OBJECTIVES

- To acquire geological data for the Firth of Forth (FoF) for the high level characterisation and 3D visualisation of the basin and coal reserves.

- To assess the potential of candidate drilling sites for trial and commercial underground coal gasification (UCG) with close-coupled CO₂ capture and storage (CCS) or enhanced coal bed methane (ECBM).

- To undertake mine planning, allocate reserves and produce a well layout for the initial UCG trial.

- To assess the environmental impact of surface and sub-surface operations, and possible amelioration methods.

- To determine the risk of caving, subsidence and product dispersal using rock mechanics and reservoir models of the seam and adjacent strata.

- To evaluate the scoping economics, licensing and regulatory regime of commercial UCG in the FoF.

- To prepare a prospectus for future investors.

SUMMARY

Previous scoping studies suggested that the coal basins of the River Forth could provide a suitable site for the first UCG project in the UK. Other studies have indicated that the most significant environmental concerns for UCG are the risks of groundwater contamination through gas escape and leachate migration. Careful site selection, process control and post-gasification site management should minimise those risks.

This feasibility study was established to re-examine the existing geological data, and to determine how
the latest UCG technology, based on directional drilling and movable injection, could be used in an offshore project.

The study confirmed that the geological conditions may be suitable for large-scale UCG and the economics have moved in its favour for the supply of UCG gas to existing power stations and chemical plant in the area. The combination of UCG with local CO$_2$ storage in suitable geological structures and coal seams is also possible, although further exploratory work is still required. The presence of impermeable igneous structures suggests that the likelihood of significant groundwater contamination of onshore water supplies is minimal.

This study achieved its main aims. It identified a suitable site for a UCG trial under Scottish waters. It also showed that UCG could be the basis for a viable business plan in the present energy market, especially when combined with carbon capture and storage (CCS). Near-shore UCG offers security of supply and a clean coal option for the UK and this study has indicated that the FoF region is a suitable location, see Figure 1.

**BACKGROUND**

The project developed from a comprehensive review by the Department of Trade and Industry (DTI) of the feasibility of underground coal gasification in the UK, which concluded that UCG in combination with CO$_2$ capture and storage (UCG-CCS) is a potential future technology for the exploitation of UK coal resources, particularly under river estuaries and near-shore. An earlier search in 2002 had identified the upper reaches of the FoF as one of several potential sites for a UCG trial on the grounds of hydrogeology, surface environmental factors and planning issues, although doubts were raised at the time about the structure of the local coal geology and further investigation was recommended.

The two coalfields that straddle the FoF are the Stirling and Clackmannan coalfield to the west and the Fife/Lothian coalfield in the lower reaches of the estuary. Most of the shoreline coal has been mined, but large tracts of deeper coal, potentially suitable for UCG, still remain and excellent data sets were available from the previous mining activity. These data enabled firstly a regional study and then site specific analysis to be undertaken. Most are multi-seam coal deposits which offer the possibility of both UCG and ECBM, and there are additionally sandstone structures in the wider estuary which might theoretically be suitable for CO$_2$ storage, as shown conceptually in Figure 2. Previous work on the scoping economics of UCG was extended to estimate the likely costs of offshore operation.

Environmental issues of UCG range widely from groundwater protection to the more familiar areas of power plant emissions and regulation. A study of rock mechanics, using the
computer codes available for reservoir modelling, has provided insight into the likely dispersal pathways, roof collapse and subsidence issues.

Recent UCG field trials and large-scale operation in the former Soviet Union, combined with the advances in drilling technology, have given confidence that UCG can move towards commercialisation. Studies and trials are underway all over the world, although most of them are associated with onshore trials in shallow to medium depth. The current project in near-shore waters and deep coal seams presents a further advance in UCG technology, which will require extensive evaluation and testing. If successful, however, it could open up the UK’s indigenous coal resource to a new wave of exploitation and extraction.

THE FEASIBILITY OF UCG-CCS UNDER THE FoF

Geological and Environmental Studies

The study examined four areas of the FoF as potentially suitable for UCG, namely Kincardine, Grangemouth, Musselburgh and East Fife. The methodology for the initial site selection was based on a simple scoring system which took account of coal attributes (Table 1), structure, surface factors, planning issues, environmental factors and the syngas market opportunities. Detailed geological examination followed, based on borehole and seismic data. A 3D visualisation capability was developed for the subsequent mine planning, and tested for one of the sites, namely Grangemouth.

The search for a site became a greater challenge than initially expected. Kincardine was soon ruled out because the river narrows to the west of Kincardine Bridge and any UCG operation beyond the initial trial would require the inclusion of onshore resources, parts of which are licensed for CBM extraction. Grangemouth was more promising as the river is unusually wide and the surface banks already have significant industrial activity. However, the previous work had found that the Longannet-Grangemouth area had an unacceptable geological risk, and this was largely supported by the present study. Some structurally benign areas can be found within the prospect for trial purposes, but large areas are likely to be affected by structural and igneous features which would probably eliminate a commercial scale operation.

As the study progressed, the coal seam area of Musselburgh to the west of Edinburgh

<table>
<thead>
<tr>
<th>Resource</th>
<th>Kincardine M tonnes</th>
<th>Grangemouth M tonnes</th>
<th>Musselburgh M tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under the FoF</td>
<td>20</td>
<td>38</td>
<td>41</td>
</tr>
<tr>
<td>Additional onshore potential</td>
<td>54</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>Likely discounts (if long wall mining)</td>
<td>60-75%</td>
<td>75%</td>
<td>50-60%</td>
</tr>
<tr>
<td>Total discounted potential resource</td>
<td>50</td>
<td>43</td>
<td>23</td>
</tr>
</tbody>
</table>

(Tonnage from East Fife was not estimated)
was found to be superior on geological and hydrogeological grounds and the best geological option for large-scale UCG production. However, the parallel environmental impact study showed that surface constraints at the shoreline would make access and shore facilities difficult to locate, and any UCG operation would need to be based entirely on offshore platforms. For the other sites, there were more options for the location of shore-based plant, but the geology was less certain, and more data were required to prove whether any of the sites would be suitable for a UCG trial.

Rock Mechanics Studies and the East Fife Coalfield

An analysis of the rock mechanics above UCG cavities was undertaken using the finite difference model SAVFEM suite of geo-mechanical software. Using the coal and strata geology from Grangemouth, it showed that the extent of the stress field created by a UCG cavity at 200m stand-off would still give a safety factor of about five between the stressed area and the old coal workings. This new criterion, although still to be confirmed by specific site modelling, opened up new UCG opportunities in the extension of the East Fife coalfields into the river, where offshore workings currently extend to about 1-1.5km from the shore. The favourable geological structure and the presence of impermeable dykes just offshore suggest potentially significant new offshore reserves.

Carbon Capture and Storage (CCS)

The zero-emission UCG-CCS scheme should benefit from the new market in carbon tax credits, and so capturing the CO₂ economically and finding a suitable underground storage location would be a major advantage for the FoF project. The CO₂ capture and storage options from UK stationary power plant have been studied as part of the UK Carbon Abatement Technologies (CAT) Strategy. On-going work on pre-combustion capture, enhanced oil recovery (EOR) and CO₂ storage in depleted offshore gas wells would be equally applicable to UCG power generation. The study suggests, however, that in addition to these North Sea options for CO₂ storage, the FoF has potential storage locations much nearer to the shore. In the lower Forth, for example, coal sequences have up to ten seams in some areas. Storage in some of the deeper coal seams and the development of ECBM may be a future option. It has also been established from drilling data in the nearby Mid Forth Anticline (located in the wider reaches of the Forth Estuary to the east) and reinterpreted seismic data by the British Geological Survey that the large up-faulted area (or horst) may contain porous sandstone and could be a candidate for large-scale CO₂ storage. Access to this potentially large storage area might be achieved by horizontal long-reach drilling from the shore, thereby eliminating the need for injection platforms and potentially reducing the cost of CO₂ injection.

Engineering and Mine Planning and Economic Considerations

A review of the international literature on UCG and first-hand experience of the European UCG trial pointed to a UCG process based on directional drilling and movable injection or CRIP. Ideally, the long-reach wells would be drilled from shore for both the injection and production wells, although the option of a jack-up rig for target sites at greater distance from the shore has not been excluded. The 3D visualisation of the Grangemouth site was used to design a detailed well configuration and provide detailed trajectories, wellhead positions and the associated data required for drilling and completion (Figure 3). Attention has also been given to the commercial-scale configuration that would be required for offshore operations, and drilling companies have been consulted on the practicality of different commercial configurations.

At surface, it is envisaged that the gas would be cooled and prepared for transmission to one of several power stations in the vicinity

1 Controlled Retractable Injection Point.
of the FoF. Possible recipients of the UCG gas in the longer term are the thermal power plant at Longannet (2,300MWe), the power station at Cockenzie (1152MWe) on the south shore and the gas turbine plant at Westfield (120MWe), located 15km to the north.

The scoping economic analysis suggests that clean gas could be produced from an offshore location at around £1.7/GJ, which is considerably lower than the current buying price for natural gas by UK power stations. Electrical generation based on the supply of UCG gas to an existing power station would appear to be highly profitable.

**Legislation, Licensing and Environmental Issues**

Discussions with the regulatory authorities in Scotland have established the likely requirements for a UCG project under the IPPC Regulations. A prime requirement would be the need to demonstrate the impact on groundwater quality through hydrogeological modelling and monitoring. It is thought, however, that the environmental risk from UCG operations in the lower reaches of the river are not major concerns, because of the impermeable rock intrusions between target site and shore. The Coal Authority has resolved the mechanisms for the issuing of an underground licence for UCG and the way is clear for an application to be made when required.

**CONCLUSIONS**

- Four potential regions of the FoF, Kincardine, Grangemouth, Musselburgh and East Fife, were examined as potential areas for commercial UCG. All had commercial quantities of coal potentially suitable for UCG (>20M tonnes), but the first three regions identified above had either data deficiencies, limitations on coal geology or surface constraints.

- The modelling of rock mechanics for the FoF strata demonstrated that stand-off distances from existing mine workings could be safely reduced from 500m to 200m under the conditions prevailing in the FoF. This opened up the possibility of UCG in the offshore coal along the Fife Coast, where geological and hydrogeological conditions are favourable.

- The FoF is well placed to provide commercial quantities of UCG gas for power stations and industrial complexes located along its shoreline. A shore-based operation, based on long-reach injection well drilling to the target site, was investigated and found likely to be feasible.

- A scoping economic evaluation suggests that the cost of producing gas from an offshore location such as the FoF would be about one third lower than the equivalent price of natural gas based on 2004 industrial gas prices. The current differential in price (March 2006) is much greater.

- UCG gas has the inherent gasification advantages of CO₂ capture in the pre-combustion gas. In addition to the North Sea options for CO₂ storage considered in the UK CAT Strategy, the FoF offers the possibility of local storage in unminable coal sequences and in porous sandstone structures in the outer reaches of the Forth
estuary. Long-reach drilling from shore may be possible for the CO₂ injection.

- The 3D visualisation laboratory was shown to be an effective tool for characterising the geology and mine planning for UCG. Trajectories for a UCG trial have been produced for one of the sites and could be extended to others as required.

**POTENTIAL FOR FUTURE DEVELOPMENT**

This initial feasibility stage has shown that the coal geology under the FoF is suitable for a large-scale UCG project supplying gas to existing power stations and chemical processing in the area. The surrounding geology and hydrogeology in the lower reaches of the river are also favourable to UCG operations.

The next phase is a detailed investigation of the geological conditions of the near-shore target areas. This will involve new exploratory drilling, a 3D seismic survey and a consultation process, with directional drilling specialists to design the long-reach wells and underground completion for the UCG process. The potential for local CCS needs to be further investigated. Significant investment will be required and a phase of consultation, economic evaluation and further work on UCG as a clean coal option under the Government’s CAT Strategy is anticipated. The study has also suggested areas of further research in CRIP control and down-hole operations.

A successful development in the FoF could lead to widespread adoption of near-shore UCG on the NE coast of England, the South Wales coast and around the Mersey area. The export potential of the technology could be very significant.

**COST**

The total cost of this project is £200,000, with the DTI contributing £50,000, Scottish Enterprise, £50,000 and the balance shared between Scottish and Southern Energy plc and Heriot-Watt University.

Further information on the Carbon Abatement Technologies Programme, and copies of publications, can be obtained from:
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