UK CCS policy areas: The CCS Competition, Overseas Links
(A personal view)

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CRITICAL ROLE FOR CCS

‘Unconventional oil’ includes oil sands and oil shales. Unconventional gas’ includes coal bed methane, deep geopressed gas etc. but not a possible 12,000 GtC from gas hydrates.

http://www.ipcc.ch/
STERN REVIEW: The Economics of Climate Change

Eventual Temperature change (relative to pre-industrial)

- 0°C
- 1°C
- 2°C
- 3°C
- 4°C
- 5°C

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Risk of rapid climate change and major irreversible impacts</th>
<th>Risk of weakening of natural carbon absorption and possible increasing natural methane releases and weakening of the Atlantic THC</th>
<th>Onset of irreversible melting of the Greenland ice sheet</th>
<th>Increasing risk of abrupt, large-scale shifts in the climate system (e.g. collapse of the Atlantic THC and the West Antarctic Ice Sheet)</th>
</tr>
</thead>
</table>
CCS in Stern Review – Role of CCS

- “There is still time to avoid the worst impacts of climate change, if we take strong action now.”

- “Carbon capture and storage is essential to maintain the role of coal in providing secure and reliable energy for many economies.”

- “[CCS] is a technology expected to deliver a significant portion of the emission reductions. The forecast growth in emissions from coal, especially in China and India, means CCS technology has particular importance.”
CCS in Stern Review – What Next?

• “There is a strong case for greater international co-ordination of programmes to demonstrate carbon capture and storage technologies, and for international agreement on deployment.”

• “Building on these announcements, the enhanced co-ordination of national efforts could allow governments to allocate support to the demonstration of a range of different projects…”

• “One element that enhanced co-ordination could focus on is understanding the best way to make new plants “capture-ready”…”
HIERARCHY OF POLICIES AFFECTING CCS ON COAL

Post-post-Kyoto agreement 2021 to ?
Post-Kyoto agreement 2013-2020

EU energy & climate policy
UK energy & climate policy
Utility portfolio policy
Customers’ aspirations
Other stakeholders’ aspirations
### CCS Proposals – UK

- Proposed full-scale (~300 MWe and above) CCS projects
- Based on media reports, press releases and personal communication so indicative only!

<table>
<thead>
<tr>
<th>Company/ Project Name</th>
<th>Fuel</th>
<th>Plant output/cost</th>
<th>Capture technology</th>
<th>Start</th>
</tr>
</thead>
<tbody>
<tr>
<td>Progressive Energy/Centrica, Teeside, UK</td>
<td>Coal (petcoke)</td>
<td>800 MW (+ H2 to grid) ($1.5bn)</td>
<td>IGCC + shift + precombustion</td>
<td>2009</td>
</tr>
<tr>
<td>BP/SSE DF1, Peterhead/Miller, Scotland</td>
<td>Natural gas</td>
<td>475 MW, (&gt;=$600M)</td>
<td>Autothermal reformer + precombustion</td>
<td>2010</td>
</tr>
<tr>
<td>Powerfuel/ Kuzbassrazrezugol Hatfield Colliery, UK</td>
<td>Coal</td>
<td>~900 MW</td>
<td>IGCC + shift + precombustion</td>
<td>2010</td>
</tr>
<tr>
<td>Conoco-Phillips, Immingham, UK</td>
<td>Coal (+petcoke?)</td>
<td>450 MW (or more, with retrofit)</td>
<td>IGCC+CCS addition to planned NGCC CHP plant</td>
<td>2010 (for CHP)</td>
</tr>
<tr>
<td>E.ON, Killingholme, Lincolnshire coast, UK</td>
<td>Coal (+petcoke?)</td>
<td>450 MW (£1bn)</td>
<td>IGCC + shift + precombustion? (may be capture ready)</td>
<td>2011</td>
</tr>
<tr>
<td>RWE, Tilbury, UK</td>
<td>Coal</td>
<td>~500 MW (£800m)</td>
<td>PC (supercritical retrofit) + post-combustion (may be capture ready)</td>
<td>2016</td>
</tr>
</tbody>
</table>

- Plus capture-ready plants at Ferrybridge (SSE) and Kingsnorth (E.On)
**CCS Proposals – World**

- Proposed full-scale (~300 MWe and above) CCS projects
- Based on media reports, press releases and personal communication so indicative only!

<table>
<thead>
<tr>
<th>Company/ Project Name</th>
<th>Fuel</th>
<th>Plant output/cost</th>
<th>Capture technology</th>
<th>Start</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statoil/Dong, Mongstad, Norway</td>
<td>Natural gas</td>
<td>280 MW</td>
<td>NGCC+ Post-combustion amine 100,000 tCO2/yr from 2010, 1.3Mt CO₂ from 2014, CO₂ for EOR (Gullfaks and others)</td>
<td>2010</td>
</tr>
<tr>
<td>BP DF2, Carson, USA</td>
<td>Petcoke</td>
<td>500 MW, ($1bn)</td>
<td>IGCC + shift + precombustion, CO₂ for EOR</td>
<td>2011</td>
</tr>
<tr>
<td>Statoil/Shell, Tjeldbergodden, Norway</td>
<td>Natural gas</td>
<td>860 MW</td>
<td>NGCC+ Post-combustion amine, CO₂ for EOR (Draugen)</td>
<td>2011</td>
</tr>
<tr>
<td>SaskPower, Saskatchewan, Canada</td>
<td>Lignite coal</td>
<td>300 MW</td>
<td>PC oxyfuel</td>
<td>2011</td>
</tr>
<tr>
<td>Stanwell, Queensland, Australia</td>
<td>Coal</td>
<td>275 MW</td>
<td>IGCC + shift + precombustion</td>
<td>2012</td>
</tr>
<tr>
<td>Futuregen, USA</td>
<td>Coal</td>
<td>275 MW</td>
<td>IGCC + shift + precombustion</td>
<td>2012</td>
</tr>
<tr>
<td>Xcel Colorado, USA.</td>
<td>Coal (sub.bit)</td>
<td>300-350MW</td>
<td>IGCC, may be partial capture only</td>
<td>2013</td>
</tr>
<tr>
<td>RWE, Germany Germany</td>
<td>Coal (€1bn)</td>
<td>450 MW</td>
<td>IGCC + shift + precombustion</td>
<td>2014</td>
</tr>
</tbody>
</table>
CO$_2$ STORAGE, POSSIBLE LEAKAGE PATHS AND MONITORING REQUIREMENTS

LONDON PROTOCOL RECENTLY EXTENDED TO ALLOW CO$_2$ STORAGE

OSPAR NOW DEBATING STORAGE

DTI TSR025, March 2005
To provide global leadership, the EU must provide a clear vision for the introduction of CCS:

- Regulatory framework (including EU ETS)
- More and effective research
- International action
- By 2020 all new coal-fired plants should be fitted with CCS
- Existing plants should then progressively follow the same approach

The Commission will in 2007 start work to stimulate construction and operation by 2015 of up to 12 large scale demonstrations of sustainable fossil fuels technologies in commercial power generation in the EU25.

The Commission will assess whether, if not equipped with CCS, new coal- and gas-fired installations are prepared for later addition of CCS technologies ('capture ready'). If this turns out not to be the case, the Commission will consider proposing legally binding instruments as soon as possible, after a proper impact assessment.
The Government is committed to delivering a strong economy based not just on high and stable levels of growth, but also on high standards of environmental stewardship. This Budget responds to the Stern Review on the Economics of Climate Change and sets out the next stage in the Government’s strategy for tackling climate change both domestically and globally, including:

- that the Government will launch a competition to develop the UK’s first full-scale demonstration of carbon capture and storage, the result of which will be announced next year;
- a review to examine the vehicle and fuel technologies which over the next 25 years could help ‘decarbonise’ road transport;

in May
President George Bush is coming under unprecedented pressure from Tony Blair and the German Chancellor, Angela Merkel, to agree to tough new international measures to stop global warming accelerating out of control.

The measures are contained in a strongly worded draft communiqué for June's G8 summit in Heiligendamm, Germany - obtained by *The Independent on Sunday* - which warns that "tackling climate change is an imperative, not a choice". It adds that if "resolute and concerted international action" is not "urgently" taken, global warming will become "largely unmanageable".

It promises "strong and early action" to hit this target, and says that this will involve cutting worldwide emissions of greenhouse gases in half by 2050. It commits developed countries to taking the lead, but adds that developing ones will also have to make "fair contributions" to the reduction. And it contains a lengthy section on how to reduce emissions through greater energy efficiency.

The .. issue will come to a head at a crucial preparatory meeting for the summit on 4 May.
Climate change could lead to increased instability and world conflict, Britain's foreign secretary is due to tell the UN.

Margaret Beckett, who is chairing the Security Council's first ever debate on global warming, will highlight the food and water shortages it may cause. This will make the security situation in the world worse, she will warn.

But the BBC's Matt McGrath says there are many UN members who are unlikely to accept Mrs Beckett's arguments.

Russia and China have already said the council is not the appropriate place to debate the issue.

And many developing countries see global warming as a problem of global justice, rather than just a security threat.

These countries believe that helping their people adapt should be the priority.
SaskPower Clean Coal Project

- World’s first “Near Zero Emissions” pulverized coal plant - oxyfuel technology selected
- 450 MW gross, 300 MW net
- Capturing 90%+ of CO₂
- 3 MT/y CO₂ for sequestration or EOR Sale
- 1.6 MT/y emission reduction
- Fast tracked for in service 2011
- Site depends on coal quantity & price, water, relative capital cost, line losses, CO₂ pipeline costs
- MOU commits Sask/Canada Gov’t cooperation
Master Schedule

<table>
<thead>
<tr>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>###</th>
<th>2011</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Definition &amp; Proposal</strong></td>
<td>(Pre Commitment Engineering)</td>
<td></td>
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<tr>
<td><strong>Transmission Studies</strong></td>
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<tr>
<td>Submit Line EIS</td>
<td>Plant EIS and Project Recommendation</td>
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<tr>
<td>Full Environmental &amp; Project Approval</td>
<td></td>
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<tr>
<td>Release to Manufacture</td>
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<tr>
<td><strong>Manufacture</strong></td>
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<tr>
<td>Release for Site Work</td>
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<tr>
<td>Manufacture, Erect and Commission</td>
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<tr>
<td>Optimize</td>
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FIRST TRANCHE
Priority is speed not numbers

SECOND TRANCHE
Semi-commercial but support still needed

ROLLOUT, CCS becomes the standard
New build and retrofit

PHASES IN GLOBAL CCS

TIMING SET BY ATMOSPHERE AND GLOBAL POLITICS

2010?

2015?

2020?

Overall effort Important to maintain continuity

Big prize is getting two learning cycles before rollout

Overall effort Important to maintain continuity

Big prize is getting two learning cycles before rollout
Coal Capacity History and Forecast AEO’05

1973 additions greater than total for last 15 years

Capacity Added MWs

Capacity Added MWs

Will the Nation’s Industry be Prepared and Capable of Meeting This Coal Plant Forecast?

NETL

Forecast - Annual Energy Outlook 2005
Historic Data - UDI 2005 Operating Data

José O. Figueroa / APPA New Generation Meeting / June 28, 2005
Any legislation intended to protect the environment and limit emissions is bound to have a profound impact on power project costs, equipment and construction — on a new and retrofit basis.

M. Richard Smith, vice president with Bechtel, pointed to another growing problem facing the development of new power projects - the specter of rising prices for everything from basic building materials to labor.

And, he said, “as orders for new power plants continue to mount, delivery lead times continue to stretch into the future and thus quality becomes a challenge.”

According to Smith, prices of major power plant components have risen 20-30% percent since January of this year — with labor costs in some markets also climbing by more than 20 percent.

As if the shortage of people for new power plant development and construction is not enough, electricity demand is beginning to outgrow installed generating capacity.
OTHER US DEVELOPMENTS

California AB32 (Dec 2006)
Imported electricity 1100 lb CO\(_2\)/MWh max
(0.5 kg CO\(_2\)/kWh)

TXU coal plants stopped by NRDC (Feb 2007)
Looking at IGCC, CR PC, nuclear now

Mesaba, Excelsior IGCC project in Minnesota (April 2007)
Judicial review - not lowest cost and not CCS

Democratic control in Congress – many proposals
Industry calls for legislation
WHAT ADVANCES ARE NEEDED?

- Start on first tranche plants – will immediately trigger R&D
- Get new technologies working:
  - IGCC - mainly engineering
PREDICTED IMPROVEMENT IN IGGC PLANT PERFORMANCE

Cost reduction vs Efficiency improvement

- 75% to 85% load factor
- 95% to 98% fuel conversion
- Two stage gasification
- Wet to dry feed
- FB advanced gas turbine (vs F)
- Advanced gas cleaning
- Ion Transfer Membrane vs Cryogenic Oxygen Plant
- 85% to 90% load factor
- H ultra-advanced gas turbine (vs. FB)
- SOFC+turbine hybrid cycle

POWER PLANT ESSENTIALS:

RELIABILITY

AVAILABILITY

MAINTAINABILITY

OPERABILITY
IGCC or PC?

SIMILAR COST TRENDS FROM A NUMBER OF GENERIC UK AND US STUDIES, BUT ACTUAL PROJECTS MORE VARIABLE

Costs include compression to 110 bar but not storage and transport costs. These are very site-specific, but indicative aquifer storage costs of $10/tonne CO2 would increase electricity costs for natural gas plants by about 0.4 c/kWh and for coal plants by about 0.8 c/kWh.
WHAT ADVANCES ARE NEEDED?

• Start on first tranche plants – will immediately trigger R&D
• Get new technologies working:
  - IGCC - mainly engineering
  - oxyfuel - basic research and engineering in parallel
• Get the best out of existing PC technology
  - post-combustion capture options
  - capture-ready and retrofit strategies
Secretary of Energy Announces Nearly $24 Million in Grants for Carbon Sequestration Research, Washington, DC, October 23, 2006

Carbozyme, Inc.: Enzyme-based membrane (x2)
Membrane Technology and Research, Inc.: Membrane-based process, will deliver high-pressure, supercritical CO₂ to a pipeline.
University of Akron: Metal monoliths, material synthesis, and low-cost fabrication for CO₂ from flue gas.
Praxair, Inc.: Oxygen transport membrane
Research Triangle Institute: Dry, regenerable sorbent
SRI International: Membrane material for pre-combustion-based capture of CO₂.
University of Notre Dame: New liquid absorbent
UOP LLC: Microporous metal organic frameworks

ALSTOM to build Pilot Plant in the US to demonstrate its unique CO₂ capture process
05 October 2006

ALSTOM, the Electric Power Research Institute (EPRI) and We Energies are combining forces to build a pilot plant to demonstrate a unique carbon dioxide (CO₂) capture process - a major step in assessing new technology that could have a significant impact on lowering emissions from fossil-fuel-burning power plants.

ALSTOM will design, construct and operate a 5 MW pilot system that will capture CO₂ from a portion of boiler flue gas at the We Energies power plant in Pleasant Prairie, Wisconsin, US.

The pilot is scheduled to be commissioned at the Pleasant Prairie Power Plant in mid-2007 and will be operated for at least one year. EPRI will conduct an engineering/environmental performance and cost analysis during the operation.

http://www.power.alstom.com/pr_power/2006/october/27531.EN.php?languageId=EN&dir=/pr_power/2006/october/&idRubriqueCourante=2727
WHAT ADVANCES ARE NEEDED?

• Start on first tranche plants – will immediately trigger R&D

• Get new technologies working:
  - IGCC - mainly engineering
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• Get the best out of existing PC technology
  - post-combustion capture options
  - capture-ready and retrofit strategies

• Storage issues: ETS, capacity optimisation, safety, monitoring, long term liability – but not for first tranche

• Transport and storage systems – pipeline routing issues

• Political, regulatory, fiscal backup – post-Kyoto process

• Build capacity: people, expertise, manufacturing capacity

Incremental development vs. innovation?

CCS systems will operate in new ways in new markets