount to 17 billion tonnes (or nearly 300 years supply at current consumption) and this excludes at least a similar tonnage where the coal is unverifiable for UCG. The detailed maps show that the largest areas are in Yorkshire, the Dee area and Warwickshire, with smaller deposits in Central Scotland and South Wales. Most of the coal seams with potential for UCG are located in rural areas, but important and useful exceptions exist under rivers and brown field areas.
  - The most promising early targets for UCG in the UK are rivers and estuary, which could be accessed from brown field sites along the shoreline, where the drilling, process and power plants would be located. Opportunities are likely to exist in the Firth of Forth, the Dee Estuary and around the River Humber.
  - A preliminary exercise based on conservative assumptions for power plant location and coal seam access suggests that large UCG power projects could be located in at least five brown field areas. If these sites had access to temporary satellite UCG stations within 25 km of the generating plant, an estimated 27GWe of electricity could be generated over at least 20 years. This is greater than the current generating capacity from coal in the UK.
6. Planning and public perception
- The experience of the attempted planning application at Silverdale colliery, and the pilot study of public perceptions suggest that the public will be concerned about factors such as uncontrolled combustion, escape of pollutants and ground water contamination and subsidence. Although technical solutions exist, the conclusion is that planning and public perception will impose significant restraints on the exploitation of UCG in rural areas.
  - The Town Country and Planning Acts of England and Wales and the equivalent in other parts of the UK give ample opportunity for local communities to object to any proposed UCG project. Planning regulations, on the other hand, recognise that minerals have to be extracted where available, including rural areas, and there is a presumption in favour of permitting planning applications if environmentally acceptable.
  - Regional variations can be anticipated and planning applications for real sites, with appeals if necessary will resolve whether UCG on land is an acceptable method of coal exploitation in the longer term.
  - UCG under estuaries and in near-shore waters with the power and processing island located on a brown field onshore site is seen as the best prospects for early project entry in the UK. The step to offshore UCG could then be within reach, see below. Potential sites in the Firth of Forth are being identified as a first stage in this process.

## 7. Regulatory issues

- The framework for approval of a UCG project is a permit under the IPPC Regulations. The utilisation of UCG product gas at surface will have to conform to the LCPD, the UK air quality requirements and any future further restrictions that might be imposed on gasification plant through European IPPC guidance notes (known as BREF). Although air emissions controls are already stringent, the technology of mitigation is well developed and UCG should have no special difficulties in meeting current and future Regulations.
- Groundwater Regulations are likely to impose a challenge to the regulatory approval of UCG. Groundwater Regulations can be met when the target coal seam is located in an area of “permanently unsuitable” water without communication to existing aquifers. This must be proven by environmental investigation and analysis, and the concept still has to be tested in the context of UCG at specific sites.
- Licensing of UCG operations under the current arrangements through the Coal Authority should present no difficulties, although the position with respect to the licensing of oil and gas operations still needs to be established.

## 8. Offshore UCG

- The offshore coalfields in the lower North Sea hold considerable promise for large-scale UCG. Potentially redundant, drilling and production oil and gas platforms could be used for the offshore production of UCG gas, which would be brought ashore, possibly in existing pipelines, for processing and power production. Potential CO<sub>2</sub> sequestration sites, like aquifers, EOR opportunities and unmineable coal could be in close proximity.

## 9. UK industry and export potential

- The UK has related expertise in the various technologies of UCG, particularly in the surface plant and hardware required for a UCG process, i.e. air separation, gas cleaning, CO<sub>2</sub> capture and power generation. The UK has key knowledge of the geological selection process, environmental issues and the underground processes itself of UCG. Only in directional drilling in coal is the UK currently lagging its overseas competitors, but this is compensated by relevant directional drilling expertise associated with North Sea oil and gas.
- Offshore UCG, if successfully developed, would use much of the expertise in platform design and servicing that already exists in the UK to support the oil and gas industry. As North Sea production of conventional hydrocarbons decreases, these UK industries will require new markets for their advanced drilling and platform expertise and offshore UCG presents an opportunity with considerable technological synergy. The market potential for the technology would be very significant; for example, Japan, has large offshore coal deposits. Feasibility studies of UCG are underway in Asia, S Africa and parts of various parts of Europe. These studies, if successful could lead to the supply of gas processing power and drilling equipment. In China opportunities exist for UK to export power generation and gas cleaning equipment. A co-ordinated policy on the export of UCG technology could lead to a demand for UK equipment and services

## **Conclusions on the Technical Status of UCG**

1. The UCG field trials confirm that this technology does have potential. The reliability of in-seam gasification between vertical boreholes has been achieved by the techniques of directional drilling (UK, US and Europe), man-made galleries (China) and closely spaced vertical boreholes (Chinchilla, Australia). In-seam drilling in deep seams is the favoured option, in the long run, to meet UK environmental, and there are advantages in operating at high pressure.
2. For deep UCG, further field investigation (at least one trial, and a semi-commercial scheme) would be required to obtain operational and environmental data, before a full-scale “bankable” project, with acceptable financial risk, could be considered for construction. The key unknowns are sustainable gasification over long in-seam wells (>200m in length), the branch drilling of borehole networks for commercial scale operations, and the control of a large gasification process in simultaneous channels. Contaminant escape is minimised by gasification of the in situ coal at the equilibrium hydrostatic pressure in deeper seams (>600m) and further environmental data and trial monitoring is required for the environmental impact assessment of future schemes.
3. Scale-up to commercial UCG operation was demonstrated in the early Soviet UCG stations to produce gas for thermal power stations, two of which are still in operation (Uzbekistan and Siberia). More recently in the 1990s, the only scale-up activities for UCG have been the design studies in the US (SNG Plant) and Australia (Chinchilla), but a full-scale demonstration plant will need to be built, before UCG can be commercialised.
4. The European trial demonstrated that directional in-seam drilling and a moveable injection point (CRIP) are the key requirements for seam access and UCG process control in deep coal seams, and the study has concluded that the process can be applied satisfactorily and scaled up to UCG process well construction, although this has to be demonstrated.

## **Recommendations for Future Action**

The DTI initiative on UCG was started in 1999 on the premise that with the exception of directional drilling, the technology and engineering of small scale UCG were largely solved and that trials (drilling and UCG) should be conducted in typical UK coals to demonstrate the technology in the UK. To move towards this objective, the DTI targets for UCG were identified (see Chapter 1); this work is now reaching completion, and the current activities (September 2004) which the DTI are supporting are:

- A watching brief of overseas activities.
- Evaluation of the Firth of Forth, as a potential future UCG project site. (Heriot-Watt/DTI/Scottish Enterprise/Scottish and Southern Energy plc)
- Promotion of the study results on UCG through the DTI Website.
- Dissemination through the publication of papers and posters at relevant conferences.

This report has established that UCG-CCS is a potential future technology for the exploitation of UK coal resources, particularly for coal resources under river estuaries near-shore and eventually offshore coal, although concerns remain about the environmental impact of UCG, approval under the Groundwater Regulations and public perception issues. In addition, the scoping economics of UCG-CCS need refinement and offshore UCG (from platforms) requires further investigation. In short, UCG-CCS is a promising technology for the UK, although it has to be a commercial decision whether to deploy it taking into account the planning hurdles that would need to be overcome before any project can go ahead.

The feasibility study for the Firth of Forth has the potential to become a “lighthouse” project for taking this technology forward although decisions on this will have to be taken on a commercial basis. By investigating a specific site area, the study has the potential to clarify and potentially resolve many of the outstanding environmental, planning and hydrogeological issues identified in this report. UCG-CCS has reached the stage where ideally an industry consortium should lead the future development of the technology, and there is probably a range of service providers (drilling, process design, mineral and hydrocarbon extraction), equipment manufacturers (plant, power generation), which would benefit from a successful development of UCG. The Firth of Forth study is currently the leading opportunity to develop a UCG demonstrator in the UK.

UCG should be seen within the context of the Carbon Abatement Technology Strategy that is currently being developed by the DTI. It is expected that UCG (with CCS) will be seen alongside other sustainable fossil fuel technologies such as IGCC and natural gas fired generation with CCS. Which of these technologies prevails will very much depend on their relative commercial and technical attractiveness.

## **Appendix 1 Directional Drilling in Coal**

### *Current Status of Directional Drilling*

The Spanish UCG trial in the mid-1990s used the latest technology from American and European Companies to construct the process wells for the trial and undertake the post gasification investigation of the cavity. It was successful in that a useable in-seam borehole was constructed in the coal seam, and a satisfactory intersection with the production well was achieved. This enabled the gasification trial to take place, but drilling costs were high and the maximum in-seam length that could be achieved at the time was about 50m. Controlling the drill bit in the seam proved difficult with the equipment available at the time, which was attributed to unsuitable down hole assemblies and a lack of coal experience by the drilling operatives.

The UCG initiative by the DTI (1999 to present) identified directional drilling as an area that needed further investigation, and a worldwide review of advanced coal drilling was initiated in 2001. The study found that UK and European experience of directional drilling in coal from the surface was virtually non-existent, but outside Europe, a small number of specialist mining and CBM Contractors from Australia, South Africa and the United States had acquired the skills and experience necessary for directional drilling in coal: one American Company alone had 240km of cumulative experience mostly for CBM applications.

The overseas applications of directional drilling in coal have been in CBM production (USA), the degassing of coal ahead of long wall mining (Australia) and exploration (S Africa); in most cases, vertical wells from the surface act as the point of departure for the deviated borehole. None of the specialist directional coal drillers identified in the study have constructed UCG process well configuration, but there is now little doubt that given the necessary exploration data, the interconnecting wells for UCG could be constructed at reasonable cost.

This assertion still needs to be tested and a trial of directional drilling in UK is a necessary step in the development of UCG in the UK. Such a trial would also have benefits for conventional mining and the nascent CBM industry in the UK, which needs to raise production rates per well to be commercially viable at current gas and power prices.

### *Single Channel Drilling*

The basic UCG module is an in-seam gasification channel of at least 200- 300m in length, which is constructed by directional drilling from the injection well to the production well, figure A1.1.

### *Multi-channel Gasification for Commercial UCG*

The scale-up of UCG from single process wells, to a multi-welled commercial operation has major drilling implications. Wells will have to operate simultaneously (~20 wells for a 300MWe plant), and a programme of continuous well construction and connection will be required, to replace the exhausted gasification channels.

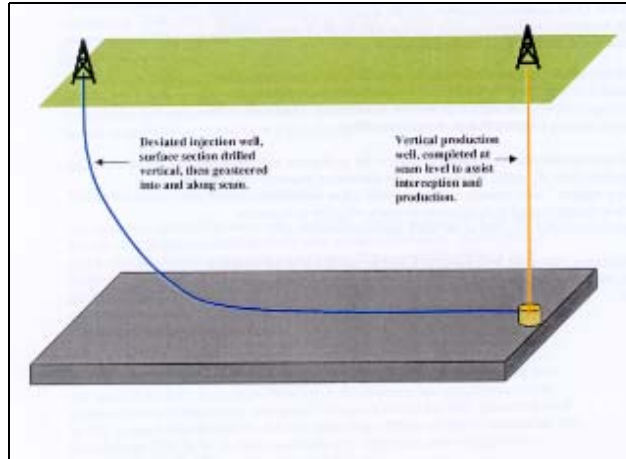


Figure A1.1 Basic UCG Module (drawn to scale, coal seam depth 800m)

An important conclusion of the advanced drilling study is that the vertical wells, from cost and environmental considerations, will have to service a number of in-seam wells, and multiple branching and intersections will be required. This technology is well advanced in the hydrocarbons industry and recent drilling for CBM in the US has used a branching system to connect several coal seams to a single well. An example of a commercial configuration is shown in figure A1. 2.

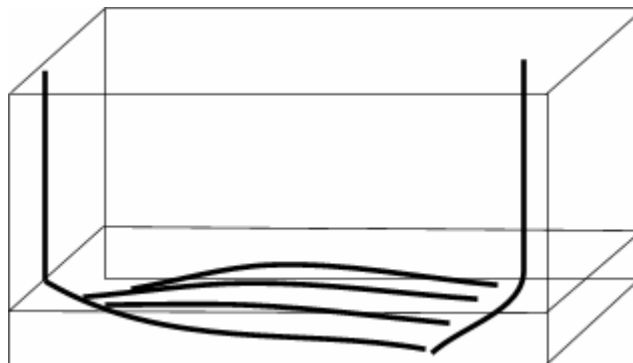


Figure A1.2 Commercial UCG Configuration using branching and intersections

*Equipment for Downhole Steering*

The study found that the specialist contractors were using conventional steerable downhole motors (DHMs) which can be hired at relatively low cost to construct the in-seam coal section but crucially, they added additional pressure monitoring in the borehole to take account of the relatively soft conditions of the coal, and to provide better drilling control. A team with in-seam drilling experience in coal is essential and costs as low as £25/metre have been quoted (S Africa, and US). DHM's are available in standard sizes down to 4 ½" diameter, perhaps lower, and rely on power for drilling from the circulation of drilling fluid.

The position of the drill bit is determined by a system of "measurement while drilling (MWD), which uses the earth's magnetic field to establish directional and distance of travel along a pre-determined trajectory. Backup sensing may be required in the form of

gyro logging, monitoring the cuttings (for coal or strata) and the running of additional logs to determine the conditions around the inseam borehole.

It was recognised by the Australians that an inbuilt logging system, rather than a simple MWD, provides more responsive control of the drill bit and they have developed a specialist package, known as DMM MECCA, which uses a hardwired connection through the drill string to connect the proprietary downhole sensing unit to a surface processing and display box. The sensing unit is tailored for drilling in coal, and can be placed close to the drill bit for better control.

The specialist drillers accept that wells would occasionally exit the seam, and some actually engineer a breakout or roof touch to obtain an improved fix on the coal boundaries. This is an acceptable method of drilling in coal for exploration and gas drainage, and would probably be satisfactory for the construction of inseam boreholes for UCG, which have to be located more accurately in the lower part of the seam.

Online gamma ray (OGR) sensing behind the drill bit, detects the boundary between coal and adjacent strata, which normally has a higher gamma reading than the coal. In most UK coals, the distinctive marker band is the seam roof and floor, and typically natural gamma tools at a distance of 0.25 to 0.5m can detect these horizons. The drilling contractors are aware of the benefits of gamma logging for coal, but it is not clear whether these have been used in practice.

A detailed specification for the drilling tools, drilling mud and mode of operation is produced in advance, normally with the aid of special drilling software, but many of the decisions, including final choice of equipment must be left to the drilling supervisor as the work progresses. It is common to provide the onsite team with a variety of back up equipment, including drill bits, additional BHA components and a complete downhole motor assembly.

#### *CRIP use in the Spanish Trial*

The form used and tested in the Spanish Trial is shown in figure A1.3. It employs a coiled tubing to transport the gasification agents (oxygen and water) and position the injection head inside the pressurised inseam well. The tubing is fully retractable onto a drum at the surface, and the coiled tubing equipment, which is commonly used in the oil and gas industry, is supplied with a wellhead injection assembly, pressure seals and a manifold for connecting the injection gas mixtures to the tubing.

CRIP is the key to control of the UCG process in long inseam channels, and the engineering problems associated with its detailed design and operation, have been largely solved as a result of the Spanish UCG trial.

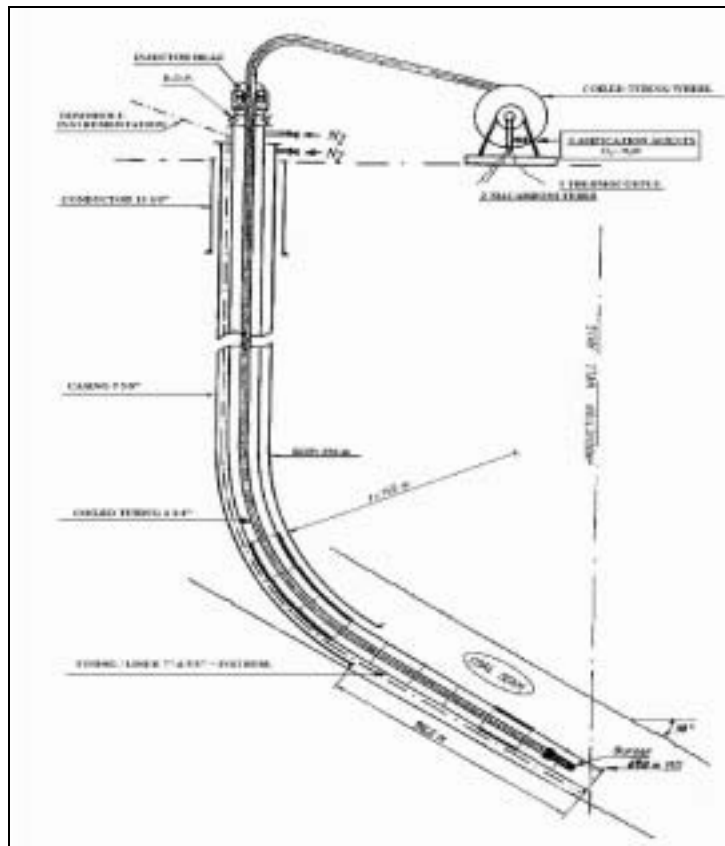


Figure A3.3 Controlled Retraction Injection Point (CRIP) in the inseam injection well

*Coiled Tubing Drilling*

Coiled-tubing drilling is another method of constructing small bore sidetracks from main wells, and may be important for UCG as coiled tubing technology has already been used successfully in the Spanish trial for oxidant injection. The same coiled-tubing support equipment could be used for both branch drilling and injection. CBM production companies in the United States are understood to be experimenting with coiled-tubing drilling to develop multi-branch production wells.

## Appendix 2 Ground Water Impact and Environmental Risks

### Introduction

The gasification cavity is a source of both gaseous and liquid pollutants. They are created as a by-product of the gasification and pyrolysis processes, and may further react with the surrounding strata or dissolve in nearby ground water. The risk of groundwater pollution from UCG depends on whether the contaminants can migrate beyond the immediate reactor zone to more 'sensitive' groundwater areas. The transport of aqueous phase contaminants depends on the geological setting of the gasification reactor and the hydrogeology of the area.

### Operation of the UCG Cavity as a Self Contained Bubble

UCG, in theory, can operate over a range of pressures up to the geological fracture condition, but the controlling pressure for UCG is the hydrostatic pressure, which increases with depth (10 bar for every 100m of depth). Gases and pyrolysis contaminants in and around the gasification cavity will be 'contained' if pressures within the gasification reactor are less than or equal to hydrostatic pressure (as groundwater flow will be towards the gasification reactor). A UCG process, which is operated in equilibrium with its surroundings, takes place in a bubble, from which no gas or liquids should escape during the operational phase of UCG, figure A2.1.

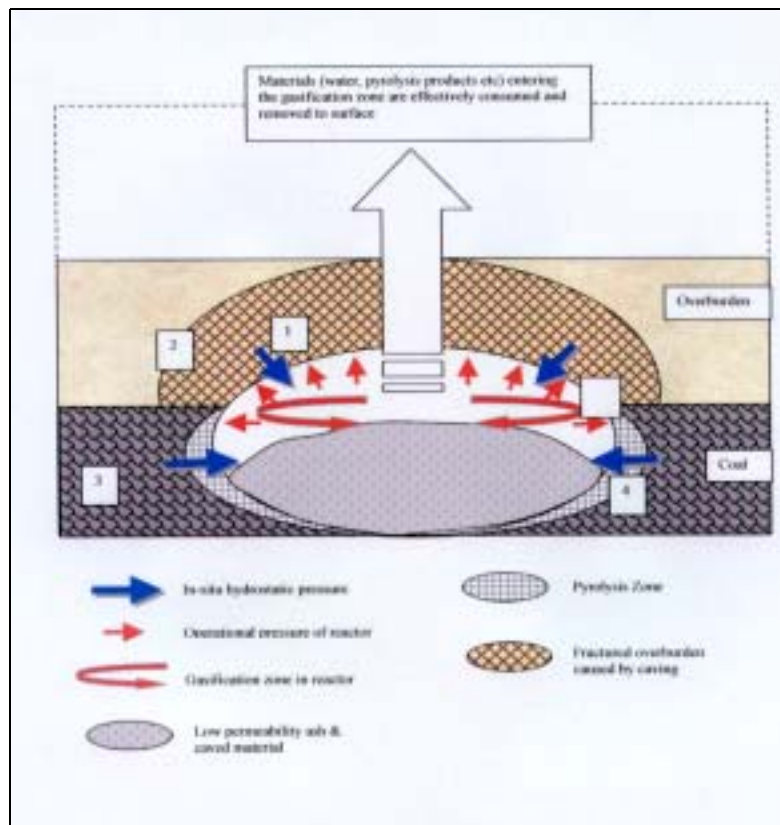


Figure A2.1 Underground Pressure Conditions and Bubble during UCG Operations

Active pressure control, in which the cavity pressure is held in equilibrium with the surroundings, was tested for the first time in the European trial. It was found that gas

escape, which is the driving force for contaminant dispersal, could be substantially reduced.

As well as suitable site selection, the three main mitigation measures during UCG operations are:

- The use of operational monitoring systems that can detect gas losses and ensure that reactor pressures are maintained below hydrostatic;
- Ensuring that wells and boreholes used in the process are adequately sealed.
- Maintaining a ‘cone of depression’ in the groundwater around the reactor.

#### *Post Gasification environmental impact of the Cavity*

The post operation phase is the most critical condition for ground water contamination as pressure and contaminants can build up when the cavity returns to equilibrium. The surrounding strata may have increased permeability from the newly de-stressed condition and maintaining the depression during the cool down and water influx phase is essential.

Final concentrations of the phenols in the flooded cavity of the European trial were 500ppm, which was achieved within 24 hours, but removing one cavity volume of water by pumping reduced the level to less than 2ppm. At Chinchilla, water ingress was very much slower due to the general arid conditions, and a steam jacket was allowed to develop at a lower pressure to contain the contaminants. Pro-active shutdown, including venting, flushing and cooling were also practiced in the US trials<sup>36</sup> with reasonable success.

The recommended strategy<sup>37</sup> for shut down is to:

- Minimise post-burn contaminant generation from pyrolysis products by accelerating the cooling of the cavities and preventing pressure build up post gasification;
- Maintain the flow of groundwater towards the cavities by pumping water from the cavities and hence maintaining a hydrostatic gradient towards the reactor areas; and
- Maximise the removal of potential organic and inorganic groundwater contaminants from the underground strata by pumping and treating contaminants;

Eventually, the cavity conditions will revert to the pre-gasification hydrogeological conditions of the coalfield and the natural dispersal and leaching mechanisms will take over on the residual contaminants in the cavity, now measured in parts per million. Some of the contaminants will be retained by the coal seam itself, which is a natural and physical adsorbent, while others will be dispersed under the prevailing groundwater flow conditions into the surrounding strata, where they eventually react and degrade.

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<sup>36</sup> Review of Environmental Issues of UCG, Final Report, December 2003 (available shortly on the website of the DTI Cleaner Coal Programme.

<sup>37</sup> Best Practice Guide for UCG, Dec 2003 (available shortly on the website of the DTI Cleaner Coal Programme

### Appendix 3 Example and Calculation of a UCG Resource area- South Yorkshire



#### Calculation of Resource area for Power Generation

The above diagram shows the UCG potential resource area in South Yorkshire, with radii of 5Km and 25Km marked. Using the coal thickness for this area (from table 4.1) is 3.5m. The thermal output using realistic assumptions for the underground gasification process is estimated to be 3.2MWh/tonne of coal resource. It is assumed that the power station has a 20-year life (80% load factor), and conservatively only 35% of the UCG resource would prove useable after site exploration. The following table can be constructed:

	Within 5km from site	Within 25km from site
Area of UCG resource km <sup>2</sup>	44	350
Coal resource available Mtonnes	200	1,590
Potential UCG energy available GWH x 10 <sup>-3</sup>	640	5,080
Power Station supported over 20years operation	0.9 GWe	7.1 GWe

## Appendix 4 – Glossary of Terms

ASU	Air separation unit
BAT	Best available technology
CAT	Carbon Abatement Strategy
CCS	CO <sub>2</sub> capture and storage
CBM	Coal bed methane
CICETE	China Int. Centre for Economic and Technical Exchanges, Beijing
COMAH	Control of Major Accident Hazards Regulations 1999
CSIRO	Commonwealth Scientific & Industrial Research Org., Australia
CUMT	Centre for Underground Mining Technology, Beijing
CRIP	Controlled retraction injection point (for UCG)
DD	Directional Drilling
DEFRA	Department of Environment, Food and Rural Affairs
DHM	Downhole Motors
DTI	Department of Trade & Industry
EA	Environment Agency
EIA	Environmental Impact Assessment
EOR	Enhanced oil recovery
EPA	Environmental Protection Agency (US and Australia)
EU	European Union
GTCC	Gas turbine Combined Cycle
HSE	Health and Safety Executive
IEA GHG	International Energy Agency – Greenhouse gas R&D Programme
IGCC	Integrated gasification combined cycle
IPCC	Intergovernmental Panel on Climate Change
IPPC	Integrated Pollution Prevention and Control
JCOAL	Japanese Coal Energy Centre
LCPD	Large Combustion Plant Directive
MWD	Measurement while drilling
MPS	Mineral Policy Statement
NEDO	New Energy Development Organisation, Japan
OSD	Offshore Safety Division of the Health & Safety Executive
PEDL	Petroleum Exploration and Development License
PPM	Parts per million
PU	Permanently Unsuitable Ground Water (see Chapter 3 for definition)
UKCS	United Kingdom continental shelf
UCG	Underground coal gasification
UMIST	University of Manchester Institute of Science and Technology