UNDERGROUND COAL GASIFICATION

CLEAN? SECURE? AFFORDABLE?

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OUTLINE OF PRESENTATION:

• Cleaning up dirty coal
• Brief description of UCG
• Potential coal resource for UCG in UK and globally
• UCG projects around the world
• Cost of clean power from UCG in UK market
• Comparison of shale gas and UCG processes
• Prognosis for UCG in Britain
TACKLING POLLUTANTS FROM BURNING COAL vs UCG

PARTICULATES: Flue gas scrubbing; electrostatic precipitators
   UCG: Ash remains in the ground
OXIDES OF SULPHUR: Flue gas desulphurisation
   UCG: Sour gas treatment, e.g. Claus process
NITROGEN OXIDES: Limit temperatures (Low-NOx burners)
   UCG: Also limit temperatures in ground and CCGT
CARBON DIOXIDE: Flue gas scrubbing; oxy-combustion
   UCG: CO₂ removal pre-combustion; oxy-combustion
POTENTIAL FOR UCG DEVELOPMENT

• Fossil fuels will remain a vital energy source for many decades
• Coal is the most abundant fossil fuel, widely distributed
• Large resources of coal are not economically mineable
• A significant proportion of this is suitable for UCG
• UCG recovers a higher proportion of energy in coal
• The environmental impact of UCG is much less than mining
• UCG gas is produced at pressure and amenable to CO2 capture
• By reforming CO and CH4, UCG gas can become carbon-free H2
• Product can be clean power, process feedstock, or fuel cell feed
World Coal Resource for UCG

World Resource 5-8000BT
• Proven Reserve (2005) 909BT
• Est. UCG addition 600BT
Areas of the UK Suitable for Commercial UCG

BGS study of coal resources for UCG, supported by DTI

Offshore coal resource suitable for UCG estimated in excess of 35bn tonnes

<table>
<thead>
<tr>
<th>Area of UK</th>
<th>&quot;Good&quot; UCG Resource M-tonnes</th>
<th>Power Output over 40 years MW</th>
<th>UCG as Nat Gas BCM</th>
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</thead>
<tbody>
<tr>
<td>Eastern/NE England</td>
<td>6,824</td>
<td>11,900</td>
<td>681</td>
</tr>
<tr>
<td>Lancs/Dee</td>
<td>4,770</td>
<td>14,100</td>
<td>476</td>
</tr>
<tr>
<td>Wales</td>
<td>220</td>
<td>730</td>
<td>22</td>
</tr>
<tr>
<td>Scotland</td>
<td>171</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>16,784</strong></td>
<td><strong>26,730</strong></td>
<td><strong>1,676</strong></td>
</tr>
</tbody>
</table>
UK ELECTRICITY GENERATION FROM COAL

That was the plan in 2000 –
ACTUAL COAL FIRED OUTPUT 2011/2012 WAS AROUND 40%!

BUT WE CAN’T DO IT AGAIN!
## 21st Century UK Coal Output

<table>
<thead>
<tr>
<th></th>
<th>2000</th>
<th>2005</th>
<th>2010</th>
<th>2012/13</th>
<th>NOW</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNDERGROUND</td>
<td>15Mt</td>
<td>9Mt</td>
<td>7Mt</td>
<td>6Mt</td>
<td>4Mt?</td>
</tr>
<tr>
<td>OPENCAST</td>
<td>20Mt</td>
<td>11Mt</td>
<td>10Mt</td>
<td>10Mt</td>
<td>8Mt?</td>
</tr>
<tr>
<td>TOTAL</td>
<td>35Mt</td>
<td>20Mt</td>
<td>17Mt</td>
<td>16Mt</td>
<td>12Mt?</td>
</tr>
</tbody>
</table>

UK mining met less than one-third of demand of last year’s remaining coal-fired power stations.
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UCG - Energy Recovery Comparison

Energy extraction by method for a typical Australian 12km² coal deposit

Energy in PJ

- UCG syngas
  - H₂
  - CO
  - CH₄

- Underground mining
- Coal seam gas
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REMOVAL OF CO2 FROM UCG GAS

- CO2 can be scrubbed with physical solvent before combustion
- Solvent regeneration uses much less energy than chemical solvents
- Well-head gas is typically 20 – 40% CO2; if only this CO2 is stripped, residual gas CV is about half that of natural gas but carbon footprint is comparable
- If CO and CH4 are reformed to H2 + CO2 and that CO2 is also stripped, the remaining gas, mainly H2, is essentially carbon-free
- The cost of total CO2 removal is less than a fifth of post-combustion flue gas scrubbing from a boiler
- An alternative is to leave the CO2 in the gas, combust with O2 in a special turbine, and condense CO2 from the exhaust ("oxyfuel")
- The total cost of CO2 removal, transportation and underground disposal is calculated to be less than $30/t carbon
UCG PROJECTS AROUND THE WORLD

• Virtually every country with significant coal resources is now aware of UCG

• There is current active attention being given to UCG in at least 33 countries

• Active testing, or evaluation of previous testing, is being conducted in at least 15 countries

• Commercial projects are under development in at least 8 countries
MAJUBA POWER STATION, SOUTH AFRICA

PROGRESSIVE ADOPTION OF UCG

- The station was built as a conventional, pf coal-fired plant, to be fed with locally-mined coal.
- Geological problems prevented the design rate of mined coal being achieved; the shortfall was being transported a considerable distance.
- Trials of UCG on the unmineable coal were carried out for more than 2 years, successfully co-firing the syngas to the pf boilers.
- It has been announced that the UCG operation will be extended, to increase the rate of co-firing and broaden experience.
- Ultimately, the objective is to build a CCGT fired with UCG gas.
- CCS could be added later
- **THIS IS AN EXCELLENT EXAMPLE OF PROGRESSIVE DEVELOPMENT AND ADOPTION OF UCG.**
In common with many European countries, UK is facing a crisis of shortage of generation capacity and increase in generation costs.

- Coal has been the lowest-cost source of power, but coal burning has been coming under increasing environmental pressure.
- Enormous resources of coal remain in Britain.
- No other generation method, not even prolific shale gas, can match the expected cost of power generated from UCG gas.
Cost of UCG for Power Generation

<table>
<thead>
<tr>
<th>Cost (£/MWh)</th>
<th>UCG</th>
<th>COMPARED WITH JUNE 2010 REPORT FOR DECC</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL COST OF BULK GENERATION</td>
<td>172</td>
<td></td>
</tr>
<tr>
<td>RENEWABLES</td>
<td>94</td>
<td></td>
</tr>
<tr>
<td>ONSHORE WIND</td>
<td>67</td>
<td></td>
</tr>
<tr>
<td>BASE LOAD MATURE</td>
<td>115</td>
<td></td>
</tr>
<tr>
<td>CLEAN COAL</td>
<td>115</td>
<td></td>
</tr>
<tr>
<td>CLEAN GAS</td>
<td>105</td>
<td></td>
</tr>
<tr>
<td>UCG</td>
<td>66</td>
<td></td>
</tr>
</tbody>
</table>

NOTES
- INCLUDING COST OF 90+% CARBON CAPTURE AND STORAGE
- NO PAYMENT FOR VALUE OF COAL IS INCLUDED FOR UCG
- MOTT MACDONALD: "UK ELECTRICITY GENERATION COSTS UPDATE" JUNE 2010

UCG
HOW ABOUT UCG IN 2014?

IN 2010, THE COST OF GENERATING POWER IN UK ON A CCGT FED WITH UCG GAS, INCLUDING CCS, WAS CALCULATED AS £66/MWh.

TODAY, THAT FIGURE MAY HAVE INFLATED TO AROUND £70/MWh.
FORECAST GENERATING COSTS 2014
(including CCS for new fossil fuel stations)

- OFFSHORE WIND £140 – 170/MWh
- ONSHORE WIND £80 – 100/MWh
- NEW NUCLEAR £93/MWh
- CLEAN COAL (combustion) £110/MWh
- COAL GASIFICATION (IGCC) £110/MWh
- EXISTING CCGT (no CCS) £80 – 100/MWh
- NEW CCGT + CCS £110/MWh
- UCG + CCS £70/MWh
CURRENT UK BULK POWER PRICES

• WERE £40/MWh,
• THEN £50/MWh,
• SOON £60/MWh?
• BUT NONE OF THE FORECAST GENERATION COSTS EXCEPT UCG COME CLOSE TO MAINTAINING THIS
SHALE GAS VS. UCG (1) ECONOMICS

• WILL COST OF SHALE GAS UNDERCUT UCG?
• PROBABLY NOT; SHALE GAS IN UK IS FORECAST TO COST AROUND PRESENT COST OF NATURAL GAS
• WILL SHALE GAS BE ABLE TO BE BURNT WITHOUT CCS?
• MAYBE INITIALLY, NOT IN MEDIUM / LONG TERM

THE RISK:-

“UNCERTAINTY INCREASES THE VALUE OF WAITING”
SHALE GAS VS. UCG (2) ENVIRONMENT

• UCG REQUIRES THE STRATA AND GROUNDWATER TO BE UNDISTURBED AND GAS-TIGHT

• IT DOES NOT ENTAIL FRACTURING

• IT DOES NOT ENTAIL PUMPING OUT WATER

• IT DOES NOT ENTAIL PUMPING IN CHEMICALS
SHALE GAS VS. UCG (3) LICENSING

• SEPARATE LICENSING REGIMES APPLY IN UK FOR SHALE GAS AND FOR UCG

• BOTH CANNOT BE WORKED IN PRACTICE IN THE SAME LOCATION

• ARRANGEMENTS TO CO-ORDINATE AND PRIORITISE ARE BEING FORMULATED
TYPICAL COASTAL SITES LICENSED FOR UCG
ENGLAND AND WALES
PROGNOSIS FOR UCG IN UK

COMPARED WITH ALL OTHER AVAILABLE MEANS OF POWER GENERATION, UCG OFFERS THE LIKELIHOOD OF BEING A MAJOR, AFFORDABLE, CLEAN, DOMESTIC ENERGY SOURCE AND SHOULD BE PURSUED ACCORDINGLY
THANK YOU FOR LISTENING

• REFERENCES:

• Review of the Feasibility of UCG in the UK, October 2004, DTI Pub URN 04/1643


• UCGA website: www.ucgassociation.org
IMechE ONE BIRDCAGE WALK

11th MARCH, 2014

A global alliance of knowledge, expertise, training, networking & information for Underground Coal Gasification

www.ucgassociation.org