Underground Coal Gasification (UCG)

CCTR Basic Facts File # 12

Brian H. Bowen, Marty W. Irwin

The Energy Center at Discovery Park
Purdue University
CCTR, Potter Center, 500 Central Avenue
West Lafayette, IN 47907
http://www.purdue.edu/dp/energy/CCTR/
Email: cctr@ecn.purdue.edu

October 2008
UCG Essentials

Underground Coal Gasification (UCG) converts coal into a gaseous form (syngas) through the same chemical reactions that occur in surface gasifiers.

The economics of UCG are very promising. Capital expenses are considerably less than surface gasification because the purchase of a gasifier is not needed.

UCG makes it economically possible to obtain energy from 300% more coal than is recoverable with current technology.
Air is injected into the cavity, water enters from surrounding rock & partial combustion with gasification take place at the coal seam face following ignition. The resulting high pressure syngas stream is returned to the surface, where the gas is separated & contaminants are removed.
Worldwide UCG Sites

USA - Centralia WA & Hoe Creek WY
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 Projects in the United States

By Capacity (MW)
- 0 - 250
- 251 - 1000
- 1001 - 4000

Prior test sites
Sites of note
Announced/planned

Indiana Center for Coal Technology Research
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.

Criteria for a suitable UCG site location:

- Geology is key to **safeguard** environment
- Geologically **isolated** deep beds
- Deep aquifers should consist of saline, non-potable water & have stratigraphic seals
- Structural integrity & **no possibility** of cavity roof caving in
Most important is the method for establishing a channel between the injection & production wells.

# Fundamental Coal Gasification Reactions

**Most important reaction (1)**

**Syngas from $H_2$ and CO**

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Enthalpy</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Heterogeneous water-gas shift reaction</td>
<td>$\Delta H = +118.5 \text{ kJ mol}^{-1}$</td>
</tr>
<tr>
<td>$C + H_2O = H_2 + CO$</td>
<td></td>
</tr>
<tr>
<td>(2) Shift conversion</td>
<td>$\Delta H = -42.3 \text{ kJ mol}^{-1}$</td>
</tr>
<tr>
<td>$CO + H_2O = H_2 + CO_2$</td>
<td></td>
</tr>
<tr>
<td>(3) Methanation</td>
<td>$\Delta H = -206.0 \text{ kJ mol}^{-1}$</td>
</tr>
<tr>
<td>$CO + 3H_2 = CH_4 + H_2O$</td>
<td></td>
</tr>
<tr>
<td>(4) Hydrogenating gasification</td>
<td>$\Delta H = -87.5 \text{ kJ mol}^{-1}$</td>
</tr>
<tr>
<td>$C + 2H_2 = CH_4$</td>
<td></td>
</tr>
<tr>
<td>(5) Partial oxidation</td>
<td>$\Delta H = -123.1 \text{ kJ mol}^{-1}$</td>
</tr>
<tr>
<td>$C + 1/2O_2 = CO$</td>
<td></td>
</tr>
<tr>
<td>(6) Oxidation</td>
<td>$\Delta H = -406.0 \text{ kJ mol}^{-1}$</td>
</tr>
<tr>
<td>$C + O_2 = CO_2$</td>
<td></td>
</tr>
<tr>
<td>(7) Boudouard reaction</td>
<td>$\Delta H = +159.9 \text{ kJ mol}^{-1}$</td>
</tr>
<tr>
<td>$C + CO_2 = 2CO$</td>
<td></td>
</tr>
</tbody>
</table>

**Methane formation reactions (3)&(4)**

Two oxidation reactions (5)&(6) provide heat to (1)

Ruprecht, et al., 1988
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**
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

Worldwide UCG Experience
Coal Seam Depth & Thickness

Process parameter: Operating Pressure ~ governed by coal & rock properties

1. Higher pressure in UCG working zone assures no groundwater flow seeping into the cavity
2. Influences chemistry & contamination
3. Pressure increases with depth of seam.
4. Higher values will increase the loss of the product gas
5. An impermeable overburden helps provide a reasonable balance between pressure & gas losses
6. Deep seams with high coal & overburden permeability pose a problem (pressure can make gas losses unacceptable)

Process parameter: **Outlet Temperature**

~ governed by coal & rock properties

Ideal UCG temperatures are similar to above ground coal gasification temperatures, > **1000°C (1832°F)**

Achieving the ideal UCG temperatures depends on careful control of the water influx & gas flows

Site Selection Factors
Porosity & Permeability

More **permeable 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**.

Seam permeability can be artificially enhanced through various methods.
CO$_2$ Emissions from Coal

Different rank coals produce different amounts of CO$_2$ lbs per Million Btu (MBtu)

CO$_2$ pounds/MBtu from Coal

U.S. averages:

- 227.4 for anthracite
- 216.3 for lignite
- 211.9 for sub-bituminous
- 205.3 for Indiana bituminous

Consider pumping CO$_2$ back into the UCG cavity for permanent storage

Source: [http://www.eia.doe.gov/cneaf/coal/quarterly/co2_article/co2.html](http://www.eia.doe.gov/cneaf/coal/quarterly/co2_article/co2.html)
Attractions of UCG

Less than one sixth of the world’s coal is economically accessible & so **UCG increases usable coal resources**

Potential UCG sites correspond to locations where sites are plentiful for **CO$_2$ sequestration**

The syngas produced is taken from the ground & **then by-products are taken out** (CO$_2$ being returned)
Attractions of UCG

Reduced expenditure, no gasifier is required to be purchased, reduced transportation & no ash removal operational costs

UCG provides a clean & economic alternative fuel

Further information: https://eed.llnl.gov/co2/11.php