Reflections on CCS Demonstration: Demonstrating what, when, where and why?

David M Reiner
Assistant Director, EPRG

Shell-EPRG-CEEPR Conference
9 July, 2015
A Potted History of the Rise of CCS (Policy)

• **Targets v Technology**
  – 1997 Kyoto Protocol focus on legally-binding QELROs
  – CCS included in KP Art 2.1 & IPCC GHG Guidelines 2006 but repeated failures to get CCS into CDM before Decision 10/CMP.7 at Durban in 2011.
  – Election of George W Bush see US withdrawal from KP replaced by technology focus and creation of CSLF. In 2003, Bush 43 announces $1B for Futuregen 1.0

• **What does it mean to pick winners?**
  – Proposed 475MW CCS demonstration proposed by BP at Peterhead with HMG support for ‘low-carbon’ technologies requested by end 2005 to make FID in mid-2007 (instead Blair Govt calls for open competition in late 2006)
Great Expectations

• In March 2007 European leaders issued a declaration calling for ‘up to 12’ CCS demonstration projects to be in operation by 2015 (by time of ZEP launch’10-12’ ‘by 2020’)
• At 2008 Hokkaido Toyako G8 Summit, leaders:
  • Announced 20 large-scale CCS demonstration projects globally by 2010, taking into account various national circumstances, with a view to beginning broad deployment of CCS by 2020.
  • Established an international initiative with the support of the IEA to develop CCS technology roadmaps and enhance global co-operation through existing and new partnerships.
  • Committed to various policy and regulatory measures to provide incentives for commercialising CCS technologies.
• Norway PM Stoltenberg describes CCS as their ‘moon landing’
• ZEP Demonstration Programme envisions 80-120 commercial CCS projects by 2030
ZEP on demonstrating along multiple dimensions

CO₂ capture technologies
Type of CO₂ infrastructure
Geographical location
CO₂ storage types
CO₂ storage geologies
CO₂ trapping mechanisms
CO₂ transport infrastructure
Fuel types
Plant technologies

Source: ZEP, EU Demonstration Programme for CCS
Narrowing down the demo programme

Portfolio criteria (16 in total):
- The total set of projects needs to meet a number of criteria on capture, transport & storage technologies, and on geography

Eligibility criteria (5 in total):
- Each project/party needs to meet these conditions for their proposal to be considered

Project criteria (11 in total):
- Each project must meet minimum project requirements
- Choice between two (otherwise equal) projects is based on their performance on ‘comparative’ criteria
ZEP’s 7 archetypal projects to span the space

<table>
<thead>
<tr>
<th>Archetype 1</th>
<th>Archetype 2</th>
<th>Archetype 3</th>
<th>Archetype 4</th>
<th>Archetype 5</th>
<th>Archetype 6</th>
<th>Archetype 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignite/co-firing with Biomass</td>
<td>Gas</td>
<td>Hard Coal</td>
<td>Hard Coal</td>
<td>Lignite</td>
<td>Hard Coal</td>
<td>Hard Coal</td>
</tr>
<tr>
<td>Pre-combustion, variant A</td>
<td>Post-combustion, variant A</td>
<td>Oxy-fuel, variant A</td>
<td>Post-combustion, variant A</td>
<td>Oxy-fuel, variant B</td>
<td>Pre-combustion, variant B</td>
<td>Post-combustion, variant B</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cross-border pipeline</td>
<td>Pipeline</td>
<td>Ship</td>
<td>Pipeline</td>
<td>Pipeline</td>
<td>Pipeline</td>
<td>Pipeline</td>
</tr>
<tr>
<td>Offshore depleted oil &amp; gas field</td>
<td>Onshore structural deep saline aquifer</td>
<td>Offshore open deep saline aquifer</td>
<td>Onshore depleted oil &amp; gas field</td>
<td>Onshore structural deep saline aquifer</td>
<td>Offshore depleted oil &amp; gas field</td>
<td>Onshore open deep saline aquifer</td>
</tr>
<tr>
<td>International cooperation</td>
<td>Retrofit</td>
<td>Improved efficiency</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
A 2008 view of convergence?

**Demonstration phase:**
CCS not commercially viable. Public contribution necessary for some portion

**Commercial phase:**
CCS expected to be commercially viable, as costs and CO₂ price reach similar levels

* Carbon price band for 2015 from 2008-15 estimates from Deutsche Bank, New Carbon Finance, Soc Gen, UBS, Point Carbo. Impact of the (possible) new ETS directive and the Copenhagen conference are not included in the analysis
Source: McKinsey & Company “CCS – Assessing the Economics” for the cost numbers; policy implications drawn by ZEP
Visions of sugar-plum fairies danced in their heads

Gibbins and Chalmers (2008)
Reality Bites

Project Cancellation
Longannet project costs: pre- and post-FEED study

F. Jones, CCS Case Study
UKERC/WP/TPA/2013/004
NAO Report on First UK Competition

• "In the context of value for money, developing new technologies is an inherently risky undertaking. Taking calculated risks is perfectly acceptable if those risks are managed effectively; but in this case DECC, and its predecessor, took too long to get to grips with the significant technical, commercial and regulatory risks involved.

• "Four years down the road, commercial scale carbon capture and storage technology has still to be developed. The Department must learn the lessons of the failure of this project if further time is not to be lost, and value for money achieved on future projects.” (italics mine)
  – Amyas Morse, head of the National Audit Office, 16 March 2012
Back to the Future (gen)

Futuregen 2.0
Escalation of Zerogen Costs

Source: Chris Greig. 2012 EPRI CCS Cost Workshop
2012 DECC Roadmap on Demonstration

• CCS Commercialisation Programme with £1 billion capital support focused on learning by doing and sharing knowledge to reduce cost of CCS so that it can be deployed in early 2020s

• Roadmap should enable [20-30 GW by 2030], subject to CCS demonstrating its effectiveness as a cost-competitive low carbon source of electricity generation in time to meet projected demand

• Our aim is to create for the first time a market in which there is a clear commercial model for CCS in the UK, provided it can demonstrate the ability to compete with other low carbon technologies

• International engagement focused on sharing the knowledge we have generated through our programme and learning from other projects around the world to help accelerate cost reduction
In addition to working intensively to help support these first projects, the Government is also thinking ahead. If the market can demonstrate that costs are falling in line with expectations, the Government will assess how it can support industry.

We believe that the immediate priority is to demonstrate the commercial and economic viability of CCS at commercial scale in the power generation sector.

Most new technologies reduce in cost as they develop and mature. Examples of this cost reduction theory include mobile phones, electric vehicles and photo-voltaic solar panels.

For CCS, like other low carbon energy technologies such as offshore wind, this cost reduction is crucial for it to play a part in the UK’s electricity system to 2030.

In order to receive CfDs, these projects will need to demonstrate value for money.
Standard Image of Learning in Energy Technology

Source: IEA (2000)
CRTF view of cost reduction

CCS Cost Reduction Trajectory

- Transport and Storage Scale and Utilisation
- Improved financeability for CCS chain
- Improved engineering designs and performance
- Other cost changes*

Potential additional EOR benefit in the range £5 - £12/MWh for gas CCS and £10 - £26/MWh for coal CCS. Could make starting point of ‘FID 2013’ plant less than £140/MWh, with similar impacts on plant with FID dates in the 2020s.

Note: Shows average costs across technologies. *E.G. Increasing CO₂ price, falling storage abandonment costs

Source: CCS Cost Reduction Task Force, May 2013
Cost uncertainty over time for Coal CCS

LCOE of 2013 CCS Technologies (2012 GBP)

Source: CCS Cost Reduction Task Force, May 2013
LCOE of 2020 CCS Technologies (2012 GBP)

Source: CCS Cost Reduction Task Force, May 2013
LCOE of 2028 CCS Technologies (2012 GBP)

Source: CCS Cost Reduction Task Force, May 2013
CRTF view of learning and FGD systems

[Graph showing cumulative capacity of wet FGD systems (GWe) over years, with data points for US, Japan, Germany, and Other.]

[Graph showing percent sulfur dioxide removed and capital costs over cumulative capacity of wet scrubbers (GWe).]
The earlier part of the story

Source: Boston Consulting Group (1968)

Source: Azevedo et al (2014), IAEE Presentation
## Wide range in learning rates across many techs

<table>
<thead>
<tr>
<th>Technology</th>
<th>Number of studies reviewed</th>
<th>Number of studies with one factor</th>
<th>Number of studies with two factors</th>
<th>Range of learning rates for “learning by doing” (LBD)</th>
<th>Range of rates for “learning by researching” (LBR)</th>
<th>Years covered across all studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1902-2006</td>
</tr>
<tr>
<td><em>PC</em></td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>6% to 12%</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>IGCC</em></td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2% to 8%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural Gas*</td>
<td>8</td>
<td>6</td>
<td>2</td>
<td>-11% to 34%</td>
<td>2% to 18%</td>
<td>1980-1998</td>
</tr>
<tr>
<td>Nuclear</td>
<td>4</td>
<td>4</td>
<td>0</td>
<td>&lt;0 to 6%</td>
<td></td>
<td>1975-1993</td>
</tr>
<tr>
<td>Wind (on-shore)</td>
<td>35</td>
<td>29</td>
<td>6</td>
<td>-3% to 32%</td>
<td>10% to 27%</td>
<td>1980-2010</td>
</tr>
<tr>
<td>Solar PV</td>
<td>24</td>
<td>22</td>
<td>2</td>
<td>10% to 53%</td>
<td>10%</td>
<td>1959-2001</td>
</tr>
<tr>
<td>BioPower</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Biomass production</em></td>
<td>4</td>
<td>4</td>
<td>0</td>
<td>12% to 45%</td>
<td></td>
<td>1971-2006</td>
</tr>
<tr>
<td><em>Power generation</em></td>
<td>7</td>
<td>7</td>
<td>0</td>
<td>0% to 24%</td>
<td></td>
<td>1976-2005</td>
</tr>
<tr>
<td>Geothermal power</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td>1980-2005</td>
</tr>
<tr>
<td>Hydropower</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>&lt;1% to 11%</td>
<td>3% to 21%</td>
<td>1980-2001</td>
</tr>
</tbody>
</table>

Two-factor learning:  

\[ C_i = a_i (x_i^{-b_{LBD}})(RD_i^{-b_{LBR}}) \]

**Source:** Azevedo et al (2014), IAEE Presentation
Spread in learning rates for onshore wind

\[ \text{an} = 12\% \]
\[ \text{Std Dev} = 14\% \]

Source: Azevedo et al (2014), IAEE Presentation
Why has EU underdelivered on CCS?

- Lack of bankable support (no CO2 demand for EOR or other revenue streams)
- Poor policy design (link to EUA price, no mechanism to deliver technology in a liberalised market (i.e., no EPS, little dedicated technology support))
- Lack of coordination between Member states and EU
- Tepid government support and local public opposition
- Continued reliance on ‘cheap talk’
- Never has been clarity on what is being demonstrated nor the rationale for commercial-scale operations
Demonstrate What?

• Which technology? at what scale? at what cost? to what end?

• Possible objectives:
  – speed of deployment
    • but speed of initial demo deployment does not necessarily imply that this will produce more plants in 2030 and beyond it may produce less
  – industrial policy
    • can help stimulate interest in CCS and expand geographic coverage, but in general more applicable to industrial CCS than power CCS
  – value for money
    • some element of cost competition will be vital, but it is still impossible to assess value for money without a better understanding of what “value” is and, for demonstration at least, value ultimately lies in learning
  – learning potential
    • learning from diversity: validation of the main available technological options
    • learning from replication: learning-by-doing

• Who should bear the costs of demonstration?
So what should we support? Replication v diversity

• Replication:
  – Unlike, say, wind turbines, which has seen significant learning-by-doing benefits, the number of replications involved in CCS is much smaller
  – There is little good evidence of the benefits of replication for CCS. One of the few public data points is SaskPower’s claimed 20-30% reduction in capital costs for the next unit after BD3

• Diversity:
  – More attention needs to be paid to the types of diversity that should be encouraged, which requires coordination (or at last greater cognizance) of projects
  – The principle of diversity should extend to the firms involved in CCS demonstration projects, diversity in their industrial background and core competencies, as well as the proposed integrated capture-transport-storage solutions

• The value of learning-by-doing from almost simultaneously implemented projects may be limited.

• Other key factors include R&D and technical change, competition, and time
Otherwise, how was the play Mrs Lincoln?

- Not having CCS in the energy mix reflects the absence of a politically, economically and commercially viable path towards a 650 ppm world.
- Absent large scale rollout of ‘demonstration’ of CCS projects, learning is far more challenging so understanding what projects can demonstrate is critical.
- Benefits of learning-by-doing from replication are typically better achieved at the commercialization stage of development, but jury is still out as to which CCS technologies will be most successful and how CCS will fare relative to other low-carbon technologies.
- Coordination is essential to ensure the needed diversity and avoid early picking of winners and support a varied range of technical solutions.
- Goal of any CCS demonstration ‘programme’ is not just to learn what designs and configurations are best suited to various environments, but to encourage suppliers to invest in supply chain so scaling up can be managed more quickly and cheaply in the future and ramp up RD&D.
- Danger of overemphasising ‘value for money’ or CO₂ savings at demo stage may lead to missed opportunities such as learning about flexibility.
- A CCS project delivers two outcomes – learning about costs and technical improvements, and the know-how needed to operate the plant reliably and the demo phase should attempt to improve along both dimensions.
Thanks!

David Reiner
dmr40@cam.ac.uk
+44 (0)1223 339616
Could be worse…

- ITER designed to produce 500 MW output (50 MW to operate) in order to demonstrate the principle of producing more energy from the fusion process than is used to initiate it.
- As of June 2015, building costs now >US$14 billion (3 times the original estimate). The facility is expected to finish its construction phase in 2019 and will start commissioning the reactor that same year and initiate plasma experiments in 2020 with full deuterium-tritium fusion experiments starting in 2027.
RD&D Expenditures for SO2 control

Patents for SO2 Control

Moving from RD&D to Commercial Operations

Source: IIASA (1997)
Impact of location factor on costs

Skagestad, Lach, Røkke, and Eldrup, Critical Factors Influencing CO2 Capture Cost, a Case Study, GHGT12
More ‘real-world’ impacts: supply chain bottlenecks

![Bar chart showing estimated capex costs for Post-combustion coal CCS, Post-combustion gas CCS, and IG CC + CCS, with and without congestion premium.]

*Figure 4: The estimated ‘congestion premium’ for CCS cost estimates arising from supply chain bottlenecks. Based on estimates by Mott MacDonald (2010).*

F. Jones, CCS Case Study
UKERC/WP/TPA/2013/004
Examining learning rates by CCS technology

Yeh and Rubin (2013), Learning in Energy Technologies, UC-Davis
Estimated capital costs for CCGT plants

F. Jones, CCS Case Study
UKERC/WP/TPA/2013/004
Estimated capital costs for coal plants

F. Jones, CCS Case Study
UKERC/WP/TPA/2013/004
Levelised cost estimates of CCS technologies

F. Jones, CCS Case Study
UKERC/WP/TPA/2013/004
Changing estimates of in-year mean capex values

(2011 million GBP/MW)

Source: UKERC Technology & Policy Assessment Function
Improvement in efficiency of coal-fired plants

Fig. 6. Improvement (percent change from the previous year, 10-year moving average) in thermal efficiency of coal-fired utility plants over 1935–2002 and corresponding market structural changes.

 Estimates of future capital costs: post-comb gas CCS

F. Jones, CCS Case Study
UKERC/WP/TPA/2013/004
Moving from generic to ‘real world’ costs

For case of post-combustion MEA capture plant on a 400 MW gas turbine

Skagestad, Lach, Røkke, and Eldrup, Critical Factors Influencing CO2 Capture Cost, a Case Study, GHGT12
Where are we now?

EU Energy Union ‘Four Core’ Priorities

• world leader in developing the next generation of renewable energy technologies, including environment-friendly production and use of biomass and biofuels, together with energy storage;

• Facilitating the participation of consumers in the energy transition through smart grids, smart home appliances, smart cities, and home automation systems;

• Efficient energy systems, and harnessing technology to make the building stock energy neutral, and

• More sustainable transport systems that develop and deploy at large scale innovative technologies and services to increase energy efficiency and reduce greenhouse gas emissions.
Additional ‘research priorities’

• On top of these four common priorities, there are additional research priorities which merit a much greater level of collaboration between the Commission and those Member States who want to use these technologies:
  
  – A forward-looking approach to carbon capture and storage (CCS) and carbon capture and use (CCU) for the power and industrial sectors, which will be critical to reaching the 2050 climate objectives in a cost-effective way. This will require an enabling policy framework, including a reform of the Emissions Trading System and the new Innovation Fund, to increase business and investor clarity, which is needed to further develop this technology.

  – Nuclear energy presently produces nearly 30% of the EU's electricity. The EU must ensure that Member States use the highest standards of safety, security, waste management and non-proliferation. The EU should also ensure that it maintains technological leadership in the nuclear domain, including through ITER, so as not to increase energy and technology dependence.
Principles De Coninck, Stephens and Metz (2009)

- Global coordination: the initiative should enable a variety of CCS technologies to be demonstrated in various contexts and countries.
- Transparency: the initiative should ensure open information availability and exchange between countries to promote broad global efficient learning on CCS.
- Cost-sharing: the initiative should set up a cost-sharing structure that pools global demonstration funds and reallocates them efficiently to allow for fast access of emerging economies to CCS technology and demonstrations.
- Communication: the initiative should design mechanisms to support demonstration projects that engage broad and different types of stakeholders and that incorporate education and outreach efforts. Open and effective communication with stakeholders, the media and the general public should be integral, and the cooperation should heed principles of risk communication, and support an open dialogue on CCS with all involved.
Have you read about any of the following in the past year?

- Solar energy
- Wind energy
- More efficient cars
- Shale gas
- Nuclear energy
- More efficient appliances
- Deforestation/Reforestation
- Hydrogen cars
- Bioenergy/biomass
- Carbon capture and storage
- Ocean acidification
- Enhanced oil recovery
- Geoengineering
- Land reification
- Iron fertilisation
- Fracking
- None of the above
Do you think ‘Carbon capture and storage’ or CCS can or cannot reduce each of the following environmental concerns?
Less than 2% can recall any details of CCS demos

The UK has narrowed down funding for these CCS projects to two main proposals. One project is meant to be in Yorkshire and the other in Scotland. Can you name either of these projects or any of the companies involved? IF you cannot name either of these projects or the companies involved, please skip this question, please do not look up the answer, this question will automatically skip forward in 1 minute.

<table>
<thead>
<tr>
<th>Response</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drax</td>
<td>11</td>
</tr>
<tr>
<td>Peterhead</td>
<td>8</td>
</tr>
<tr>
<td>Longannet</td>
<td>6</td>
</tr>
<tr>
<td>Shell</td>
<td>5</td>
</tr>
<tr>
<td>EDF</td>
<td>4</td>
</tr>
<tr>
<td>SSE</td>
<td>4</td>
</tr>
<tr>
<td>White Rose</td>
<td>4</td>
</tr>
<tr>
<td>British Gas</td>
<td>3</td>
</tr>
<tr>
<td>Ferrybridge</td>
<td>2</td>
</tr>
<tr>
<td>Fracking</td>
<td>2</td>
</tr>
<tr>
<td>Humber</td>
<td>2</td>
</tr>
<tr>
<td>Quadrilla</td>
<td>2</td>
</tr>
<tr>
<td>Kingsnorth</td>
<td>1</td>
</tr>
<tr>
<td>Hatfield</td>
<td>1</td>
</tr>
<tr>
<td>SCCS</td>
<td>1</td>
</tr>
<tr>
<td>Eon</td>
<td>1</td>
</tr>
</tbody>
</table>
The UK Government plans to spend £1 billion to support the demonstration of carbon dioxide capture and storage (CCS) technologies, which would capture carbon dioxide from a large power plant and store it under the North Sea. To what extent do you support or oppose this commitment?