Cost Reduction for CCS by 2030

Jon Gibbins
Director, UK CCS Research Centre
Professor of Power Plant Engineering and Carbon Capture
University of Edinburgh
www.ukccsrc.ac.uk
jon@ukccsrc.ac.uk
About the UKCCSRC

www.ukccsrc.ac.uk

The UK Carbon Capture and Storage Research Centre (UKCCSRC) leads and coordinates a programme of underpinning research on all aspects of carbon capture and storage (CCS) in support of basic science and UK government efforts on energy and climate change.

The Centre brings together over 250 of the UK’s world-class CCS academics and provides a national focal point for CCS research and development.

Initial core funding for the UKCCSRC is provided by £10M from the Engineering and Physical Sciences Research Council (EPSRC) as part of the RCUK Energy Programme. This is complemented by £3M in additional funding from the Department of Energy and Climate Change (DECC) to help establish new open-access national pilot-scale facilities (www.pact.ac.uk). Partner institutions have contributed £2.5M.

The UKCCSRC welcomes experienced industry and overseas Associate members and links to all CCS stakeholders through its CCS Community Network. 
https://ukccsrc.ac.uk/membership/associate-membership
https://ukccsrc.ac.uk/membership/ccs-community-network
"In our December 2008 report, we set out a range of scenarios to meet our 80% emissions reduction target in 2050. The common theme running through these scenarios was the need for early decarbonisation of the power sector, with the application of low-carbon electricity to transport and heat. We showed therefore that the carbon intensity of power generation should decline over time, whilst at the same time electricity demand could increase."

UK climate targets call for rapid electricity decarbonisation

Electricity CO₂ emission intensity decreases

Electricity generation falls then rises
UK Government planning for 2 more phases of CCS with EMR funding

DECC – August 2014

Next Steps in CCS: Policy Scoping Document

August 2014

The Policy Scoping Document summarises the Government’s policies and actions taken so far in supporting Carbon Capture & Storage (CCS), and it seeks views and evidence on a possible phase 2 of CCS deployment in the UK.

Chapter 14

UK’s first potential commercial scale CCS projects
Peterhead and White Rose

Potential further CCS deployment building on infrastructure and experience of Phase 1 projects
Decreasing amounts of potential government support.

10 YEARS TO PREPARE
for a low carbon transition

By 2030 the UK should seek to produce
10 GW of CCS capacity

10 GW is enough to supply electricity for approximately 15 million households

this is feasible and affordable if built upon co-ordinated cluster and hub development

10 GW of CCS capacity could capture
50 million tonnes

of CO₂ emissions per year from power and industry by 2030

The value of CCS comes from its multiple operations

power generation + gasification - negative emissions

power generation, capturing industrial emissions, providing low carbon energy through gasification and delivering “negative emissions”

Infrastructure is key

by using the DECC Commercialisation projects transport and storage infrastructure you can unlock future cost reductions and increase strategic build out options

Any low carbon transition should include CCS and Bioenergy

including them halves the cost of meeting UK climate change targets

Delay in CCS implementation increases costs

£ £ £

through the need to deploy higher cost technologies to cut emissions

1-2% GDP

failure to deploy CCS entirely would imply a doubling of the annual cost of carbon abatement from 1-2% of GDP by 2050

For decarbonisation no CCS means

greater reliance on nuclear and offshore wind

ETI scenarios for 2030 have ~5GW natural gas CCS (+ coal + industry)

- Deployment of CCS capacity at scale (i.e. ~10 GW electricity) and infrastructure capable of capturing 40-50 MtCO$_2$/year from power and industry by 2030.
- Three scenarios varying cluster and storage locations
- Storage ~ 100 MtCO$_2$/year by 2050.

Cost reductions
- Economies of scale for T&S
- EOR if it happens

Learning by doing for capture technology
- Always some learning for gas
- Coal most in EOR scenario
- Limited across Balanced scenario...
- but most opportunity for technology transfer from overseas

But coordination probably needed to maximise learning by doing with a very limited number of projects, globally as well as in the UK.

CCS Sector Development Scenarios in the UK, May 2015
ETI scenarios for 2030 have ~5GW natural gas CCS (+ coal + industry)

Deployment of CCS capacity at scale (i.e. ~10 GW electricity) and infrastructure capable of capturing 40-50 MtCO$_2$/year from power (as part of <100 kgCO$_2$/MWh) and industry by 2030.

Eventual storage target for 2050 scenarios (80% cut in UK emissions) ~ 100 MtCO$_2$/year.

ETI scenarios for 2030 have ~5GW natural gas CCS (+ coal + industry)
Timelines for capture and storage development in the Concentrated scenario

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Illustrative Cost Breakdown for UK Generation Options

Based on Redpoint: Decarbonising the GB power sector: evaluating investment pathways, generation patterns and emissions through to 2030, A Report to the Committee on Climate Change, September 2009.

2008 capital costs, assumed £30/tCO₂ carbon price, gas price £12.5/MWh_{th}, coal price £6.25/MWh_{th}, 10% interest rate.
System-wide costs, rather than just £/MWh, more prominent

The chart starts with an assumed 2030 mix of 10 GW nuclear, 28 GW wind and 5 GW gas-CCS resulting in a system close to 100 g/kWh. The technology tracks have the same shape but sometimes curve more sharply. Carbon price is set at £70/t. The earlier upward curve from CCS is due to the residual emissions assumed in the modelling.
Future Fossil Fuel Prices

Fossil fuel prices are expected to decrease in a carbon-constrained world, will have to adjust to make it possible to use fossil fuels with CCS at a similar cost to competing non-fossil energy sources,
The Climate Problem

A. ~ 10 years? : Key players need to agree on the allocation of the remaining space in the atmosphere to get over the commons problem (value is order 1 trillion tCO₂ @ $100/tCO₂ ~ 1 yr GWP or more).

B. 50-100 years? : The net rate of global emissions needs to go to zero in time to cap global cumulative emissions at an acceptable level.

To help get agreement A it is important to have a high confidence that we are able to deliver on achievement B within the limits of what is politically, economically and technically feasible.

By the end of the next ~ 10 years the CCS community needs to have:

1. Deployed 10’s of successful CCS projects on a range of large stationary sources.

2. Demonstrated working Direct Air Capture (DAC) technology options that prove the concept is available as a back-stop option – i.e. could be built in large numbers at an acceptable cost.

3. Be ready for the next 10 years, and the next, and ....
Typical stages in power plant clean-up technologies:

1. ‘It’s science fiction!’
2. ‘It’s impossibly expensive and complex!’
3. ‘It’s a major investment but necessary.’
4. ‘It’s obviously just a routine part of any power plant.’

CCS is now in early stage 3 and we are working hard to get it to stage 4 as quickly as possible.

CCS on stationary sources gives a critical option for achieving zero emissions without stopping fossil fuel use for power and industry

- Can expect 2nd generation projects to appear soon that are based on 1st generation projects and that benefit from learning-by-doing ….
- But CCS started recently and there still only a small amount of activity
- So CCS needs to be developed to give tens of second and third generation projects to become a serious option that can help resolve future climate change negotiations
2. Demonstrated working Direct Air Capture (DAC) technology options that prove the concept is available as a back-stop option – i.e. could be built in large numbers at an acceptable cost.

Air capture is the capture of last resort

- can handle emissions from any and all sources
- sets upper limit on cost of carbon management
- assures feasibility of zero carbon scenarios
- provides a solution to the risk of leaky storage
- encourages point source capture

Klaus Lackner, Gordon Research Conference 2015
Direct Air Capture Overview

• Examples of working DAC technologies now being developed

• Initial independent* cost estimate ~ $600/tCO₂ – it seems likely that this will be improved significantly with experience.

• High marginal costs of abatement have been paid via Feed in Tariffs etc. for renewables, with the expectation of reducing costs as a result of experience.

• But even $600/tCO₂ would add ~ $1.50 per litre of gasoline (i.e. less than doubling pump price in Europe).

• And for any stationary source operating at low load factors (e.g. natural gas plant filling in for wind) the point source CCS cost per tonne of CO₂ has to be a LOT lower to beat a DAC unit that is operating all the time.

• DAC technologies can be developed and proven relatively cheaply as individual units that are then mass-produced to reduce costs for deployment.

• **VERY important for countries to commit within ~ 10 years to finite future emission budgets and hence, eventually, to net zero emissions - demonstration of viable DAC options as a back-stop could be a deal-maker.**

What R&D could reduce CCS costs in the 2020s?

- This must be R&D that actually gets applied
- So will have to be R&D that will evolve ‘current’ technologies – not inventing completely novel approaches

Why current technologies? - Industry ‘clockspeed’ is the time to complete an iteration of design-build-test-market-learn, e.g:

- Clothing fashions – weeks
- Consumer goods - months
- Automotive - years,
- Pharmaceuticals – decade
- Big energy - CCGT, nuclear, coal or CCS – one or more decades

- Also, the organisations who will build the series of Phase 2 and Phase 3 projects need to shape and influence the R&D agenda and must apply the results

Acknowledgement: J. Carey
2014/TR4 Assessment of emerging CO₂ capture technologies and their potential to reduce costs
UKCCSRC industry working group conclusions for UK Phase 2 and Phase 3 post-combustion

a) Natural gas only – NGCC+CCS
b) Conventional solvents and compatibles
2. How can research contribute to R&D that will evolve ‘current’ CCS technologies

• Only ‘current generation’ CCS with reference plants at TRL 9 now, or in the next few years, will be bankable in the 2020s; but isn’t academic research more appropriate at lower TRLs?

• Need to consider system level TRL vs. sub-system or component TRL

• TRLs for evolving current technologies should be applied to innovation in sub-systems not across a whole system; improvements to sub-systems can start at TRL 1 while the overall technology is at TRL 9

E.g. NASA Chevron

http://www.nasa.gov/topics/aeronautics/features/trl_demystified.html
Four stages of energy innovation

Creating Options
- ‘Ideation’
- Laboratory research
- Development
- Proof of concept testing
- Prototyping
- Pilot-scale
  
  **Scale:** $100K-100M

Demonstrating Viability
- Market testing
- Debugging
- System integration
- Demonstration at commercial scale
- Complementary technologies
- Risk reduction
  
  **Scale:** $10M-$1B

Early Adoption
- Cost reductions
- Learning-by-doing
- Learning-by-using
  - Market development
  - Regulatory development
  - Manufacturing
  - Infrastructure development
  
  **Scale:** Up to $10s of billions

Improvements-in-use
- Large-scale take-up
- Continued cost reductions
- Incremental improvements
- Learning-by-doing
- Learning-by-using
  
  **Scale:** Up to $100s of billions

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Basic research is important at every stage of the innovation process (as is the take-up of knowledge from other sectors).
Figure I.2  Systems-based interactive innovation

Key point  Interactions across the entire innovation system will enable actors to develop necessary incremental improvements and breakthroughs in technologies needed to meet climate goals.

Contextual factors
e.g. macroeconomic environment
 e.g. geography and climate

Future Roles for UKCCSRC

A. Phase 1 project(s) approved in 2016 and Phase 2/3 next objective
B. No Phase 1 projects approved but reserve projects being developed
C. No Phase 1 projects approved, CCS deployment postponed until 2020’s

Scenario A
- A. Phase 1 project(s) approved in 2016 and Phase 2/3 next objective
- B. No Phase 1 projects approved but reserve projects being developed
- C. No Phase 1 projects approved, CCS deployment postponed until 2020’s

Scenario B
- No Phase 1 projects approved but reserve projects being developed

Scenario C
- No Phase 1 projects approved, CCS deployment postponed until 2020’s

Timeline for Scenario A
- 2015 Phase 1 project(s) approved
- 2020 Phase 2
- 2025 Extend to 10GW
- 2030
- 2040

Acknowledgement: R. Irons
Capture readiness: CCGT owners needn’t feel left out


It looks likely that gas fired combined cycle plants will need to be retrofitted with carbon capture systems in the future, and need to be demonstrating capture readiness now, certainly in the UK. What are the options for raising the steam that is likely to be needed to regenerate the solvent in a post combustion system?
The Gas-FACTS project is supported by the Engineering and Physical Sciences Research Council as part of the Research Councils UK Energy Programme.

Gas-FACTS: Gas - Future Advanced Capture Technology Options

Jon Gibbins University of Edinburgh
Mathieu Lucquiaud University of Edinburgh
Hyungwoong Ahn University of Edinburgh
Mohamed Pourkashanian University of Leeds
Paul Fennell Imperial College London
John Oakey Cranfield University
Chris Wilson University of Sheffield
Prashant Valluri University of Edinburgh
Hannah Chalmers University of Edinburgh

Martin Trusler Imperial College London
Kevin Hughes University of Leeds
Meihong Wang Cranfield University
Pericles Pilidis Cranfield University
Geoff Maitland Imperial College London
Chemical Eng and
Amparo Galindo Imperial College London
George Jackson Imperial College London
Claire Adjiman Imperial College London
Nina Thornhill Imperial College London

£3M
2012-2015
EPSRC Gas-FACTS Project

http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/J020788/1

Gas turbine capture systems

Gas turbine

Exhaust Gas Recycle - EGR

CO₂ Transfer & Recycle - CTR

Decarbonised flue gas out

Air inlet

Water/steam injection

Low carbon electricity out

Advanced Post Combustion Capture

Decarbonised flue gas out
UKCCSRC Pilot Advanced Capture Test (PACT) Facilities

Additional facilities at Cranfield, Edinburgh, Nottingham

**CAPABILITIES:**
1. Post-combustion carbon capture (synthetic flue gas)
2. Post-combustion carbon capture (coal/biomass)
3. Oxyfuel carbon capture (coal/biomass)
4. Post-combustion carbon capture (Gas Turbines)

www.pact.ac.uk
Pilot-Scale Advanced Capture Technology Facilities

Gas Turbine Facilities with EGR + HAT
Fuel Flexibility: NG, Biogas, Liquid Fuel, Biofuel & H₂ Enriched Gas

www.pact.ac.uk
The Amine Capture Plant:

- Adsorption and desorption, a fresh & spent amine storage tanks, an electric boiler (steam for regeneration of the solvent)

Other specific details include:
- Treats 100% of flue gas from the 165KW test facilities
- Removes 1 tonne of CO2 per day using MEA (>85% capture)
- Can Operates for extended test periods using synthetic gas option
- 8m column height
- 0.07MWe consumption (50kg/h CO2)
- Multiple solvent sampling locations along the columns
- Provisions for corrosion coupons and alternative materials test sites
- Trace gas injection capability
Example of a typical regenerative gas/gas rotary heater used in coal power plants

Laura Herraiz et al. / Energy Procedia 63 (2014) 559 – 571; Acknowledgements Howden
Block flow diagram of the different configurations in an air-fired natural gas combined cycle plant with post-combustion capture technology

Laura Herraiz et al. / Energy Procedia 63 (2014) 559 – 571
Block flow diagram of the different configurations in a natural gas combined cycle plant with exhaust gas recycling and post-combustion capture technology

Laura Herraiz et al. / Energy Procedia 63 (2014) 559 – 571
Development status and timeline

- Partnered with Toshiba, CB&I and Exelon to develop 50MWT demo
- Successful combustor ignition and initial operation completed
- 50MWT Pre-FEED completed
- FEED for 50MWT and Pre-FEED for 250MWe in progress
- Funding received from UK DECC
- Coal development program underway

2016
- 50MWT demonstration startup (somewhere in Texas)

2017
- Begin construction of first 250MWe natural gas plants

2019
- Begin operations of commercial plants

Allam Cycle

50MWT Demonstration Plant

Double-shell turbine structure

Single can-type combustor

Overview

June 2013

NET Power

## NET Power natural gas cycle target efficiencies

<table>
<thead>
<tr>
<th>Energy Components</th>
<th>HHV</th>
<th>LHV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross Turbine Output</td>
<td>75%</td>
<td>83%</td>
</tr>
<tr>
<td>CO₂ Compressor Power</td>
<td>-11%</td>
<td>-12%</td>
</tr>
<tr>
<td>Plant Parasitic Power (primarily ASU)</td>
<td>-11%</td>
<td>-12%</td>
</tr>
<tr>
<td>Net Efficiency</td>
<td>53%</td>
<td>59%</td>
</tr>
</tbody>
</table>
NET Power natural gas cycle

Hideo Nomoto, Toshiba Corporation, Rodney Allam, NET Power, Presentation to 7th Trondheim Carbon Capture and Sequestration Conference, June 5, 2013

Contains the intellectual property of 8 Rivers Capital, NET Power and Toshiba.
The NET Power natural gas system

- Oxy-fuel, closed-loop, CO₂ working fluid
- High-pressure cycle, low pressure ratio turbine
- 200-400 bar; 6-12 pressure ratio
- Target Efficiency 58.5% (LHV with 100% CC at 300 bar)
- Addition of a simple hot compression cycle maintains efficiency and eliminates the need for ASU side heat
- HP CO₂ and liquid water are the only byproducts
- No added costs of capture, separation or compression of CO₂

Hideo Nomoto, Toshiba Corporation, Rodney Allam, NET Power, Presentation to 7th Trondheim Carbon Capture and Sequestration Conference, June 5, 2013
Possible research examples

• Flexibility – systems able to use the best solvents available and be upgraded in service

• Integration – power plant and capture systems for controllability

• Standardisation - enable a series of multiple units with similar design and common sub-systems

• Water and waste management – move to zero discharge systems if possible

• Multiple applications – similar designs for coal, gas, industry capture to transfer benefits of cost reduction across sectors

• Effective construction – to match GTCC factory build and rapid site erection characteristics and reduce capital costs

• Objective assessment of alternative CCS options deliverable in the 2020s
Summary

- UK potentially has a unique series of CCS projects being built between now and 2030, with a focus on cost reduction.
- R&D is needed that will evolve ‘current’ technologies to deliver cost-competitive CCS projects in the UK in the 2020s.
- Improvements to sub-systems can start at TRL 1 while the overall technology is at TRL 9.
- The people who will build the series of Phase 2 and Phase 3 projects need to shape and influence the R&D agenda.
- Major role for UKCCSRC, PACT and others in national programme.
- Progress on CCS in the UK and elsewhere will also build confidence for global commitment to 2 degree scenarios.
- In a carbon-constrained world fossil fuel prices will adjust to make CCS competitive with other low-carbon energy sources.
Potential collaborative activities

- MOTIE visit to UK; 5-6 November 2015
- Offshore storage meeting, Guangdong; 13-14 or 20-21 January 2016 (TBC)
- UKCCSRC Biannual meeting, Manchester; 13-14 April 2016
- PACT visit; 15 April 2016
- CCS Deployment Scenarios to 2030 and Cost Reduction; 18-19 April 2016

Common areas of interest include:

- Developing 5-10 CCS projects by 2030 and building up the related transport and offshore storage infrastructure
- Offshore storage, pipeline and shipping transport
- Post-combustion capture using liquids and potentially solids