Underground Coal Gasification (UCG)

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All “London sources” refer to the materials supplied on the UCG Course at Imperial College & organized by UCG Partnerships, September 22-26, 2008
(A) Underground Coal Gasification (UCG) converts coal into a gaseous form (syngas) through the same chemical reactions that occur in surface gasifiers.

(B) The economics of UCG look promising as capital expenses should be considerably less than surface gasification.

Four UCG essential areas to consider?

- **Site location** - biggest issue to ensure success
- **Principles** - chemistry, coal characteristics
- **Technologies** - connecting wells, drilling, process control
- **Demonstrations** – Australia, USA, Spain, Angren
Injection-Production Configuration

The oxidant & gasifying agent are fed through the injection borehole & the combustion & gasification products are recovered from the production bore hole. **Injecting oxygen & steam instead of air** produces the most useful product gas, since the dilution effect of nitrogen is avoided. The main constituents of the product gas are H2, CO2, CO, CH4 & steam. The **proportion of these gases varies** with the type of coal & the efficiency of the gasification process.

**Enhanced permeability:**
- Air pressurisation
- Man-built galleries
- Directional drilling
Factors Affecting UCG Designs

1. Coal seam geology
   - Thickness, depth and dip
   - Permeability to gas, liquid

2. Coal properties
   - Rank (ash, volatile, carbon content)
   - Chemical composition (hydrogen, sulphur)

3. Strata/overburden properties
   - Geology
   - Hydrology
   - Geomechanics
   - Drilling properties

4. Operating conditions
   - Injection composition and flow rate
   - Operating pressure
   - Well layout

5. Product gas
   - Required volume
   - Composition, calorific value
   - Flow rate

6. Process efficiency
   - Thermal
   - Chemical
   - Resource recovery

7. Interaction with the environment
   - Thermal
   - Chemical
   - Resource recovery
   - Subsidence effects
US Site Selection Criteria
Williams, 1982

- Seam thickness greater than one metre or 0.6 m for steeply dipping seams
- Avoid variable thickness seams
- Avoid seams with variable partings
- Avoid seams with overlying coal within 15m that is thicker than 0.6 m
- Minimum of 3.5 Mt in resource
- Minimum overburden of 100m
- Minimum of 1.6 km from populated areas (>100 people)
- Minimum distance of 0.8 km from major faults
- Minimum distance to oil and gas recovery development of 1.6 km
- Minimum distance of 0.4 km from major highways and rail
- Minimum distance of 1.6 km from rivers and lakes
- Minimum distance of 3.2 km from active mines
- Minimum distance of 1.6 km from abandoned mines

Other notes
- Steeply dipping (>30°) seams favoured due to lack of mining interest
- Floor and roof conditions need be examined
Australia Site Selection Criteria
Commonwealth Scientific & Industrial Research Organization, CSIRO

- Seam thickness greater than five metres
- Coal ash less than 40% (air dried basis)
- Seem dip less than 20°
- Seam depth 200-400 metres
- Minimal faulting and no dips/sills
- Roof thermally stable with minimal permeability, preferably structured to encourage even caving
- Hydraulic head > 200m
- Adjacent aquifers can contain poor quality water and are of minimal permeability

Other notes
- Limited human activities in the vicinity
- No waterways overlying the site
- Subsidence must be acceptable at location
- Coal resource size suitable for long term operation
UK Site Selection Criteria
National Coal Board 1976

- 5 Mt of coal in resource to provide 20 years of operation
- Not marked for conventional mining
- Not adjacent to working mines
- Removal will not cause unacceptable subsidence
- Seam thickness at least one metre or banded seam totals over one metre
- Ash content less than 60% including any dirt bands as combustion may be impeded
- Area free of excessive faulting

Other notes
- Leakage may be excessive if adjacent to old mine workings or in a faulted area
- Impact of faulting and roof material on operation largely unknown
- Progress and control of multi-seam operations
## Ranking of Coal Prospects for UCG Trial Site Search in UK

<table>
<thead>
<tr>
<th>Coal Attribute</th>
<th>Optimal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seam Thickness</td>
<td>30 ft +</td>
</tr>
<tr>
<td>Rank</td>
<td>Lignite to Bituminous, non-swelling</td>
</tr>
<tr>
<td>Ash</td>
<td>&lt; 40%</td>
</tr>
<tr>
<td>Faulting</td>
<td>Rare</td>
</tr>
<tr>
<td>Depth</td>
<td>600 to 1,500 ft</td>
</tr>
<tr>
<td>Dip</td>
<td>0 to 20 degrees</td>
</tr>
<tr>
<td>Intrusions</td>
<td>Minimal</td>
</tr>
<tr>
<td>Immediate Roof</td>
<td>Strong, stable</td>
</tr>
<tr>
<td>Hydraulic Head</td>
<td>&gt; 600 ft</td>
</tr>
<tr>
<td>Water Quality</td>
<td>Poor</td>
</tr>
</tbody>
</table>

- Geological environment – faults, dip, intrusions, roof, floor, ground water.
- Seam Attributes – thickness, composition, caking, swelling, rank
- Other Attributes - no of seams, depth, data density and proximity to old workings.
UCG Site Selection Factor
Depth of Coal Seam

Deeper seams require **guided drilling technology** to initiate a well at the surface that is deviated to intercept & follow a coal seam & establish a link between injection & production wells (incurs higher drilling costs)

Deeper seams are less likely to be linked with potable aquifers, thus avoiding drinkable water contamination & subsidence problems

If the product gas is directly used in gas turbines, additional compression may not be necessary
Contact Between Coal & Gases

Constant gas composition requires a large surface area available for contact between coal and hot gases

- Excess CO2 will be converted to CO: CO2 + C $\rightarrow$ 2 CO.

- This reaction increases the heating value of the gas.

- New sections of the seam need to be added in order to keep a high surface area.

- However, it is not desirable to cool down the gases too much.
Site Selection Factors
Porosity & Permeability

More permeable coal seams make it easier to link the injection & production wells, & increases the rate of gasification by making reactant transport easier.

But higher porosity & permeability increase the influx of water, & increase product gas losses.
Control Parameters

The use of oxygen instead of air:

- improves the calorific value of the product gas, 3-5 MJ/m³ vs 13 MJ/m³ in the trial at El Tremedal.
- Improves gasification stability
- Reduces the volume of gas injected
UCG Site Selection Factor
Coal Seam Thickness

Thicker seams need fewer wells, so reducing drilling costs.

Often problems when attempting to gasify seams < 2m thick.

Heat losses are considerable with thin seams, leads to low thermal efficiency & lower product gas quality.

UCG is generally easier to sustain in dipping seams as tars & fluids flow away from the gasification zone.
Control Parameters

- Coal seam thickness.
  - Thin seams lose more heat to the surroundings.
  - Decreasing seam thickness has roughly the same effect as increasing water intrusion.
  - As expected, CH₄ concentration is largely unaffected.

Gasification rate:
2 tons coal per hour
Control Parameters

- **Water intrusion.**
  - Its rate depends on hydrostatic pressure and permeability.
  - Higher blast rates decrease water content in the product gas.
  - It does matter **where** water intrusion takes place.

- **Blast rate.**
  - Higher blast rates may lead to high calorific values of the product gas.
  - This is related to the effect of water inlet on the water-gas shift reaction.

- **Plastic properties of coal.**
  Swelling properties are important.
  Some coals can swell up to 3-4 times their original volume.
  This may result in channel blockages.
UCG Trials, Dates & Depths, 1948-2005 (Meters)
## UCG Trials: Date, Depth, Thickness

<table>
<thead>
<tr>
<th>Location</th>
<th>Coal type</th>
<th>Thickness (m)</th>
<th>Depth (m)</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lisichanskaya</td>
<td>Bituminous</td>
<td>0.44–2</td>
<td>60–250</td>
<td>1948–1965</td>
</tr>
<tr>
<td>Yuzhno-Abinskaya</td>
<td>Bituminous</td>
<td>2.2–9</td>
<td>50–300</td>
<td>1999–current</td>
</tr>
<tr>
<td>Angrenskaya</td>
<td>Lignite</td>
<td>2–22</td>
<td>120–250</td>
<td>1957–current</td>
</tr>
<tr>
<td>Podmoskovnaya</td>
<td>Lignite</td>
<td>2.5</td>
<td>30–80</td>
<td>1946–1953</td>
</tr>
<tr>
<td>Shatskaya</td>
<td>Lignite</td>
<td>2.6–4</td>
<td>30–60</td>
<td>1963–1956</td>
</tr>
<tr>
<td>Sinelnikovsky</td>
<td>Lignite</td>
<td>3.6–6</td>
<td>80</td>
<td>–</td>
</tr>
<tr>
<td>Chinchilla (Australia)</td>
<td>–</td>
<td>8–10</td>
<td>130</td>
<td>1999–2004</td>
</tr>
<tr>
<td>Belgium</td>
<td>Anthracite</td>
<td>–</td>
<td>860</td>
<td>1979–1987</td>
</tr>
<tr>
<td>Newman Spinney (UK)</td>
<td>Sub-bituminous</td>
<td>0.75</td>
<td>75</td>
<td>1959</td>
</tr>
<tr>
<td>USA (Hanna 2)</td>
<td>Sub-bituminous</td>
<td>6.8</td>
<td>90–120</td>
<td>1973–1974</td>
</tr>
<tr>
<td>USA (Hoe Creek)</td>
<td>Sub-bituminous</td>
<td>7.6</td>
<td>38</td>
<td>1976–1979</td>
</tr>
</tbody>
</table>

[http://www.sciencedirect.com/science?_ob=ArticleURL&udi=B6V2S-4P2J32B-1&user=29441&rdoc=1&_fmt=&orig=search&sort=d&view=c&_version=1&_urlVersion=0&userid=29441&md5=5a1f31dcfa458a1c2f5b075633dd75b](http://www.sciencedirect.com/science?_ob=ArticleURL&udi=B6V2S-4P2J32B-1&user=29441&rdoc=1&_fmt=&orig=search&sort=d&view=c&_version=1&_urlVersion=0&userid=29441&md5=5a1f31dcfa458a1c2f5b075633dd75b)
Model results for UCG gas composition compared with field measurements made during the 1980s Rocky Mountain 1 Controlled Retraction Ignition Point test.

<table>
<thead>
<tr>
<th>Component</th>
<th>UCG model predictions (percent)</th>
<th>Field measurements (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>27.2</td>
<td>27.3</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>13.0</td>
<td>6.4</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>19.4</td>
<td>27.2</td>
</tr>
<tr>
<td>Methane</td>
<td>7.4</td>
<td>6.4</td>
</tr>
<tr>
<td>Water</td>
<td>33.0</td>
<td>33.0</td>
</tr>
</tbody>
</table>

UC model quite accurately predicts the hydrogen, methane & water content of the gas. However, it predicts twice the actual level of CO & about 2/3 actual level of CO2.

2007: BP executed an agreement with the Lawrence Livermore National Laboratory to develop simulations for optimizing the UCG process as well as tools for drilling, monitoring, & environmental management. University of California, at Berkeley, is modeling UCG.
Injection-Production Configuration

- A more controlled injection is obtained with the Controlled Retractable Injection Procedure (CRIP):

Gasification cavity shape using the traditional method

Gasification cavity shape in CRIP
Worldwide Horizontal Wells

Number of horizontal wells

Only 2625 horizontal wells worldwide in 1995.

Since 1995 “Scientific Drilling” has drilled over 4000 horizontal wells in North America

Source: Oil & Gas Journal, November 23, 1998
Directional Well Profiles

Horizontal Wells

- Horizontal from Slant-Hole
- Slant Hole
- Short Radius
- Medium Radius
- Long Radius

Opposing Horizontal Wells

- “HST” Sidetracking from Vertical or Deviated Well to Horizontal
- “Grass Roots” Stacked Laterals

Horizontal Well Types

Categories of Horizontal Wells
- LRH (LONG RADIUS)
- MRH (MEDIUM RADIUS)
- SHR (SHORT RADIUS)

Example
North Sea typically
1000m down &
2000m horizontally
Horizontal Well Classification

<table>
<thead>
<tr>
<th>Type</th>
<th>Radius (Feet)</th>
<th>Achievable Lateral Length (Feet)</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero</td>
<td>0</td>
<td>10</td>
<td>Telescopic probe with hydraulic jet</td>
</tr>
<tr>
<td>Ultra-Short</td>
<td>0.5-5.0</td>
<td>200</td>
<td>Coiled tubing with hydraulic jet</td>
</tr>
<tr>
<td>Short</td>
<td>35-45</td>
<td>1,500</td>
<td>Curved drilling guide with flexible drill pipe; entire string rotated from surface</td>
</tr>
<tr>
<td>Medium</td>
<td>300-500</td>
<td>1,500</td>
<td>Steerable mud motor used with compressive drill pipe; conventional drilling technology can also be used</td>
</tr>
<tr>
<td>Long</td>
<td>1,800-2,800</td>
<td>1,500 + 4,500</td>
<td>Conventional directional drilling equipment used: very long curve length of 2,800 to 4,400 feet needed to be drilled before achieving horizontal</td>
</tr>
<tr>
<td>In-Mine</td>
<td>N/A</td>
<td>5,000</td>
<td>Uses underground drilling rigs with steerable motors and position systems to achieve long, in-seam boreholes</td>
</tr>
</tbody>
</table>

**Classification of Directional Wells**

**CURVE BUILD RATES**

- **Long:** 2 - 6° / 100’
- **Medium:** 6 - 40° / 100’
- **Short:** 40 - 70° / 100’
- **Ultra Short:** 70 - 150° / 100’
Key Drilling Issues

Maintaining the bottom head assembly (BHA) heading within the target zone

– Thick Seams are sometimes more difficult to drill in zone because the BHA is prone to get out of plane with the formation

By pumping mud through the mud motor, the bit turns while the drillstring does not rotate, allowing the bit to drill in the direction it points
Key Drilling Issues

Maintaining the BHA heading within the target zone
– Thin Seams are sometimes easier to drill in zone because the BHA tends to deflect off the roof & floor of the coal seam & stay in plane with the formation

If bit gets stuck then 40% chance of getting it back
Key Drilling Issues

Faulting & Fracturing

Steer Up 1st

Steer Down 2nd

FIGURE 19. - Two methods of following the coalbed. Method B is recommended.
Directional Drilling Application to Coal

- UCG drilling follows CBM techniques
- Rotor at drill bit driven by steerable mud motor
- In 1980 directional drilling was still a ‘big deal’
- Drilling teams - to have previously drilled coal
- Availability of drilling rigs is a problem
- A rig can have 40 to 60 wells – congestion
- Drilling 2-4 ft seams is very good for CBM
- Focused gamma rays see limits of coal seams & keep 90% of time within the coal
Directional Drilling

Typical Costs

- About $20k/day for drilling rig + material/other costs
- Cost per bit is $80k+
- Lost in hole costs amount to $0.5M to $1.0 Million
- Conventional 1000m vertical well rig costs $5-10M
- Low cost H2 production ($2-3/MBtu)
Testing UCG in the **US from 1973 to 1989.** The Lawrence Livermore National Laboratory conducted tests at the Hoe Creek site in Wyoming.

The **United Kingdom started UCG testing** in 1912 & the **Former Soviet Union** in 1928. **China** has been conducting tests since the 1980s & **Australia** since the 1990s.

Worldwide UCG Sites

USA: Centralia WA & Hoe Creek WY (LLNL test sites)
Australia, China, India, South Africa, Uzbekistan
Grey areas show potential areas for geological carbon storage

Source: “Fire in the Hole”, Lawrence Livermore National Laboratory, April 2007
UCG Activities in 2007-8

**USA & Canada**
- US Nat Labs undertaking reviews
- GasTech Inc 5MW demonstration involving BP
- Wyoming Business study
- New entrepreneurial initiatives in US & Canada

**Europe**
- EU Project underway
- Firth of Forth 2nd phase
- Hungary, and E Europe interest growing

**Worldwide Activity**
- UCG Partnership with training & annual Conference
- Technology suppliers worldwide, UCGEL, Ergo, Linc, In Situ Energy

**South Africa**
- Eskom trial produces first gas
- Sasol and others doing feasibility work

**China**
- 11-16 State sponsored trials
- Start of entrepreneurial activity
- Demonstration by Xiniao in Mongolia underway

**India**
- ONGC Site selected, and technical designs underway
- Reliance, BHEL, NLC and others planning trials
- Coal of India review

**Australia**
- Linc IPO financial offering raised to A$65M for UCG-GTL
- New Joint venture with CSIRO demonstration 08
- At least one other new initiative in S Australia
UCG Projects in the United States
## Gas Composition

### Typical dry Gas Characteristics

<table>
<thead>
<tr>
<th>Data from the EU trial at “El Tremedal”, Spain, 1992-1998, run at depths of about 550m.</th>
</tr>
</thead>
<tbody>
<tr>
<td>• CO: 14-18%</td>
</tr>
<tr>
<td>• H₂: 27%</td>
</tr>
<tr>
<td>• CH₄: 14-24%</td>
</tr>
<tr>
<td>• CO₂: 31-44%</td>
</tr>
<tr>
<td>• CV: 13 MJ/Nm³</td>
</tr>
<tr>
<td>• Temperature: 200 °C.</td>
</tr>
<tr>
<td>• Pressure: 60-100 bar</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data from the Hanna trial at Wyoming, US, Mid-70’s, run at depths of 90-120m.</th>
</tr>
</thead>
<tbody>
<tr>
<td>• CO: 14.7%</td>
</tr>
<tr>
<td>• H₂: 17.3%</td>
</tr>
<tr>
<td>• CH₄: 3.3%</td>
</tr>
<tr>
<td>• CO₂: 12.4%</td>
</tr>
<tr>
<td>• N₂: 51%</td>
</tr>
<tr>
<td>• CV: 5 MJ/Nm³</td>
</tr>
<tr>
<td>• Temperature: 300 °C</td>
</tr>
</tbody>
</table>
New Projects, GasTech & BP Commercializing UCG in WY

- Outstanding lease position (16 billion tons unmineable coal)
- BP agrees to underwrite & manage project with GasTech
- Site selection process near completion
- Engagement of state of WY, Univ. WY,
- Anticipated first gas < 3 years
- The pilot project will be the first of many projects in the State
New Projects

Linc Energy, Australia (Chinchilla)
- First gas, 1999; continuous for 2.5 years
- 35,000 tons brown coal evacuated
- Current plans for CTL plant

Eskom, S. Africa (Majuba)
- Ignition Jan. 2007; electric power
- Bituminous coal
- Planning 1000 MW IGCC step out this year

GAIL, India
- Scheduled production, 2009
- Lignite coal, planned electric power

XinAo, China
- Pilot ignition, Aug. 2007
- Sub-bituminous; planned methanol plant

Other companies planning or operating hydrogen, synthetic natural gas, F-T, and power with CCS
THE POTENTIAL FOR UNDERGROUND COAL GASIFICATION IN INDIANA

Phase I Report
to the
Indiana Center for Coal Technology Research (CCTR)

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